Planning the Future of Billfishes

Part 2

National Coalition for Marine Conservation

Planning the Future of Billfishes

Research and Management in the 90s and Beyond

Part 2. Contributed Papers

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Research and Management in the 90s and Beyond

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Part 2: Contributed Papers

Richard H. Stroud, Editor

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Editorial Note

Editorial Note

The designated taxonomic standard in North America for scientific names of fishes is Special Publication No. 12 of the American Fisheries Society (AFS), *A List of Common and Scientific Names of Fishes from the United States and Canada,* published in 1980 (Fourth Edition). This document treats the blue marlin as a single worldwide species *(Makaira nigricans),* treats sailfish as a single worldwide species *(Istiophorus platypterus),* and reassigns the skipjack tuna *(Euthynnus pelamis)* from the genus *Katsuwonus* to the genus *Euthynnus*.

Subsequently, in 1985, the Food and Agricultural Organization (FAO) of the United Nations published a detailed taxonomic revision of the billfishes, *Billfishes of the World,* by I. Nakamura (FAO Fisheries Synopsis No. 125, Vol. 5), which has become the internationally accepted standard for the Istiophoridae, superceding the earlier AFS nomenclature.

Accordingly, this symposium's Scientific Advisory Committee adopted the concepts of separate species of Indo-Pacific blue marlin *(Makaira mazara)* and Atlantic blue marlin *(M. nigricans),* as well as of Indo-Pacific sailfish *(Istiophorus platypterus)* and Atlantic sailfish *(I. albicans).* It also favored use of *Katsuwonus pelamis* for skipjack tuna, following prevailing international acceptance.

Consequently, a broad measure of latitude has been granted to the authors contributing to this symposium concerning their usage of preferred scientific nomenclature for blue marlin, sailfish, and skipjack tuna. Most have elected to follow the more recent international (i.e., FAO) practice in this respect rather than the earlier AFS designations. The matter has been called to the attention of the AFS Names of Fishes Committee for their consideration and evaluation as they prepare for the fifth edition of their report, scheduled for publication in 1990.

Each paper presented in this volume (Part 2 of Symposium) was subjected to two or three pre-publication peer reviews, organized by the chairman of the session in which it appears. In a few cases (as noted there) summaries or extended abstracts appear that represent more detailed papers — considered noteworthy here — being published in other scientific outlets, or that reflect limited sets of data.

Richard H. Stroud
Symposium Editor

Introduction to Part 2 of Symposium

Frank Carlton and Peter Fithian
Jointly Presiding

Introduction to Part 2 of Symposium

Peter S. Fithian

This is Part 2 of the Second International Billfish Symposium proceedings, "Planning the Future of Billfishes," which is a compilation of contributed papers authored by a group of recognized billfish experts from around the globe. The papers were presented during the afternoon sessions of the symposium which was held in Kailua-Kona, Hawaii, from August 1-3, 1989, in conjunction with the Hawaiian International Billfish Association Tournaments. The joint arrangement had several advantages, including having an international group of billfishers who were in turn able to attend the week-long event. In addition, billfish caught during the tournaments were made available for a number of research projects by scientists who attended the symposium.

The papers published here (in contrast to the more structured morning panel sessions presented in Part 1 of the proceedings) include a broad array of diversified topics form basic biology of billfishes to applied fisheries management. The titles of the chaired sessions, reflecting the variety of the research and studies, are: Life History and Distribution, Fisheries, Socio-Economic Issues, and Age and Growth.

Much of the work presented here is an extension of the groundwork laid and published in the proceedings of the First International Billfish Symposium, which was held August 9-12, 1972, also in Kailua-Kona, Hawaii. In turn, this volume will be an information source and motivation vehicle for the further advancement of knowledge concerning billfishes. The amount of knowledge gained in recent years is substantial. But, in light of the alarming rate at which the world's billfish stocks are becoming threatened, urgency for even more knowledge of billfishes was strongly expressed by many participants. It is realized that the further advance of knowledge has been hindered by past lack of attention and funding as well as the pure difficulty of studying large free-roaming pelagic fishes. It is hoped, with the synthesis of information and knowledge exchanged during this meeting, that we will continue to expand our studies and maintain the momentum created by this landmark event. Without a thorough understanding of the basic biology, coupled with fisheries management including such aspects as socio-economics, we will never be able to manage successfully one of our greatest natural resources. This volume is another step towards this achievement.

A symposium such as this would not have become a reality without the financial support and the untiring efforts of a number of dedicated individuals from such a prestigious list of sponsoring organizations (see ii). It was very impressive that so many participants traveled from such great distances to Kailua-Kona for this memorable event. From planners and organizers to the authors of papers, plus those who contributed to the editorial and review process, we give a special note of thanks and appreciation for a job well done. I personally felt privileged to have been able to participate in this enterprise and found it greatly rewarding.

Peter S. Fithian received the B.S. degree (hotel administration) in 1951 from Cornell University, and studied small company management at the Graduate School of Business, Harvard University, 1979-1980. In 1957, he became founder-president, Greeters of Hawaii, Ltd., continuing to the present. From 1966-1972, he served successively as director, treasurer, vice chairman, and chairman of the Hawaii Visitors Bureau. He was a charter member, 1976-1980,

of the Western Fishery Management Council. In 1976, continuing to the present, he became chairman of the Pacific Gamefish Foundation; since 1977, he has been founder-chairman of the Hawaiian International Billfish Association. He has since 1978 been a member of the Board of Directors, National Coalition for Marine Conservation. From 1979-1982, he was a director, Chamber of Commerce of Hawaii. From 1986 to the present, he has served as a trustee for The Billfish Foundation, also for the International Game Fish Association.

Session 1

Life History and Distribution

Peter S. Davie, Chairman

A Paleontological Review of Three Billfish Families (Istiophoridae, Xiphiidae, and Xiphiorhynchidae)

Harry L. Fierstine

In 1974, I summarized the osteological and paleontological knowledge of billfishes and suggested some areas of research to aid future paleontological studies (Fierstine 1974). My suggestions included: (1) a comparative osteological study, especially of the rostrum, in order to obtain more accurate identifications of fossilized material; (2) a functional study of the feeding mechanism, in order to explain observed interfamilial differences in the skull; (3) a functional study of the locomotor apparatus in order to elucidate inter- and intrafamilial differences in vertebrae, body shape and fin morphology, and (4) a more thorough study of those extinct families (Blochiidae and Paleorhynchidae) and genera *(Acestrus* and *Brachyrhynchus)* having uncertain affinities to other billfishes.

Since 1974, some of the foregoing items, as well as some not listed, have been studied with varying degrees of thoroughness. In the most comprehensive treatise, Schultz (1987) investigated all extant and extinct billfishes and developed a new taxonomic arrangement and evolutionary scheme based primarily on structure of the rostrum. The present study reviews the published accounts, presents some new information, and summarizes the relevant osteological and current paleontological knowledge of three billfish families (Istiophoridae, Xiphiidae, and Xiphiorhynchidae).

Systematics of Recent Forms

Although Schultz (1987) rearranged the extant billfishes into three families (Istiophoridae), Tetrapturidae, and Xiphiidae) and six genera *(Istiophorus, Makaira, Marlina, Pseudohistiophorus, Tetrapturus,* and *Xiphias),* I will follow the taxonomic nomenclature of Nakamura (1983), with the exception that I agree with Robins and de Sylva (1960) that both the sailfish and blue marlin exist as single world-wide species, and not as separate Atlantic Ocean and Pacific Ocean forms.

Family Xiphiidae
- *Xiphias* Linnaeus
  - *Xiphias gladius* Linnaeus, 1758 — Swordfish

Family Istiophoridae
- *Istiophorus* Lacépède
  - *Istiophorus platypterus* (Shaw and Nodder, 1792) — Sailfish
- *Makaira* Lacépède
  - *Makaira indica* (Cuvier, 1832) — Black marlin
  - *Makaira nigricans* Lacépède, 1802 — Blue marlin
- *Tetrapturus* Rafinesque
  - *Tetrapturus albidus* Poey, 1860 — White marlin
  - *Tetrapturus angustirostris* Tanaka, 1915 — Shortbill spearfish
  - *Tetrapturus audax* (Philippi, 1887) — Striped marlin
  - *Tetrapturus belone* Rafinesque, 1810 — Mediterranean spearfish
  - *Tetrapturus georgei* Lowe, 1840 — Roundscale spearfish
  - *Tetrapturus pfluegeri* Robins and de Sylva, 1963 — Longbill spearfish

Relevant Osteology of Recent Forms

Skull

General account and terminology. I will follow the lead of other billfish scientists (e.g., Nakamura

1983) and use the osteological terminology of Gregory (1933) and Gregory and Conrad (1937) where possible even though it may not conform to modern comparative developmental studies (Jollie 1986). Myer et al (in press) and Schultz (1987) independently discovered that the istiophorid rostrum contained a new paired element, the prenasal, which had mistakenly been considered part of the premaxillary bone by other workers.

Rostrum. The rostrum (or bill) is defined as that part of the snout which extends anteriorly from the anterior border of the bony orbit to terminate in a projection beyond the lower jaw (Fierstine 1978). The Istiophoridae and Xiphiidae have rostra with different morphologies.

The swordfish bill is flattened in cross-section, lacks denticles in the adult (Carter 1919), and usually contains a longitudinal series of central chambers (Poplin 1975, 1976; Poplin et al 1976; Schultz 1987) that demonstrate considerable intraspecific variation. In an X-ray examination of 39 rostra, I found 24 with chambers running the entire length of the rostrum, five with chambers only in the distal one-half, seven with chambers only in the distal one-fourth, and three with no chambers. There is a minor controversy over which bones form the swordfish rostrum. Gregory and Conrad (1937) discussed the problem and concluded that the distal three-fourths is primarily composed of premaxillae with paired nasals on the dorsal surface. The proximal one-fourth is composed of the dermethmoid, frontals, maxillaries, lateral ethmoids, and vomer. After dissecting a juvenile swordfish, Conrad (1937) concluded that the true nasal is "a minute but well-formed bony element lying dorsad to the narial openings" and the bones that Gregory and Conrad (1937) called nasals were just parts of the premaxillae. To the best of my knowledge, all subsequent workers (Nakamura 1983; Poplin et al 1976; Schultz 1987), except Johnson (1986), have followed Gregory and Conrad (1937) and, not Conrad (1937). If most authors are correct, then *X. gladius* lacks the prenasal bones found in istiophorids. However, if Conrad (1937) and Johnson (1986) are correct, then it is possible that the bones they called parts of the premaxillae, and that others called nasals, are really prenasals. This matter needs to be resolved.

In contrast, the istiophorid bill has paired prenasal bones (Fig. 1), is rounded in cross-section, lacks any central chambers, and denticles adorn its ventral and generally its dorsal surfaces. The three istiophorid genera can be distinguished by the shape of their rostra at the rostral mid-point (Fig. 2). The distribution of denticles (Table 1) and relative size of the paired nutrient canals show interspecific patterns.

Schultz (1987) noticed that the denticles along the ventral midline of the rostrum of the shortbill spearfish and Mediterranean spearfish are not housed in alveoli and detach when the rostra are prepared into skeletons. He separated all spearfishes *(T. angustirostris, T. belone, T. georgei,* and *T. pfluegeri)* from the other billfishes primarily on the basis of the edentulous zone. There was no mention of intraspecific or interspecific variation of the character.

Poplin et al (1976) described the microscopic anatomy of the swordfish rostrum. It is composed superficially of a thin layer of acellular primary bone that has the appearance of dentine. The superficial layer is underlain by acellular vascular bone containing secondary osteons (Haversian units) which are arranged into large bundles in the deeper regions (center) of the sword. There are no comparable histological studies of istiophorid rostra.

Lower jaw. With the exception of mentioning the presence or absence of the predentary bone, there are no published studies of other features of the lower jaw. The istiophorids have a stout mandible that is composed of the predentary, dentary, and articular bones. There is a well-developed intermandibular joint and each mandible has a strong cone-shaped quadrate-articular joint. In contrast, the swordfish has a much weaker lower jaw with no predentary bone or intermandibular joint. It has a rather simple quadrate-articular articulation.

Intrafamilial variation is unknown. The observation, however, that the shortbill spearfish has its predentary bone reduced to a tooth patch (Fierstine and Applegate 1968), is incorrect because the observation was based on an ab-

Table 1. Relative length of denticulated area on dorsum of rostrum of five species of extant billfishes. Relative length was determined by dividing the length of the denticulated zone by L (see Fig. 2 legend for definition).

Species	Number studied (N)	Average relative length of denticulated area	Range of relative length
Makaira nigricans	8	.02	.00-.03
Makaira indica	4	.05	.04-.07
Tetrapturus audax	6	.12	.03-.19
Istiophorus platypterus	4	.34	.08-.63
Tetrapturus albidus	9	.75	.57-.78

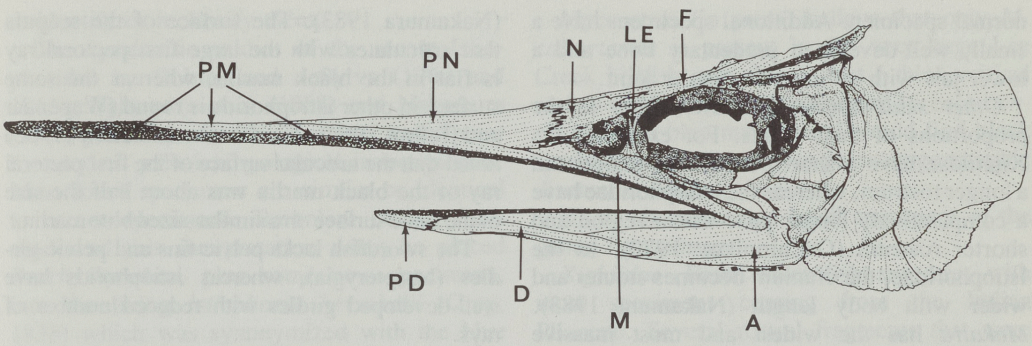

Figure 1. Skull and lower jaw of a blue marlin *(Makaira nigricans* Lacépède, 1802), left lateral view. Composite illustration by Charles Bloomer primarily from a 43.3 kg (95.5 lb) ♀ caught off Kailua-Kona, HI. Bones labeled as follows: Articular (A), Dentary (D), Frontal (F), Lateral ethmoid (LE), Maxillary (M), Nasal (N), Predentary (PD), Premaxillary (PM), Prenasal (PN).

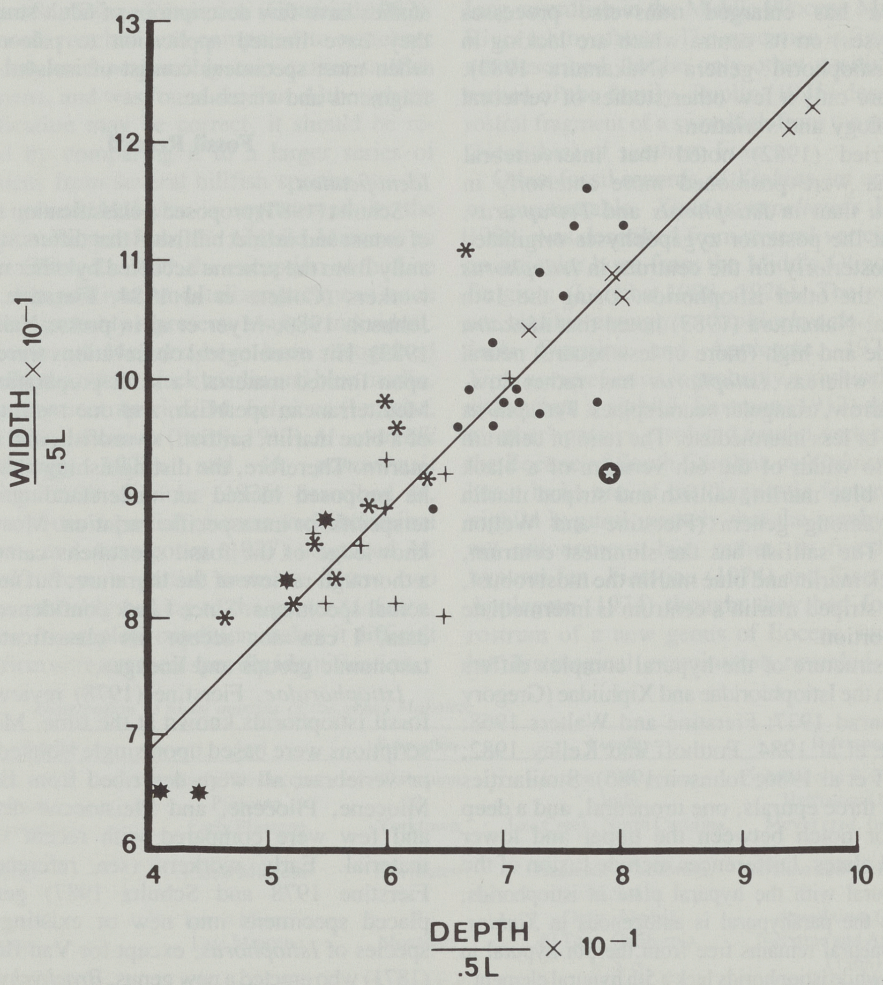

Figure 2. Simple regression of depth (D) and width (W) of 43 rostra measured at mid-rostrum length (.5L) for six species of billfishes. Rostrum length (L) was determined by measuring the straight-line distance from the distal tip to the anterior orbital margin of the lateral ethmoid. *Istiophorus platypterus* (✱), n = 4; *Makaira indica* (×), n = 5; *M. nigricans* (●), n = 15; *M. panamensis* (✪), n = 1; *Tetrapturus albidus* (✻), n = 9; *T. audax* (+), n = 9.

normal specimen. Additional specimens have a small, well-developed predentary bone and a lower jaw with an intermandibular joint.

Other skull bones. Billfishes differ in the proportions of their skulls. For example, the Xiphiidae have a short post-orbital region and a longer rostrum, whereas the Istiophoridae have a comparatively longer post-orbital region and shorter rostrum (Ovchinnikov 1970). In the Istiophoridae, the cranium becomes stouter and wider with body length (Nakamura 1983). *Makaira* has the widest and most massive cranium and *Istiophorus* and *Tetrapturus* have more moderate-sized crania.

Vertebrae. Vertebral counts and shape differ between the Xiphiidae and Istiophoridae, and *Makaira* has enlarged transverse processes (apophyses) on its centra which are lacking in other istiophorid genera (Nakamura 1983). There are only a few other studies of vertebral morphology and variation.

Gottfried (1982) noted that intervertebral foramina were positioned more anteriorly in *Makaira* than in *Istiophorus* and *Tetrapturus,* and that the posterior zygapophyses originated more posteriorly on the centrum in *Istiophorus* than in the other istiophorids. Using the 14th vertebra, Nakamura (1983) noted that *Makaira* has wide and high (more or less square) neural spines, whereas *Istiophorus* has rather low, more narrow, triangular neural spines. *Tetrapturus* is more or less intermediate. The ratio of centrum length to width of the 6th vertebra of a black marlin, blue marlin, sailfish and striped marlin differs among genera (Fierstine and Welton 1988). The sailfish has the slimmest centrum, the black marlin and blue marlin the most robust, and the striped marlin's centrum is intermediate in proportion.

The structure of the hypural complex differs between the Istiophioridae and Xiphiidae (Gregory and Conrad 1937; Fierstine and Walters 1968; Collette et al 1984; Potthoff and Kelley 1982; Potthoff et al 1986; Johnson 1986). Similarities include three epurals, one uroneural, and a deep posterior notch between the upper and lower hypural plates. Differences include fusion of the parahypural with the hypural plate in istiophorids, whereas the parahypural is autogenous in *Xiphias.* The uroneural remains free from the 5th hypural in *Xiphias* while istiophorids lack a 5th hypural element.

Fins and fin supports. The black marlin is the only istiophorid with a pectoral fin that cannot be folded back against its body in the adult (Nakamura 1983). The surface of the scapula that articulates with the large first pectoral ray is flat in the black marlin, whereas the same surface in other istiophorids is round (Wapenaar and Talbot 1964). Fierstine and Welton (1983) noted that the articular surface of the first pectoral ray of the black marlin was about half the size of the same surface on a similar-sized blue marlin.

The swordfish lacks pelvic fins and pelvic girdles (basipterygia), whereas istiophorids have well-developed girdles with reduced number of rays.

Potthoff and Kelley (1982), Collette et al (1984), and Potthoff et al (1986) studied the early osteological development of the median fin supports in the swordfish and sailfish. Since these studies have few descriptions of adult structures, they have limited application to paleontology when most specimens consist of isolated rostral fragments and vertebrae.

Fossil Record

Identification

Schultz (1987) proposed a classification scheme of extant and extinct billfishes that differs significantly from the scheme accepted by other modern workers (Collete et al 1984, Fierstine 1978, Johnson 1986, Myer et al in press, Nakamura 1983). His osteological observations were based upon limited material: a skull preparation of a Mediterranean spearfish, and one rostrum each of a blue marlin, sailfish, swordfish, and striped marlin. Therefore, the distinguishing characters he proposed lacked an understanding of interspecific or intraspecific variation. Most of his knowledge of the fossil specimens came from a thorough review of the literature, but not from actual specimens. Since I lack confidence in his data, I can not accept his classification of taxonomic groups and lineages.

Istiophoridae. Fierstine (1978) reviewed all fossil istiophorids known at the time. Most descriptions were based upon single isolated rostra or vertebrae; all were described from Eocene, Miocene, Pliocene, and Pleistocene deposits, and few were compared with recent skeletal material. Early workers (see references in Fierstine 1978 and Schultz 1987) generally placed specimens into new or existing fossil species of *Istiophorus,* except for Van Beneden (1871) who erected a new genus, *Brachyrhynchus.* Although Fierstine (1978) questioned the accuracy of these early identifications, he took the conservative approach and made no attempt to

re-identify or reclassify them.

The systematic studies of the recent Istiophoridae by Robins and deSylva (1960 and 1963), Nakamura et al (1968) and Nakamura (1983) provided a firm basis and reference point for modern paleoichthyological investigations. Most fossil specimens are similar or identical to recent specimens. Barbolani (1910) foreshadowed this interpretation when he placed *Brachyrhynchus,* plus some new specimens, into the living *Istiophorus herschelii* (Gray, 1838) which was synonymized with the blue marlin *(Makaira nigricans* Lacépède, 1902) by Nakamura et al (1968).

The only fossil record of a sailfish is based on a single, fragmentary vertebra from the Upper Pliocene San Diego Formation (Gottfried 1982). The fossil vertebra was compared to vertebrae from only one or possibly two extant sailfish specimens, and was found similar. Although the identification may be correct, it should be restudied by comparing it to a larger series of specimens from several billfish species.

The genus *Makaira* is represented in the geological record from the Middle Miocene to present (Table 2). With the exception of the Lee Creek, Pungo River, and Italian specimens, each discovery probably represents a single individual. Six species of *Makaira* have been recognized as fossils, the extant black marlin and blue marlin, and four extinct species, *M. belgicus* (Leriche, 1926), *M. calvertensis* (Berry, 1917), *M. courcelli* (Arambourg, 1927), and *M. panamensis* Fierstine, 1978. Leriche (1926) described *M. belgicus* from a partial rostrum and abdominal vertebra, and Arambourg (1927) described *M. courcelli* from a partial rostrum. These two species probably belong to the genus *Makaira,* but their incomplete condition makes it difficult to confirm or reject their specific identification.

Myer et al (in press) believe that only *M. calvertensis* is present in the very large Lee Creek billfish assemblage, but I think critical review would probably synonymize *M. calvertensis* with the blue marlin, and would find black marlin present as well (see paleozoogeographic discussion below).

There are no known fossil specimens of the genus *Tetrapturus*.

Xiphiidae. Fossil swordfish are rare, with most specimens coming from the Italian Pliocene. Several rostral fragments that were originally named *X. delfortrieri* Lawley (1876), were redescribed and renamed *X. gladius* var. *delfortriei* by Santucci (1923). Recently, Sorbini (1987) discovered a nearly complete 135-cm-long swordfish in the Middle Pliocene Marecchia River ichthyofauna. The specimen is figured but not described. In the only other positive fossil record of the family, Poplin (1975) described a rostral fragment of a swordfish from the subrecent (Neolithic) of southern France.

Other fossil records of *Xiphias* are erroneous or questionable. *Xiphias rupeliensis* Leriche, 1908, was described from several vertebrae and an articular bone from the Middle Oligocene of Belgium (Leriche 1908, 1926). The vertebrae are similar enough to *Xiphiorhynchus kimblalocki* Fierstine and Applegate, 1974, that *Xiphias rupeliensis* is probably a xiphiorhynchid rather than a xiphiid. Eastman (1917) described a rather massive, isolated caudal vertebra from the Eocene of South Carolina as *Xiphias* (?) sp., but it lacks one of the diagnostic features of an xiphiid hypural, namely that the parahypural is not autonomous but, rather, is fused to the hypural fan. Fierstine (1974) and Fierstine and Applegate (1974) thought they had found the rostrum of a new genus of Eocene swordfish, but histological examination revealed that the

Table 2. Distribution of fossil marlins of the genus Makaira.

Species	Age	Formation	Locality	References
M. indica	Early Pleistocene	?Cabatuan	Luzon, Philippines	Fierstine and Welton (1983)
M. nigricans	Pliocene	?	Italy	Barbaloni (1910)
M. calvertensis	Early Pliocene	Yorktown	Lee Creek, North Carolina, U.S.A.	Meyer *et al.* (in press)
Makaira sp.	Latest Miocene	San Mateo	Oceanside, California, U.S.A.	Fierstine and Welton (1988)
M. courcelli	Latest Miocene	?	Oran, Algeria	Arambourg (1927)
Makaira sp.	Late Miocene	Monterey	El Toro, California, U.S.A.	Fierstine and Applegate (1968)
M. panamensis	Late Miocne	Chagres S.S.	Panama	Fierstine (1978)
M. belgicus	Middle Miocene	?	Belgium	Leriche 1926)
M. calvertensis	Middle Miocene	Pungo River	Lee Creek, North Carolina, U.S.A.	Meyer *et al.* (in press)

rostrum was composed of calcified cartilage and more properly belonged to a sawfish (Pristiidae) or saw shark (Pristiophoridae).

A segment of an articulated vertebral column with partial dorsal and anal fins, from the Middle Miocene of Poland, was identified as belonging to a young specimen of *Xiphias* sp. (Jerzmanska 1962). Comparing this account with Gregory and Conrad (1937) and Potthoff and Kelley (1982), I believe that the vertebrae in the Polish specimen are too numerous and have the incorrect morphology to have anything to do with *Xiphias*.

Xiphiorhynchidae. This monogeneric family *(Xiphiorhynchus* Van Beneden, 1871) contains five species *[X. aegypticus* Weiler, 1929, *X. elegans* Van Beneden, 1871, *X. kimblalocki* Fierstine and Applegate, 1974, *X. parvus* Casier, 1966, and *X. priscus* (Agassiz, 1839)], from the Eocene of either North Africa, western Europe, or eastern North America (see references in Fierstine and Applegate 1974, Schultz 1987) and one species *(X. hungaricus* Weiler, 1943) from the Middle Oligocene of southcentral Europe (Weiler 1943).

The rostra are round in cross-section, have denticles (exact pattern is unknown), are composed of acellular bone (Beltan 1976), and are distinguished from istiophorid bills by the presence of a large central canal and more than one pair of lateral nutrient canals, and probably by the absence of prenasal bones. The original descriptions *Xiphiorhynchus* were from cranial fragments that were presumed to have had rostra (Agassiz 1838). Woodward (1901), and most recently Casier (1966), considered some of the rostra and skulls conspecific, even though none were articulated together. Until a xiphiorhynchid skull is discovered with a rostrum, I lack confidence in their identification. In fact, since most species are known only from rostral fragments, I have little faith in the validity of the characters that distinguish the species.

Schultz (1987) described a new genus and species, *Thalattorhynchus austriacus,* Middle Miocene, Austria, from a distal rostral fragment. The distinguishing feature was a single, off-center, longitudinal canal that was observed by computerized tomography. No paired, lateral nutrient canals were visible. The specimen looks similar to most istiophorid rostral fragments, except for the single canal, which may be anomalous; therefore, I do not believe the specimen is a xiphiorhynchid.

Fierstine and Applegate (1974) concluded, based on a description of *X. kimblalocki,* that xiphiorhynchids are intermediate to the Xiphiidae and Istiophoridae. The rostrum is broad at its base, similar to a swordfish, but it is round in the distal one-half, similar to the istiophorids. Both the swordfish and *Xiphiorhynchus* have a central canal in their rostra, while the istiophorids have only one pair of lateral canals. The abdominal vertebra of *X. kimblalocki* is similar to the shape of an anterior abdominal vertebra of the black marlin, whereas the caudal vertebra is similar to the shape of a swordfish caudal vertebra.

Paleozoogeography

Istiophoridae and Xiphiidae. According to Eschmeyer et al (1983), Nakamura (1983), and Robins et al (1986), istiophorid billfishes are generally distributed in tropical and warm temperate seas, whereas the swordfish is distributed world-wide in tropical (at mesopelagic depths), warm temperate, and cold temperate seas. Some istiophorid species are found world-wide, while others have a more restricted distribution. For example, the black marlin, shortbill spearfish, and striped marlin inhabit only the Pacific Ocean, with occasional strays into the southeastern Atlantic Ocean, whereas the longbill spearfish and white marlin are restricted to the Atlantic Ocean, with the latter occasionally found in the Mediterranean Sea.

Fossil discoveries of the Istiophoridae and Xiphiidae are generally found in deposits within the distributional range of the extant species, and their discoveries have neither raised nor solved any paleozoogeographic problems (Fierstine 1978; Fierstine and Welton 1983, 1988).

Recently, I have been studying the rostrum of a black marlin from the Middle Miocene of Panama. During the Middle Miocene there were no known geographic or ecological barriers in the region of the future Isthmus of Panama to impede the movement of the black marlin from the Pacific Ocean to the Atlantic Ocean (or vice versa). Gillette (1984) concluded there was a Tertiary Caribbean Faunal Province that extended from Ecuador through the Caribbean Sea to coastal North Carolina in the Atlantic Ocean. Most likely, the black marlin was part of that faunal province and reexamination of the numerous specimens of *M. calvertensis* from the Middle Miocene deposits, Lee Creek, North Carolina (Myer et al in press) will probably reveal that black marlin occurred in the Atlantic Ocean both

before and after the formation of the Panama land bridge. This early discovery weakens the hypothesis, "that the black marlin is a more recent derivative (than the blue marlin) that was unable to thrive in the Atlantic Ocean because of a temperature barrier" (Fierstine 1978), and fuels the controversy that the black marlin may be more generally present, especially in the south Atlantic Ocean, but lacks scientific confirmation.

Xiphiorhynchidae. Xiphiorhynchids have been found only in Tertiary deposits associated with the north Atlantic Ocean and western Tethys Sea (or its remnant, the Mediterranean Sea). If xiphiorhynchids are the earliest known true billfishes (see discussion below), then the Atlantic Ocean and Tethys Sea are probably the center of origin for billfishes.

Evolutionary Discussion

Collette et al (1984) discussed the phylogenetic relationships of the six families and 44 genera of extant Scombroidei and concluded that the Istiophoridae and Xiphiidae are sister groups, and together are a sister group to the Scombridae. In a more extensive cladistic analysis, Johnson (1986) concluded that the billfishes (Istiophoridae and *Xiphias)* should be placed as separate tribes within the Scombridae, and together are a sister group to *Acanthocybium*. The last two groups share the feature of a horizontal, premaxillary beak in the larvae, which elongates in adult billfishes.

Although I do not believe that billfishes belong to the same family as mackerels and tunas, I am now persuaded by the argument that billfishes do not belong in their own separate suborder (Xiphioidei) and are related to the Scombridae. The similarities between billfishes and *Acanthocybium* is not a new idea and Johnson's novel presentation makes one look for evidence to support or reject his hypothesis. For example, does *Acanthocybium* have a prenasal bone? Does the istiophorid prenasal bone appear early or late in development? Does the swordfish rostrum have prenasal bones or is it composed primarily of premaxillae? If scombrids are more primitive than billfish, then are there fossil billfish having more than 24 vertebrae (or 26 in the swordfish) or fewer than three epurals? Johnson (1986) believes that a thorough study of the extinct family Paleorhynchidae may resolve some of these questions, but I doubt it. I concluded that paleorhynchids were probably not true billfishes (Fierstine 1974) for the same reasons that Johnson found them a potential ancestor. Paleorhynchids have very elongated upper and lower jaws and numerous (45-60) vertebrae.

After extensive analysis, Nakamura (1983) believes that the shortbill spearfish is most similar to the ancestral billfish. Some of the features are: bill short and round, cranium fairly stout with a narrow parasphenoid and vomer, needle-like scales with few points, large slab-sided body, and triangular neural and haemal spines. His phylogenetic conclusions are weakened by his mixing of plesiomorphic and apomorphic characters.

No evidence has yet been presented to refute the hypothesis that the Xiphiorhynchidae are morphologically intermediate to the Istiophoridae and Xiphiidae (Fierstine and Applegate 1974) and may be closest to the scombrid-billfish connection postulated by Collette et al (1984) and Johnson (1986).

Summary

The paleontology and relevant osteology of adult billfishes are reviewed from the literature and unpublished studies. In the Istiophoridae, the premaxillary and prenasal bones form a rounded rostrum with denticles, the lower jaw has a predentary bone and well-developed intermandibular joint, and the elongated vertebrae form a rigid spinal column. Certain skull and vertebral proportions exhibit intergeneric differences, and the denticle pattern and relative size of the nutrient canals of the rostrum show interspecific differences.

All fossil istiophorids belong to one of five species of *Makaira,* with the exception of one vertebra specified as *Istiophorus*. There are no known fossil specimens of *Tetrapturus*. Istiophorids occur from the Middle Miocene to the present and have a zoogeographic distribution similar to extant species, except that *Makaira indica* may have been common in the western north Atlantic Ocean before the formation of the Isthmus of Panama. In the Xiphiidae, the rostrum is flat, is composed of acellular bone with secondary osteons, contains a variable number of central chambers, and lacks denticles in the adult. There is a controversy over which bones form the rostrum. It may be composed primarily of premaxillae, or premaxillae and nasals, or premaxillae and prenasals. The lower jaw lacks a predentary bone. The vertebrae are

cube-shaped and are not modified into a stiffened unit.

Disregarding identifications based on isolated vertebrae, the Xiphiidae is monotypic *(Xiphias gladius)* and has no fossil record before Pliocene times. The extinct Xiphiorhynchidae are characterized by a rounded rostrum with central chambers and denticles, and apparently without prenasal bones. The vertebrae are not formed into a stiffened unit. The family is monogeneric *(Xiphiorhynchus)* with six species, and is limited to Tertiary deposits (Eocene of Africa, Europe, and North America, and the Oligocene of Europe) associated with the north Atlantic Ocean and western Tethys Sea (or its remnant, the Mediterranean Sea). The Xiphiorhynchidae may be closest to the scombrid-billfish connection postulated by recent workers.

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Significance Of Coastal Resources to Sailfish And Juvenile Black Marlin In Northeastern Australia: An Ongoing Research Program

David McB. Williams

Of all Pacific billfishes, black marlin *(Makaira indica)* and sailfish *(Istiophorus platypterus)* are the most closely associated with land masses. The world famous fishing grounds for large black marlin between Cairns and Lizard Island in northeastern Australia (Fig. 1) are located just off the outer edge of the continental shelf. Fishing is often within hundreds of metres of shelf-edge coral reefs emerging from waters only 40m deep. On the continental shelf, itself, there are three recognized winter billfish grounds in northeastern Australia: off Cairns; Dunk Island, 150km south of Cairns; and Cape Bowling Green (CBG), 170km farther south (Fig. 1). A summer billfish ground also occurs off Cape Moreton, 1,000kms south of CBG.

Sailfish and juvenile black marlin are the major species on each of these shallow-water fishing grounds. The small marlin, averaging 15 to 40kg and presumed to be 6 to 24 months of age (Pepperell 1982), are only temporary residents of these grounds. Sailfish (<6kg-55kg), on the other hand, may spend most of their post-larval lives on one of the northern grounds. A tagging program run by the Fisheries Institute of New South Wales has resulted in the tagging of 1,200 sailfish in Queensland waters over ten years. Only 4 of the 31 recaptured tagged fish had moved measurable distances from their sites of tagging despite having been at liberty for as long as five years (J. Pepperell pers. comm.). Circumstantial evidence (very limited information on distribution of larvae, observations of ripe fish, and apparent absence of fish on the fishing grounds during summer) suggests that the sailfish on the northern grounds may move out to the continental slope to spawn in summer. No sailfish tagged in the north have been recaptured off Cape Moreton (J. Pepperell pers. comm.). The parasite faunas of sailfish in the two areas also suggest little if any movement of fish from the northern grounds to the south (P. Speare 1989). Such limited movements are in stark contrast to the results of similar studies on black marlin which indicate movements of hundred and thousands of kilometres during the life of an individual fish (Squire and Nielsen 1983).

The three northern winter grounds have several features in common: they are of shallow depth (24-40m) and of limited extent, the bottoms are flat and apparently featureless (i.e., there are no "drop-offs" of any kind), and exceptional concentrations of baitfish occur in each area. Stomach contents of billfishes from these grounds, plus those of jig-caught fish on the grounds, indicate that these baitfish schools are comprised of various scads *(Decapterus* spp.), herrings *(Herklotsichthys* spp. and *Sardinella* spp.), and pilchards *(Amblygaster* spp.).

In terms of both billfish and baitfish, the CBG grounds (Fig. 1) are the most productive. The existence of these grounds was established only in early 1984. Separate inner (approx. 24m deep) and outer (approx. 32m deep) grounds are recognized by fishermen. The former is approximately 5nm from shore and the latter approximately 10nm offshore (Fig. 2a). These waters are the centre of a research program recently initiated by the Australian Institute of Marine

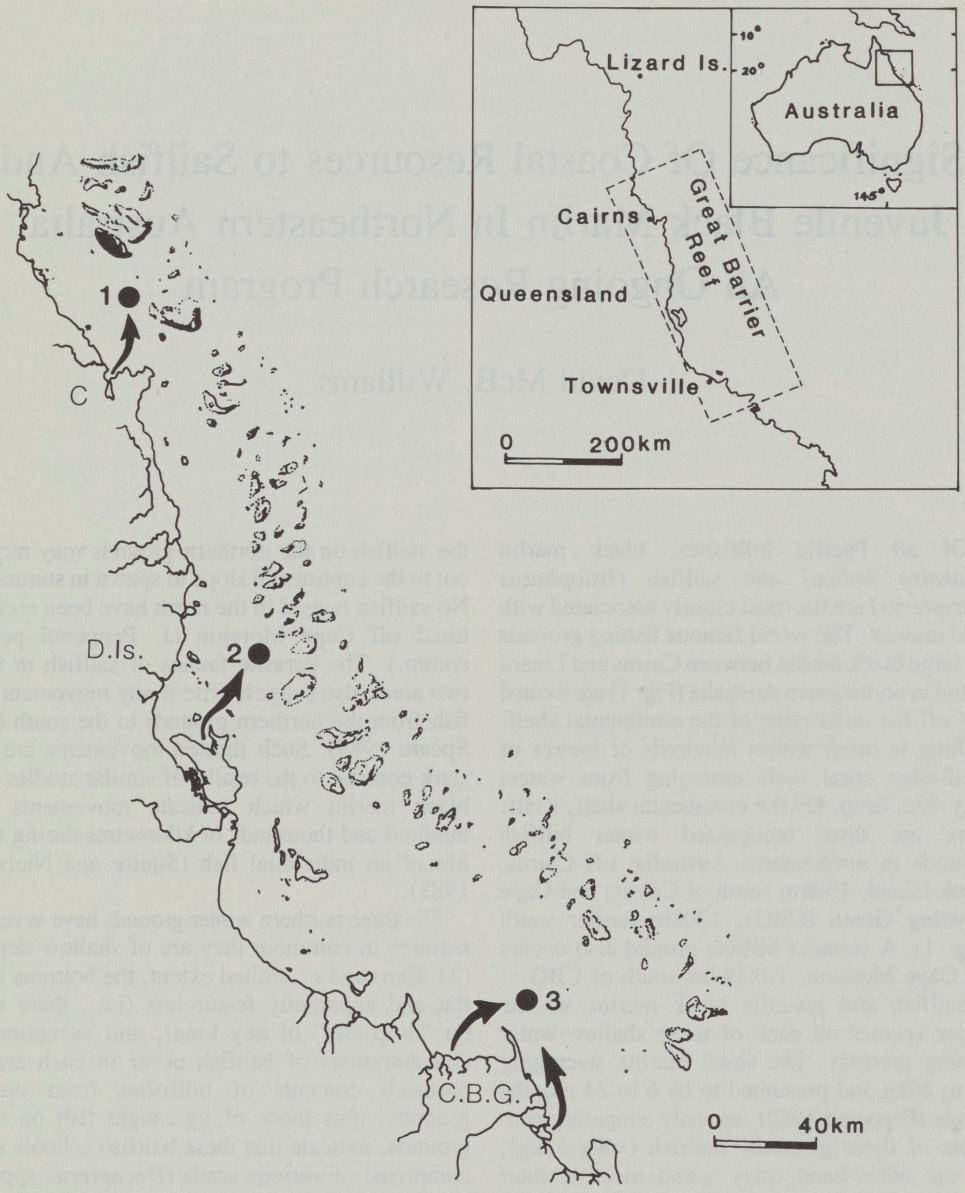

Figure 1. Locations of three major sailfish and juvenile black marlin fishing grounds in northeastern Australia. Circles represent fishing grounds: 1 = Cairns, 2 = Dunk Island, 3 = Cape Bowling Green. Arrows represent possible coastal connections discussed in text, from north to south: Trinity Inlet mangroves, Missionary Bay mangroves, Bowling Green Bay, Burdekin River.

Science (AIMS). The primary objective of the project is to, "identify the physical and biological factors determining the distribution and abundance of billfish and baitfish populations in the Bowling Green Bay region, with particular emphasis on the significance of coastal resources to offshore concentrations of billfish and baitfish".

Our preliminary research has led to a range of hypotheses to explain the occurrence of the billfish grounds, each emphasizing the apparent significance of the baitfish concentrations. While each hypothesis is attractive in itself, our studies indicate that the full explanation of the reasons for the billfish grounds is not so simple. Effective pursuit of our objective cannot be

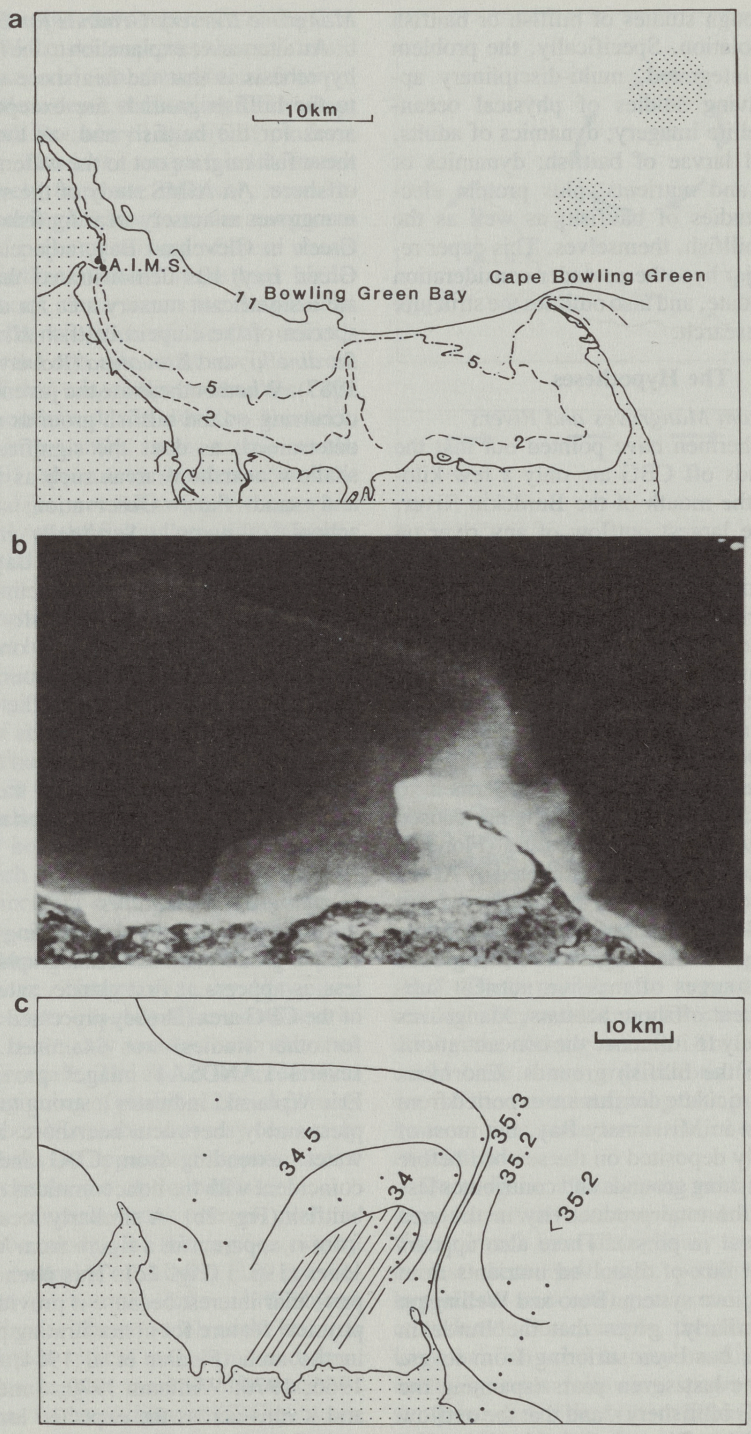

Figure 2. (a) Detailed location of Cape Bowling Green fishing grounds (stippled) with 2, 5 and 11m isobaths indicated.
(b) LANDSAT Band 4 image of Cape Bowling Green area showing water colour and turbidity front (original image enhanced by D. Carpenter and E. Wolanski).
(c) Detail of salinity distribution off Cape Bowling Green, modified from Wolanski and Jones (1981).

achieved through studies of billfish or baitfish biology in isolation. Specifically, the problem requires an integrated, multi-disciplinary approach involving studies of physical oceanography; satellite imagery; dynamics of adults, juveniles and larvae of baitfish; dynamics of zooplankton and nutrients; plus protein electrophoretic studies of baitfish; as well as the study of the billfish, themselves. This paper reviews the major hypotheses under consideration and results to date, and also outlines the structure of ongoing research.

The Hypotheses

Outwelling from Mangroves and Rivers

Several fishermen have pointed out that the fishing grounds off CBG are only a few kilometres from the mouth of the Burdekin River, which has the largest outflow of any river on the east coast of Australia (or did until completion of a major irrigation dam in the last year). Several fishermen have also pointed out that the Dunk Island and Cairns grounds are only a few kilometres down stream from two of the largest mangrove areas on the east coast of Australia: Missionary Bay and Trinity Inlet (Dowling and McDonald 1982).

These observations have led fishermen to suggest that the fish concentrations are caused by nutrient outflow from these areas (Florence 1987). Two studies recently completed by AIMS scientists concerning nutrient export from Missionary Bay, just down stream from the Dunk Island grounds, suggest that mangroves are unlikely sources of massive nutrient subsidies to adjacent offshore habitats. Mangroves are thus unlikely to influence the concentrations of baitfish on the billfish grounds. Enormous volumes of particulate detritus are exported from the mangroves in Missionary Bay, but most of this is probably deposited on the sea bed before reaching the fishing grounds and contributes less than 20% of the total productivity in the area (Robertson et al in press). There also appears to be little net flux of dissolved nutrients from the same mangrove system (Boto and Wellington in press). Similarly, given that the Burdekin drainage basin has been suffering from severe drought for the last seven years (spanning the life of the CBG billfishery), and that the outflow from the Burdekin River during this period has been minimal, nutrient export from the river would seem an unlikely explanation for the CBG grounds.

Mangrove Nursery Grounds for Billfish

An alternative explanation to the nutrient-export hypothesis is that the nearshore areas adjacent to the billfish grounds are exceptional nursery areas for the baitfish and, as they grow, that these fish migrate out to the waters immediately offshore. An AIMS study of the significance of mangroves as nursery areas for fishes (at Alligator Creek in Cleveland Bay, adjacent to Bowling Green Bay) has demonstrated that mangroves are a significant nursery area for at least certain species of the clupeid baitfish *Herklotsichthys, Sardinella,* and *Escualosa* (Robertson and Duke 1987). Whether these are the juveniles of species occurring on the billfish grounds remains to be determined, as does the significance of other shallow nearshore areas such as seagrass beds and sand flats. Observations of extensive schools of juvenile *Sardinella gibbosa* in the western end of Bowling Green Bay suggest that shallow waters close to the shoreline are of major significance during the juvenile stage of this species (which as an adult is one of the two major species on the billfish ground). The most likely hypothesis to explain the existence of these nearshore nursery grounds would appear to be availability of suitable food (Robertson et al 1988). The exact nature of the dependence of these species on coastal habitats remains to be determined.

Oceanographic Features

As a first step to determining whether the billfish grounds are as oceanographically featureless as appears at first glance, satellite imagery of the CBG area (already processed and enhanced for other studies) was examined. One of the several LANDSAT images provided by Dr. Eric Wolanski indicates a strong turbidity front, presumably between nearshore and offshore water, extending from CBG and remarkably coincident with the concentrations of billfish and baitfish (Fig. 2b). A similarly located (salinity) front is apparent in a figure from Wolanski and Jones (1981) (Fig. 2c). This phenomenon is of particular interest because it provides a possible physical feature for concentrating pelagic fishes in the area (Fiedler et al 1984; Ovchinnikov 1966, 1970; Williams 1970; Sund et al 1981) and it runs across the expected long-shore current flow.

Recent ongoing research by Wolanski suggest an oceanographic phenomenon off CBG that combines the nutrient-outwelling and frontal

hypotheses to explain the occurrence of the fishing grounds. Wolanski (in press) has established that a combination of tidal currents and friction, due to the shallow depth of Bowling Green Bay, causes a Coastal Boundary Layer (CBL) to form within the bay. This layer, only a few kilometres wide, effectively traps the relatively nutrient-rich waters entering the bay from the mangroves and rivers and prevents mixing of these waters with waters farther offshore in the bay. Under certain conditions, these waters are moved eastward around the coastline of the bay towards the Cape. On the ebb tide, a narrowly concentrated strip of this water slips around the Cape and moves southward towards the Burdekin River. More importantly, under certain conditions, this CBL appears to shoot out from the Cape as a tidal jet, not following the coast but heading directly to the fishing grounds. It is thus possible that the fishing grounds receive regular pulses of nutrient-rich water via tidal jets released from behind CBG.

The tidal-jet hypothesis is as attractive as the earlier hypotheses but, again, the story isn't as simple as it might first appear. Not yet established is the range of conditions under which these jets occur, their frequency, just how nutrient-rich the water is, or the significance of such pulses to offshore pelagic food chains.

Fishermen believe that offshore concentrations of baitfish on the billfish grounds are seasonal and coincident with seasonal occurrence of billfish. Specifically, small fish appear within a few kilometres of CBG in about March-April. These fish move offshore until, by May, they appear on the outer grounds. The movement of fish offshore is roughly incident with the start of the SE trade winds. The end of the trade-wind season and beginning of prolonged calm periods (usually October-November, but may be as early as August) marks the apparent disappearance of the baitfish schools and of the billfish.

Should this scenario prove correct, preliminary circulation models of the region (run by Dr. John C. Andrews of AIMS) may provide an explanation for seasonal shifts in billfish and baitfish abundance. These models of the residual (mean) currents in typical trade-wind and summer conditions suggest marked differences in current patterns in the vicinity of CBG between the two seasons (Fig. 3). The models further suggest that conditions during the trade-wind (fishing) season are more likely to be favorable for the formation of fronts and tidal jets on the

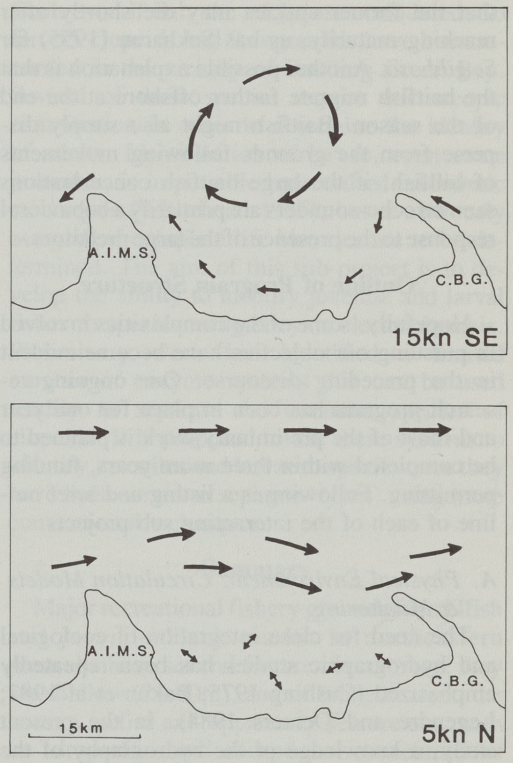

Figure 3. Residual circulation of currents in vicinity of Bowling Green Bay during typical trade-wind (15kn southeasterly wind) and summer (5kn northerly wind) conditions (based on data of J.C. Andrews).

grounds than those during summer when the offshore waters appear well-flushed by the extension of the East Australian Current onto the shelf. These models also suggest that a large residual eddy system may form within the region during the fishing season. This circumstance could have many implications for the fishes, one of the most intriguing being that the eddy system might serve as a retention area for larvae of baitfish.

Once again, although the circulation models provide us with interesting and exciting hypotheses, much inter-disciplinary work is required to test them and other, perhaps interacting, hypotheses concerning seasonality need to be considered. For example, the disappearance of large baitfish schools may be due to very high mortality rates following spawning. The presumptive end of the billfish fishing season coincides well with the apparent onset of the spawning season of *Amblygaster sirm* and *Sardinella gibbosa* apparently the major species on the fishing grounds). Conand (1985) has suggested

that the former species may die shortly after reaching maturity, as has Sekharan (1955) for *S. gibbosa*. Another possible explanation is that the baitfish migrate farther offshore at the end of the season. Baitfish might also simply disperse from the grounds following movements of billfish, if the large baitfish concentrations seen on echo-sounders are primarily a behavioral response to the presence of the large predators.

Outline of Program Structure

Hopefully, some of the complexities involved in pursuing our objective have become evident in the preceding discourse. Our ongoing research program has been in place for one year and most of the preliminary work is planned to be completed within three more years, funding permitting. Following is a listing and brief outline of each of the interacting sub-projects.

A. Physical Environment: Circulation Models & Monitoring

The need for close integration of ecological and hydrographic studies has been repeatedly emphasized (Cushing 1975; Bakun et al 1982; Legendre and Demers 1984). In the present study, a knowledge of the hydrography of the area is necessary:

1. for optimisation of sampling design;
2. to determine locations and variability of features likely to be of particular significance, such as fronts and eddy systems;
3. to predict likely patterns of dispersal of larval fishes from spawning areas;
4. to aid interpretation of satellite imagery.

An improved version of the numerical model built for previous studies in the area (Kelly and Andrews 1985) will provide the basis for simulation of water currents in the study area under a range of wind and tidal conditions and for modelling likely paths of dispersal from different spawning locations.

B. Physical Environment: Satellite Imagery

Despite the relatively small area of the CBG fishing grounds, major potential factors affecting billfishes and baitfishes, such as water temperature, turbidity, and tidal currents, vary faster than the time required to map them from a research vessel. Satellite imagery provides synoptic pictures of these variables over the entire area more effectively and cheaper than ship-based research. Satellite imagery from NOAA/AVHRR, CZCS and LANDSAT satellites is being used to examine the spatial and temporal variability of major hydrographic features in the study area and to correlate these with the circulation models. The very recent development of NASIS (Northeast Australian Satellite Imaging System) — including the establishment of a receiving station for AVHRR imagery at James Cook University, just 50km from AIMS — means that during 1988, AVHRR tapes should become available within hours of an overpass. In the future, this facility will greatly aid planning of ship-based, process-oriented studies.

C. Distribution and Dynamics of Billfishes

Much of the direct information required concerning billfishes in the area is difficult to obtain given the laudable reluctance of anglers to kill fish even for scientific purposes (95% are tagged and released) and the unwillingness of fishermen to fish outside the traditional fishing season. Virtually all billfish killed in the area are made available for scientific study. These are examined for reproductive condition, stomach contents, and parasite fauna (see following), and heads are retained for ageing studies using otoliths. The tagging program run by New South Wales Fisheries Institute (Pepperell 1989) provides considerable information on movements of the fish, particularly sailfish for which we have had 16 recoveries on the CBG grounds alone.

The most original aspects of our direct studies on billfish are:

1. An MSc project evaluating parasites as natural population tags in sailfish and black marlin (Speare 1989);
2. Attempts to relate the distribution of nearshore billfish grounds to satellite imagery;
3. Possible direct detection of billfish with colour scanning sonar. Preliminary results suggest that billfish on the CBG grounds can be identified on sonar, along with the baitfish schools. When validated, we will begin to explore behavioural and temporal relationships between billfish, baitfish schools, and the catchability of billfishes.

D. Distribution and Dynamics of Baitfish

If, as appears likely, the offshore concentrations of baitfish are the principle cause of the billfish grounds, knowledge of the basic life histories of the baitfish species (currently lacking) is required in order to determine the nature of their dependence on the coastal resources.

There are at least a dozen species of the subfamily Clupeinae alone in the vicinity of the fishing grounds. We have recently resolved the considerable taxonomic difficulties that this circumstance has presented and have studies under way to determine distribution and abundance, reproduction, growth and mortality in all the major baitfish species.

E. Distribution and Dynamics of Larvae of Baitfish

The reasons for persistent offshore aggregations of baitfish are as yet unknown. It is, however, generally considered that distribution of, and recruitment to, adult populations depends at least in part on distributions and survival of early developmental stages. The distribution and dynamics of larvae is recognized as being of major potential significance in determining the distribution and abundance of the baitfish schools. Given special sampling problems and present general interest in the relationship between early life histories and physical hydrological processes, this subject, while highly integrated with projects A and D, has been separately identified and is the subject of a PhD thesis (Mr. Simon Thorrold, James Cook University of North Queensland).

F. Distribution and Dynamics of Food of Baitfish

Significant correlations may be found between specific oceanographic features and baitfish concentrations, but an understanding of the factors causing these correlations is necessary to understand the multitude of factors ultimately determining the existence of the fishing grounds. Similarly, it is not sufficient for management purposes simply to know that a major baitfish species uses nearshore waters as a nursery area. We need to know the nature and extent of this dependence. Just what is so significant to the fish in these areas? Without this knowledge we cannot make reasonable predictions about the likely effect of specific changes or disturbances in these areas. It is likely that a major factor determining the distribution and dynamics of the baitfish is the distribution and dynamics of their zooplanktonic food. Hence, this sub-project is examining the distribution of zooplanktonic food in relation to the distribution and dynamics of the baitfishes.

G. Taxonomy and Electrophoresis of Baitfish

Taxonomy of the baitfish in the study is difficult even if only the adults are considered. So far, 15 clupeids and 9 engraulids have been recorded in the vicinity of Bowling Green Bay. Several of these species require microscopic examination in order to determine the identity of adults. Identification of larvae, even some juveniles, is impossible by standard taxonomic techniques (Whitehead 1985), but is obviously essential if complete life histories are to be determined. The aim of this sub-project is to develop the ability to identify juvenile and larval fishes to species using enzyme electrophoresis. Preliminary work has identified a limited number of enzyme systems that can be used readily to separate the common species of clupeids. It is proposed to use these systems to identify juveniles and larvae to species once they have been sorted to separate 'types' using more conventional techniques.

Summary

Major recreational fishery grounds for sailfish and juvenile black marlin in northeastern Australia have several features in common: they are shallow (24-40m), and of limited extent; the bottom is flat and apparently featureless, with no 'drop-offs'; and exceptional concentrations of baitfish occur in each area. The proximate explanation of billfish concentrations on these grounds appears to be the presence of the baitfish. Several hypotheses are presented to explain the concentrations of baitfish. These include the significance of outwelling from mangroves and rivers, the existence of coastal nursery grounds, and various physical oceanographic features. Each of these hypotheses is attractive in itself but none on its own provides a satisfactory explanation for the persistence of the physical and biological factors influencing the billfish concentrations, and hence the information required to manage these areas, will come only from a highly integrated, multi-disciplinary study. An outline of one such ongoing study of the Cape Bowling Green grounds is given.

Acknowledgements

This project would not have got off the ground except for the enthusiasm and insights of local fisherman Jim Dalling. A number of different scientists are involved in this project. In particular, I would like to thank J.C. Andrews, A.I. Robertson and E. Wolanski, all of whom provided data for this paper. Comments by M. Cappo, A.J. Fowler, A.I. Robertson, S.

Thorrold, and two anonymous reviewers, led to significant improvements in the text. This is AIMS Contribution No. 458.

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David McB. Williams was awarded the PhD in the field of ecology of coral reef fishes at the University of Sydney in 1979. He joined the staff of the Australian Institute of Marine Science, Queensland, in 1980, where he is presently a senior research scientist. Most of his research has concentrated on factors determining the distribution and abundance of coral reef fishes. This work has concentrated in the Great Barrier Reef region but also extended to other areas of the south Pacific Ocean and the Caribbean Sea. In addition to ongoing reef-fish work, he is currently leading a new coastal pelagic resources project at AIMS.

Patterns of Pacific Blue Marlin Reproduction in Hawaiian Waters

Carol N. Hopper

Throughout its distribution, the blue marlin *(Makaira nigricans)* is important in both commercial and sport fisheries. Declining catches have spurred development of management plans for the fisheries. Appropriate and effective management of the species depends, in part, upon an understanding of pivotal life history characteristics, including reproductive biology and ecology.

Basic parameters of blue marlin reproductive biology have been studied at different points throughout its range within the Atlantic and Caribbean, Pacific, and Indian oceans (Rivas 1975). While this species has been the object of commercial and sport fisheries in Hawaii for at least 40 years, there has been relatively little documentation of its reproductive activity in Hawaiian waters or of the possible contribution by Hawaiian spawners to Pacific-wide stocks.

Analyses of commercial longline catches spanning nearly twenty years (Otsu 1954, Strasburg 1970, Yoshida 1974) document the year-round presence of blue marlin in Hawaii, but also demonstrate dramatically higher catches in summer than in winter. Sport catches parallel this pattern to the present day. Longline data (Strasburg 1970) also reveal a similar pattern of seasonal abundance of skipjack tuna *(Katsuwonus pelamis),* prompting some researchers to attribute increased marlin numbers to the seasonal abundance of their prey (Strasburg 1970, Yoshida 1974).

Based on the results of a long-term baseline project that I began in 1982, I propose that the observed seasonal variation in Hawaiian blue marlin catch reflects their pattern of reproductive activity, and that this reproductive pattern also explains annual variations in population size and sex structure. My observations are consistent with other studies on blue marlin and I suggest that reproductive studies represent a tool for understanding aspects of marlin behavior, stock structure, distribution, and both small- and large-scale movements.

The objectives of my study are to: (1) clarify the pattern of reproductive activity of Pacific blue marlin in Hawaiian waters; (2) characterize the reproductive composition of this sampling population; and (3) contribute to the assessment of reproductive potential of blue marlin.

Materials and Methods

Between August 1982 and August 1987, I examined 958 blue marlin for sex and reproductive condition. Observations were made and samples collected during 21 major Hawaiian billfish tournaments: 12 during summer months (June-August); six during fall months (September-November); and six during spring months (March-May). All but four tournaments were held off the Kona (southwestern) coast of the island of Hawaii. Of the exceptions, one spring sample represented waters off the south and southwestern coasts of Oahu, and three fall samples were collected from waters off the island of Maui. During peak fishing months of some years, additional collections were made between tournaments. Collection periods ranged from two to 14 days.

Fish examined during all sampling periods were weighed to the nearest 0.2 kg (0.4 lb). Weights were used to construct size (weight) frequency distibutions for each sampling period

and were pooled to produce an overall picture of size-frequency by sex.

Sex and reproductive condition of fish sampled were determined by macroscopic examination of the gonads. State of reproductive activity was established using a staging system of easily distinguished features, most of which could be used in the field without laboratory support. This gross staging system parallels other studies of marlin reproductive anatomy that include histological confirmation (Erdman 1968; Merrett 1970, 1971; Yeo 1978).

Criteria used for staging female reproductive readiness include: (1) simple gonad/somatic index or GSI (ovary weight as a percentage of total body weight, with no correction for size class, as suggested in Hunter et al. 1984); (2) development of ovarian tissues and lumen; (3) the presence and size of oocytes. For males, staging criteria included: (1) gonad/somatic index (GSI); (2) development of testes and sperm ducts; (3) volume and viscosity of milt; and (4) index of sperm activity (relative percentage of actively-swimming sperm per field of view under 400-power magnification light microscopy). Details of these staging criteria are being prepared for publication elsewhere (Hopper in preparation).

Seven basic stages of gonadal development were recognized for both females and males. For females, ovaries were classified as: immature; prespawn; gravid (ripe); ovulatory; partially spawned; spawned out; or inactive. In males, testes were classified as: immature; prespawn; ripe; running ripe; declining; spawned out; or inactive. Gonads in the prespawn through partially spawned (females) or declining (males) stages were considered to be reproductively active. In both males and females, gonads in the immature, spawned out, and inactive stages were considered to be reproductively inactive.

Size distribution and number of oocyte size classes resident in ovaries of different stages were determined by examination of fresh samples of ovarian wall under 20-power magnification. Preliminary estimates of reproductive output (number of oocytes contained in both ovaries) were determined for four females in stages of peak ripeness (but before ovulation had begun). Small subsamples of ovarian wall (0.50 gm or less in wet weight) were removed and fixed in 10% saline formalin. The samples were teased apart, oocytes (yolked and unyolked) counted, and total number of oocytes contained in both ovaries estimated based on total ovarian weight. Further details of methodology are being prepared for publication elsewhere (Hopper in preparation).

Reproductive output in males was measured as the volume (ml) of loose milt collectible from the main sperm ducts. Sperm densities were calculated by a standard technique (Levinson and MacFate 1969), using a hemocytometer to examine subsamples of milt of known dilution. Sperm activity and longevity were assessed after activation of milt in buffered sea water (pH 8). Following activation, observations and relative measurements of the percentage of active sperm per field of view (sperm activity index) were made at regular intervals using light microscopy.

Catch records from the annual Hawaiian International Billfish Tournament (HIBT), held in Kona, Hawaii, are compiled by the Hawaiian International Billfish Association (HIBA). These data were used to plot a history of blue marlin catches from 1959 to 1987. Since, for the six years of this study, blue marlin have composed 99% of the tournament catch, I make the assumption that the "billfish" catch reported by the HIBA in early years is highly representative of the catch of blue marlin during those tournaments. These data represent one of the most consistent and reliable sampling sets available anywhere for a sport fishery of blue marlin because: the sampling area off Kona is the same from year to year; the length of the tournament is constant from year to year (5 days); the dates of the tournament vary by no more than two weeks from year to year, since the tournament is scheduled according to moon phase and tide conditions; and, since 1961, there has been a relatively constant fishing effort (number of hours per day, number of boats per day, quality of skippers and anglers). Moreover, the HIBT is the longest running blue marlin tournament extant and tournament officials have placed great emphasis on the collection of accurate catch statistics.

Results & Discussion

Size and Sex Ratio of Blue Marlin in Hawaiian Waters

Size-frequency distributions of blue marlin populations are basically bimodal when examined by sex, a reflection of the dramatic sexual size dimorphism characteristic of this species (Ueyanagi 1953, Strasburg 1970,

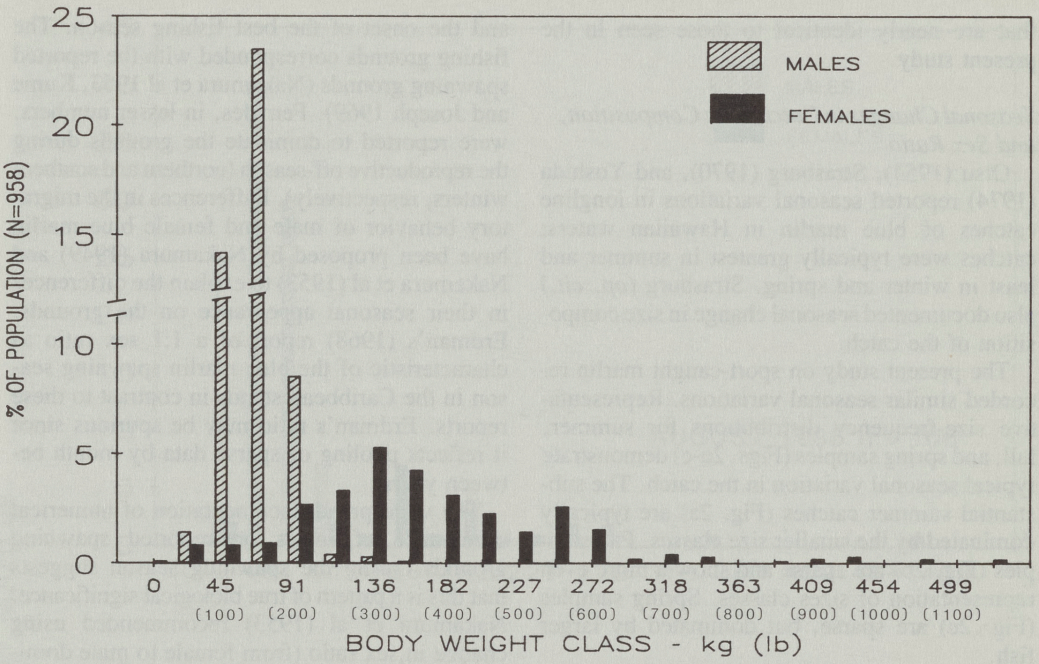

Figure 1. Pooled size-frequency distribution by sex for 958 Pacific blue marlin *(Makaira nigricans)* from Hawaiian waters. Collections made at 21 major sport fishing tournaments, August 1982 – August 1987. Males are represented by crosshatched bars, females by solid bars.

Ueyanagi et al 1970, Yeo 1978, Wilson 1984, and Hill 1986).

The size and sex composition of the 958 Hawaiian sport-caught blue marlin sampled in this study (657 males, 301 females) shows a similar bimodal pattern (Fig. 1). In this pooled sample, males comprise a narrow peak, 85% weighing between 45.5 and 90.8 kg (100 and 200 lb). Males larger than 136.2 kg (300 lb) are rare; only three were observed during the study period, weighing 141.4 kg (311.5 lb), 151.6 kg (334 lb), and 170.5 kg (375.5 lb). Females dominate the larger size classes and reach much greater weights than do males. Forming a broad peak, 79% of females weighed between 90.8 and 272.4 kg (200 and 600 lb), some reaching weights in excess of 454 kg (1000 lb).

Sex cannot be distinguished from external features, but size is often used to predict the sex of a fish with reasonable accuracy. There is no evidence, however, for protandric sex reversal in blue marlin, and small females have been reported in this and other studies. Both sexes can be distinguished even at weights less than 22.7 kg (50 lb), and no intersex individuals have ever been reported. Few small females (<90.8 kg) were reported in this sport catch, but they were better represented in Hawaiian longline catches described by Strasburg (1970) and Yoshida (1974), suggesting that small females may be more common on the offshore longline grounds than on the nearshore sport fishing grounds off Kona.

The sexual size dimorphism of blue marlin has been explained by asymptotic differential growth rates of males and females (Dean and Wilson 1982, Wilson 1984, Radtke 1983, Hill 1986). These studies indicate that females grow more rapidly than do males, so that at similar ages, fish of different sexes can be of substantially different weights. While it is tempting to speculate that the modes of 68.1 to 90.8 kg (150 to 200 lb) for males and 136.2 to 158.9 kg (300 to 350 lb) for females seen in Figure 1 may represent roughly the same age classes of fish, present estimates of fish age based on body weight are not yet reliable enough to test this hypothesis.

This recent (1982-1987) picture of Hawaiian blue marlin size and sex composition (Fig. 1), derived from six years of intermittent examination of sport tournament catches, appears to compare favorably with the size-frequency distribution from Hawaiian commercial longline catches of 1960 to 1962 (Strasburg 1970). Those patterns of size-frequency by sex reveal modes

that are nearly identical to those seen in the present study.

Seasonal Changes in Catch, Size Composition, and Sex Ratio

Otsu (1954), Strasburg (1970), and Yoshida (1974) reported seasonal variations in longline catches of blue marlin in Hawaiian waters; catches were typically greatest in summer and least in winter and spring. Strasburg *(op. cit.)* also documented seasonal change in size composition of the catch.

The present study on sport-caught marlin recorded similar seasonal variations. Representative size-frequency distributions for summer, fall, and spring samples (Figs. 2a-c) demonstrate typical seasonal variation in the catch. The substantial summer catches (Fig. 2a) are typically dominated by the smaller size classes. Fall samples (Fig. 2b) are sparse and show a more even representation of sizes classes. Spring samples (Fig. 2c) are sparse, but dominated by larger fish.

Further examination reveals that the seasonal change in both catch numbers and size composition is linked to seasonal variation in sex ratio. Figure 3 demonstrates variation in sex ratio by sampling period. Males were from two to six times as numerous as females in the substantial summer catches. In the lesser catches of the late fall, the sex ratio approached 1:1, and in the sparse spring catches, larger females outnumbered males by two to seven times. In an atypical year, 1985, catch was low and females were slightly more numerous than males (Fig. 2d).

The predominance of males during the typical summer catch was further associated with a high percentage of reproductive activity among both males and females (Fig. 4). In contrast, the percentage of fish showing evidence of reproductive activity was low in the late fall or early spring, when the sex ratio was 1:1, or when females dominated.

Similar patterns of seasonal change in catch numbers, size composition, sex ratio, and spawning activity have been reported for blue marlin elsewhere in the Pacific Ocean (Nakamura 1949, Nakamura et al 1953, Ueyanagi 1953), and in the Atlantic Ocean (Ueyanagi et al 1970). In these studies, the influx of males and high male to female sex ratio corresponded to the beginning of the reproductive season (summer in the respective northern or southern hemisphere) and the onset of the best fishing season. The fishing grounds corresponded with the reported spawning grounds (Nakamura et al 1953, Kume and Joseph 1969). Females, in lesser numbers, were reported to dominate the grounds during the reproductive off-season (northern and southern winters, respectively). Differences in the migratory behavior of male and female blue marlin have been proposed by Nakamura (1949) and Nakamura et al (1953) to explain the differences in their seasonal appearance on the grounds. Erdman's (1968) report of a 1:1 sex ratio as characteristic of the blue marlin spawning season in the Caribbean stands in contrast to these reports. Erdman's ratio may be spurious since it reflects pooling of sparse data by month between years.

The widespread documentation of numerical dominance of males on reported spawning grounds during the spawning season suggests that this is a pattern of true biological significance. Nakamura et al (1953) recommended using change in sex ratio (from female to male dominance) as an indication of the onset of the reproductive season in blue marlin. Based on these similarities, among others, it appears that the Kona sport fishing grounds represent a spawning area for Pacific blue marlin. But, why so many males? Few explanations have been proposed for this dramatic phenomenon. In Hawaii, and elsewhere, boat captains and anglers frequently report seeing a single large fish (presumably female) being escorted by multiple smaller fish (presumably males). The contribution of milt from several males may be required for high fertilization rate of eggs spawned by a single female. Conversely, large numbers of males in "spawning areas" may represent competition for the female resource. Multiple males surrounding an individual female may be awaiting an opportunity to gain access to her spawn.

Reproductive Readiness

Changes in gonad size and development with stage of reproductive readiness are most dramatic for females, and GSI and stage of ovarian development are clearly associated. Ovaries of immature females generally make up less than 0.5% of the body weight. Prespawn ovaries show increases in size and weight as oocytes are produced and yolk deposition proceeds; gravid ovaries may represent from 3% to 6% the body weight. Partially spawned ovaries account

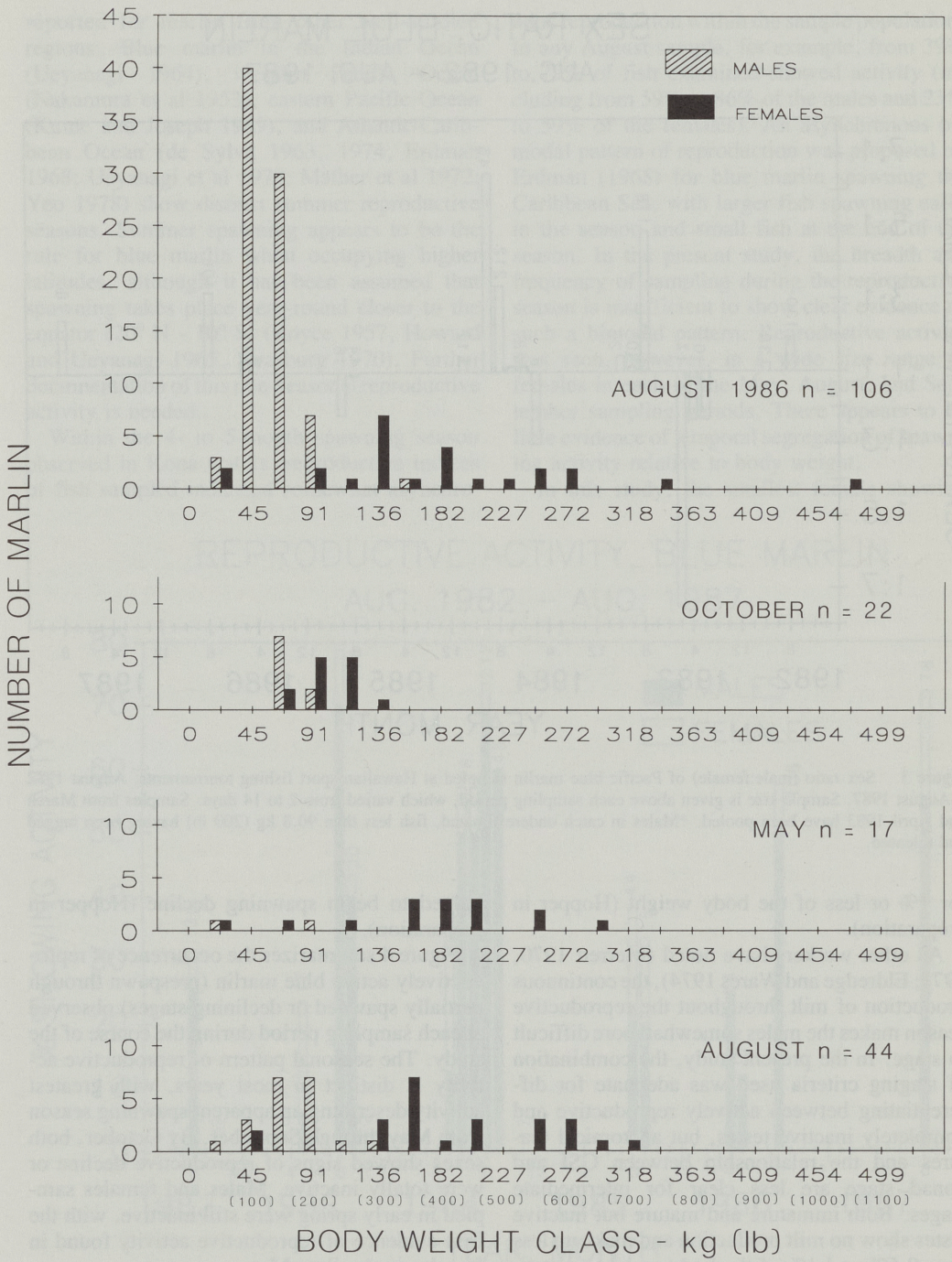

Figure 2. Size-frequency distributions by sex of Pacific blue marlin from representative seasonal sampling periods: (a) summer (August 1986, Kona, Hawaii); (b) fall (October 1983, Lahaina, Maui); and (c) spring (May 1983, Kona, Hawaii); (d) represents an atypical summer sample (August 1985, Kona, Hawaii). Males are represented by crosshatched bars, females by solid bars.

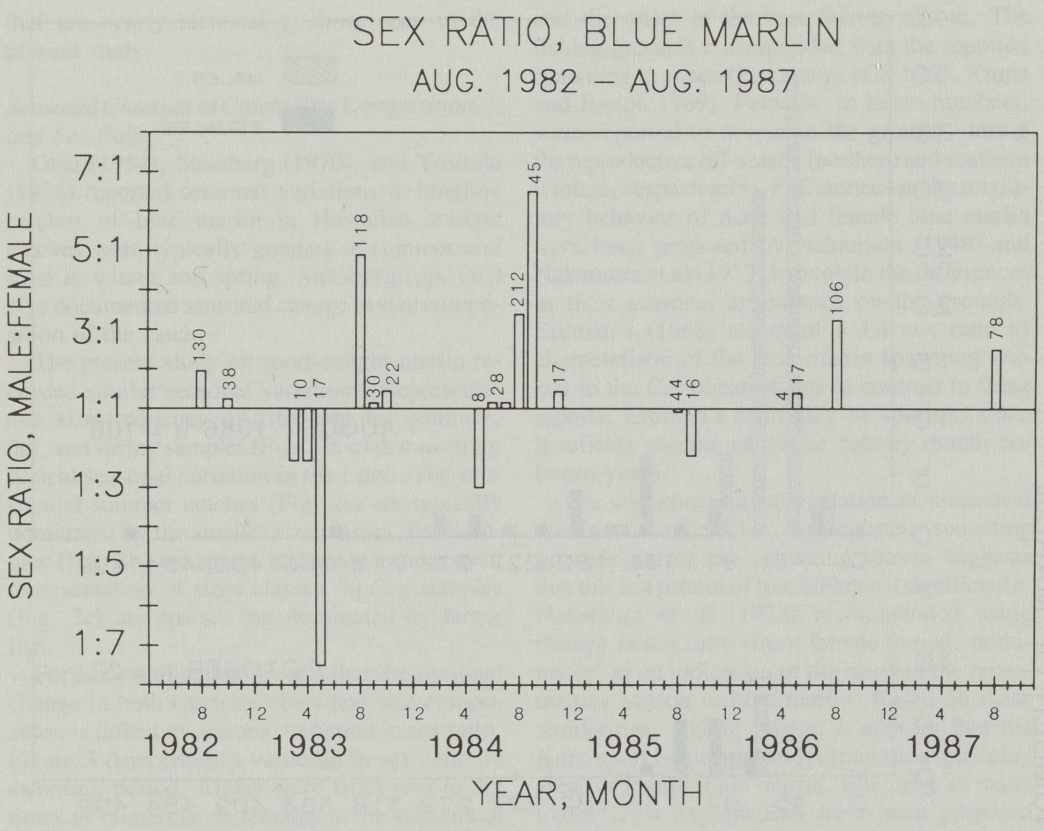

Figure 3. Sex ratio (male:female) of Pacific blue marlin sampled at Hawaiian sport fishing tournaments, August 1982 – August 1987. Sample size is given above each sampling period, which varied from 2 to 14 days. Samples from March and April 1983 have been pooled. *Males in catch underestimated, fish less than 90.8 kg (200 lb) having been tagged and released.

for 1% or less of the body weight (Hopper in preparation).

As other workers have noted (Merrett 1970, 1971; Eldredge and Wares 1974), the continuous production of milt throughout the reproductive season makes the males somewhat more difficult to stage. In the present study, the combination of staging criteria used was adequate for differentiating between actively reproductive and completely inactive testes, but anatomical features and the relationship between GSI and gonad stage are less clear for intermediate stages. Both immature and mature but inactive testes show no milt production and make up less than 0.5% and 1% of the body weight, respectively. The ripest males ("running ripe") have testes representing up to 3% of their body weight. Male intermediate stages of reproductive activity (active, but not running ripe) showed ranges of GSI similar to those of testes judged to be in spawning decline (Hopper in preparation).

Figure 4 summarizes the occurrence of reproductively active blue marlin (prespawn through partially spawned or declining stages) observed at each sampling period during the course of the study. The seasonal pattern of reproductive activity is distinct in most years, with greatest activity describing an apparent spawning season from May through Septmber. By October, both sexes showed signs of reproductive decline or were totally inactive. Males and females sampled in early spring were still inactive, with the first evidence of reproductive activity found in females in April or May.

This summer reproductive season observed for blue marlin in Hawaiian waters correlates well with the seasonal occurrence of blue marlin larvae reported by Matsumoto and Kazama (1974), as well as with spawning patterns

reported for marlin from other well-studied regions. Blue marlin in the Indian Ocean (Ueyanagi 1964), western Pacific Ocean (Nakamura et al 1953), eastern Pacific Ocean (Kume and Joseph 1969), and Atlantic/Caribbean Ocean (de Sylva 1963, 1974; Erdman 1968; Ueyanagi et al 1970; Mather et al 1972; Yeo 1978) show distinct summer reproductive seasons. Summer spawning appears to be the rule for blue marlin when occupying higher latitudes, although it has been assumed that spawning takes place year-round closer to the equator (20° N - 10° S) (Royce 1957, Howard and Ueyanagi 1965, Strasburg 1970). Further documentation of this non-seasonal reproductive activity is needed.

Within the 4- to 5-month spawning season observed in Kona waters, reproductive indices of fish sampled indicated somewhat asynchronous reproduction within the sample population. In any August sample, for example, from 39% to 79% of fish examined showed activity (including from 59% to 86% of the males and 23% to 59% of the females). An asynchronous bimodal pattern of reproduction was proposed by Erdman (1968) for blue marlin spawning the Caribbean Sea, with larger fish spawning early in the season and small fish at the end of the season. In the present study, the breadth and frequency of sampling during the reproductive season is insufficient to show clear evidence of such a bimodal pattern. Reproductive activity was seen, however, in a wide size range of females in each of the May, August, and September sampling periods. There appears to be little evidence of temporal segregation of spawning activity relative to body weight.

In this study, the smallest female showing

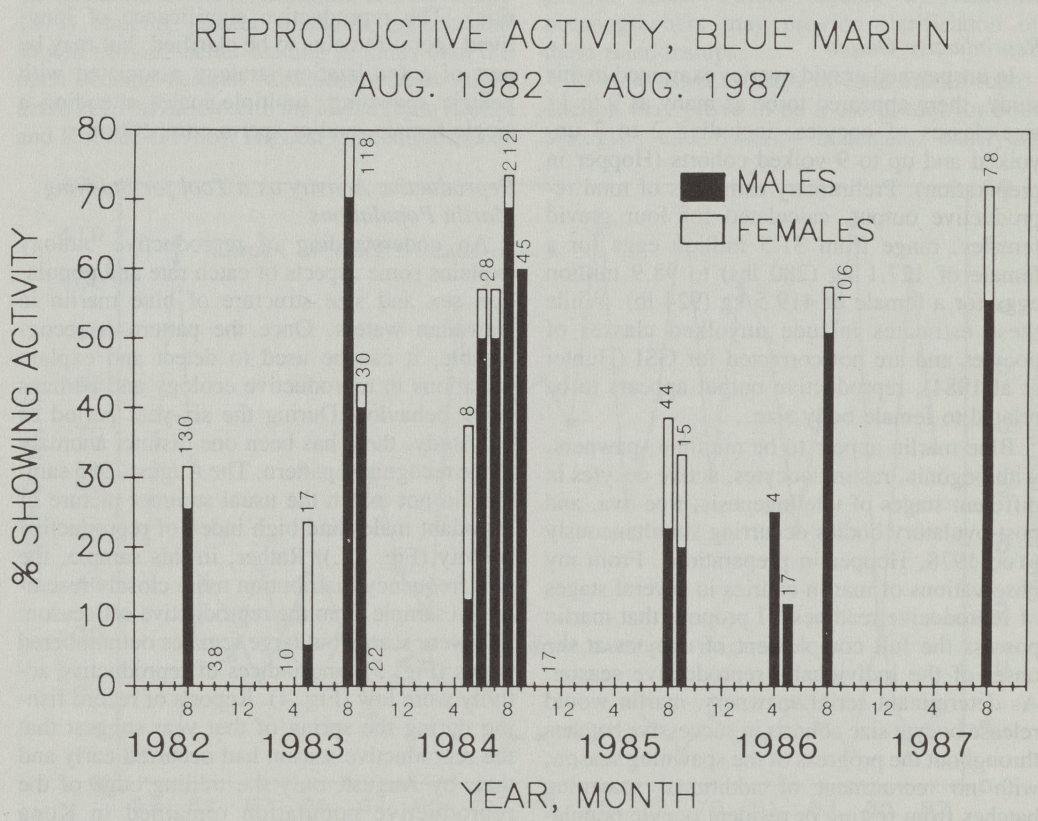

Figure 4. Pattern of reproductive activity observed in sport-caught Pacific blue marlin from Hawaiian waters, August 1982 – August 1987. Activity was documented as the percentage of the sample population having reproductive organs classified as active (in prespawn, ripe, or declining stages). Sample size is given above each sampling period, which varied from 2 to 14 days. In months in which no reproductive activity was recorded, sample size indicates the number of fish examined, all with inactive gonads (in immature, spawned-out, or inactive stages). *Male contribution underestimated, fish less than 90.8 kg (200 lb) having been tagged and released.

reproductive activity weighed 79.9 kg (176 lb) and the smallest male weighed 30.9 kg (68 lb). Other workers have reported reproductively active females ranging from 61.3 (135 lb) to 73.0 kg (161 lb) and males from 34.5 (76 lb) to 47.2 kg (104 lb) (de Sylva 1963, Erdman, 1968, Merrett 1971, Yeo 1978). Evidence from six years of observations in Kona shows that there is considerable variation in size at apparent first reproduction, particularly for females. Immature ovaries were observed in females as large as 94.9 kg (209 lb), 127.1 kg (280 lb), and 203.4 kg (448 lb). It is unclear whether these larger individuals, apparently immature, had experienced faster growth and were large for their age, had suffered poor nutritional histories and had not been able to afford the energetic costs of reproduction, or were simply incapable of reproduction as a result of physiological or anatomical anomalies.

Reproductive Output

In unspawned gravid ovaries examined in this study, there appeared to be as many as 9 to 11 size-classes of oocytes, including 2 to 3 unyolked and up to 9 yolked cohorts (Hopper in preparation). Preliminary estimates of total reproductive output, calculated for four gravid females, range from 31.5 million eggs for a female of 127.1 kg (280 lbs) to 98.9 million eggs for a female of 419.5 kg (924 lb). While these estimates include unyolked classes of oocytes and are not corrected for GSI (Hunter et al 1984), reproductive output appears to be related to female body size.

Blue marlin appear to be multiple spawners, with oogonia, resting oocytes, active oocytes in different stages of vitellogenesis, ripe ova, and post-ovulatory bodies occurring simultaneously (Yeo 1978, Hopper in preparation). From my observations of marlin ovaries in several stages of reproducive readiness, I propose that marlin possess the full complement of oocytes at the onset of the individual's reproductive season. As determinant serial spawners, marlin would release oocyte size cohorts in successive batches throughout the progress of the spawning season, with no recruitment of additional spawning batches from resting or resident oocyte populations. How often a female spawns and the number of oocytes hydrated and released per spawning event is unknown. Based on histological examination of blue marlin sampled in the Carribean Sea, Yeo (1978) estimated that at least three spawnings occurred per season. Further analysis of oocyte size classes, from unspawned and partially spawned gravid ovaries sampled during the present study, is planned to test the hypothesis of blue marlin as determinant serial spawners.

Many features of blue marlin male reproductive output (milt volume, sperm density) warrant further study. The volume of milt stored in sperm ducts and seminal vesicles of reproductively active males varied, but was greatest in individuals in peak spawning condition. Testes from a "running ripe" male of 80.4 kg (177 lb) yielded nearly 200 ml of freely flowing milt. Sperm densities ranged to over one billion cells/ml, but showed no consistent correlation with reproductive condition. The sperm cells of blue marlin are particularly interesting because of their long post-activation life of more than 3 hours in buffered sea water (Hopper in preparation). The reproductive significance of long-lived sperm remains to be clarified, but may be part of a fertilization strategy associated with pelagic spawning, multiple males attending a single female, and/or sperm competition.

Reproductive Activity as a Tool for Studying Marlin Populations

An understanding of reproductive biology explains some aspects of catch rate and population sex and size structure of blue marlin in Hawaiian waters. Once the pattern is recognizable, it can be used to detect and explain variations in reproductive ecology and perhaps stock behavior. During the six-year period of this study, there has been one distinct anomaly in the recognized pattern. The August 1985 sample did not match the usual summer picture of abundant males and high index of reproductive activity (Fig. 2d.). Rather, in this sample, the size frequency distribution more closely resembled a sample from the reproductive off-season: fish were scarce but large females outnumbered males (Fig. 3), and indices of reproductive activity were low (Fig. 4). Reports of record fishing during the spring of that year suggest that the reproductive season had occurred early and that, by August, only the trailing edge of the reproductive population remained in Kona waters. Unfortunately, there are no spring 1985 reproductive samples for confirmation. The summer of 1986 showed a return to the more typical pattern.

Understanding patterns of reproductive activity

may help clarify marlin movements and migrations. Longline data suggest that blue marlin may spend much of the year south of Hawaii along the equatorial upwelling, where waters are more productive, then move into Hawaiian waters in the summer months (Royce 1957, Ueyanagi 1964). It is well documented that blue marlin throughout the Pacific Ocean and elsewhere show distinct spawning seasons and distinct spawning areas. Pacific-wide plankton collections over 25 years confirm that areas where larvae appear frequently correspond to the richest summer fishing grounds, i.e., the spawning grounds (Nishikawa et al 1985).

Hawaii may be a focus for blue marlin spawning in the northern central Pacific because oceanographic conditions are favorable to survival of marlin larvae and juveniles. The nutrient loads generated in the lee of the island chain by the island-mass effect (Gilmartin and Revelante 1974) support greater plankton growth and should provide better feeding grounds than the open oceanic deserts. Mesoscale eddies might act to keep larvae close to the island chain (Lobel and Robinson 1986). Highest concentrations of blue marlin larvae have been reported to the west and south of the island chain during June through August (Matsumoto and Kazama 1974).

Blue marlin may concentrate seasonally and spawn near Hawaii, but their abundance is likely determined by events outside Hawaiian waters, including oceanographic conditions, feeding opportunities, or fishing pressures. A history of blue marlin catch in the Hawaiian International Billfish Tournament, held annually in late summer, shows a distinct pattern over the more than 25 years of its existence (Fig. 5). Peak catch years are followed by very poor catches. Large-scale periodic or episodic oceanographic events that change the temperature and/or productivity profiles across the Pacific may have a significant effect on the movements of blue marlin, on the timing of their reproductive activity, and possibly on their reproductive productivity and growth rates. Future studies by fisheries oceanographers may provide clarification of these relationships.

In conclusion, studies of blue marlin reproduction may prove to be a useful tool for both biologists and fisheries managers, clarifying

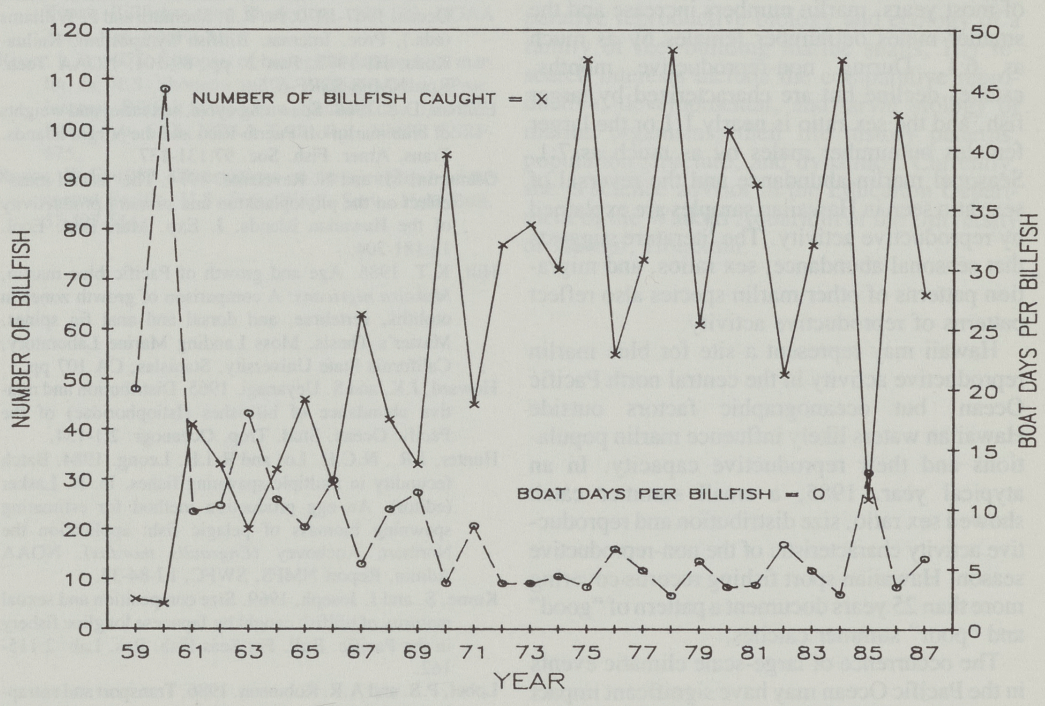

Figure 5. History of Pacific blue marlin catch and catch-per-unit-effort (boat days/billfish) for Hawaiian International Billfish Tournaments, 1959 to 1987. Fish tagged and released, 1986 and 1987, are not included in catch statistics, thus catch numbers are under-represented and catch-per-unit-effort is over-estimated.

seasonal abundance, stock structure, and migratory characteristics, well as reproductive potential. If the Hawaiian Islands are a site for marlin reproduction, the fish spawning here may in fact support significant recruitment into the northern Pacific stock(s). Estimates of stock reproductive potential should be undertaken.

Summary

Pacific blue marlin *(Makaira nigricans)* are present year-round in Hawaiian waters but, in most years, greatest abundance occurs during the summer months. Examination of 958 fish caught during Hawaiian sport fishing tournaments, August 1982 to August 1987, revealed changes in size composition, sex ratio, and reproductive condition correlated with seasonal abundance of the sample population. Blue marlin show a dramatic size sexual dimorphism, attributable to asymptotic differential growth, with 85% of the males sampled in this study weighing between 45.5 and 90.8 kg (100 and 200 lb), and 79% of the females weighed between 90.8 and 272.4 kg (200 to 600 lb).

During the reproductive season, in the summer of most years, marlin numbers increase and the smaller males outnumber females by as much as 6:1. During non-reproductive months, catches decline but are characterized by larger fish, and the sex ratio is nearly 1:1 or the larger females outnumber males by as much as 7:1. Seasonal marlin abundance and the reversal of sex ratio seen in Hawaiian samples are explained by reproductive activity. The literature suggests that seasonal abundance, sex ratios, and migration patterns of other marlin species also reflect patterns of reproductive activity.

Hawaii may represent a site for blue marlin reproductive activity in the central north Pacific Ocean, but oceanographic factors outside Hawaiian waters likely influence marlin populations and their reproductive capacity. In an atypical year, 1985, a small summer catch showed sex ratio, size distribution and reproductive activity characteristic of the non-reproductive season. Hawaiian sport fishing records covering more than 25 years document a pattern of "good" and "poor" summer catches.

The occurrence of large-scale climatic events in the Pacific Ocean may have significant impact on catches in Hawaiian waters. Studies of blue marlin reproduction may prove to be a useful tool for biologists and fisheries managers clarifying seasonal abundance, stock structure, and migratory characteristics, as well as determining stock reproductive potential.

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White Marlin Parasites: Potential Indicators of Stock Separations, Seasonal Migrations, and Feeding Habits

Ann M. Barse and Charles H. Hocutt

Parasites of marine fish that are common in one geographical area can be rare or entirely absent in another and thus may be valuable as indicators of host fish biology (Sindermann 1961; Manter 1965; MacKenzie 1983, 1986). Parasites have been used as natural tags to reveal fish migration patterns (Lester et al 1985), population structure (Leaman and Kabata 1987), and diet (Margolis 1965). Moreover, parasite data have been shown to complement data from artificial tags (Sindermann 1961; Hislop and MacKenzie 1976).

It is apparent that white marlin *(Tetrapturus albidus)* are usually parasitized [Linton 1889, Cooper 1918, Wallace and Wallace 1942, Nikolayeva and Ezpeleta 1966 (cited in Mather et al 1975), Silas 1967, Silas and Ummercutty 1967, Deardorff and Overstreet 1980, Barse 1988]. There has been no effort, however, to assess parasite faunas of white marlin in different parts of their range. This circumstance may leave unexplored a valuable source of information on this open-water predator.

Present knowledge of white marlin stock structure and migratory routes is derived from commercial longline fishery data and from the Cooperative Game Fish Tagging Program (Mather et al 1975). There is controversy as to whether white marlin in the northwest Atlantic Ocean comprise a single stock or two or more subpopulations (Edmunds 1972; Baglin 1979; Cooperative Game Fish Tagging Newsletter 1977, 1979). Migratory routes for the three summer groups (Middle Atlantic Bight, northern Gulf of Mexico, and the north coast of Venezuela) are also uncertain. In view of these gaps in our knowledge, the purposes of this paper are to: (1) summarize current knowledge of white marlin stock separation, seasonal migrations, and feeding; (2) point out the potential value of parasites as a tool for studying marlin biology; and (3) present some white marlin parasite data which illustrate information already available and indicate areas for future research.

Stocks, Migrations, and Feeding

Stocks and Seasonal Migrations

In the northwest Atlantic, concentrations of white marlin occur in summer and early fall in three locations near the edge of the continental shelf (letters in parentheses refer to Fig. 1). These are (A) the Middle Atlantic Bight, from Nantucket Island, south of Cape Cod, Massachusetts, to Cape Hatteras, North Carolina; (B) the northern Gulf of Mexico; and (C) waters north of La Guaira, Venezuela (Mather et al 1975). Artificial tag data suggest that most fish in these three areas return to the same places in subsequent summers (reviewed in Mather et al 1975; see also: Oceanic Game Fish Investigations 1976; Cooperative Game Fish Tagging Program Newsletter 1976, 1977, 1978, 1979, 1980, 1981, 1982; Oceanic Pelagics Program 1983, 1984, 1985, 1986). At other times, distinct summer groups might merge (Mather et al 1975).

White marlin that summer off the U.S. east coast are thought to migrate eastward to approximately 40°W in early fall and then move south to concentrate off northern South America from

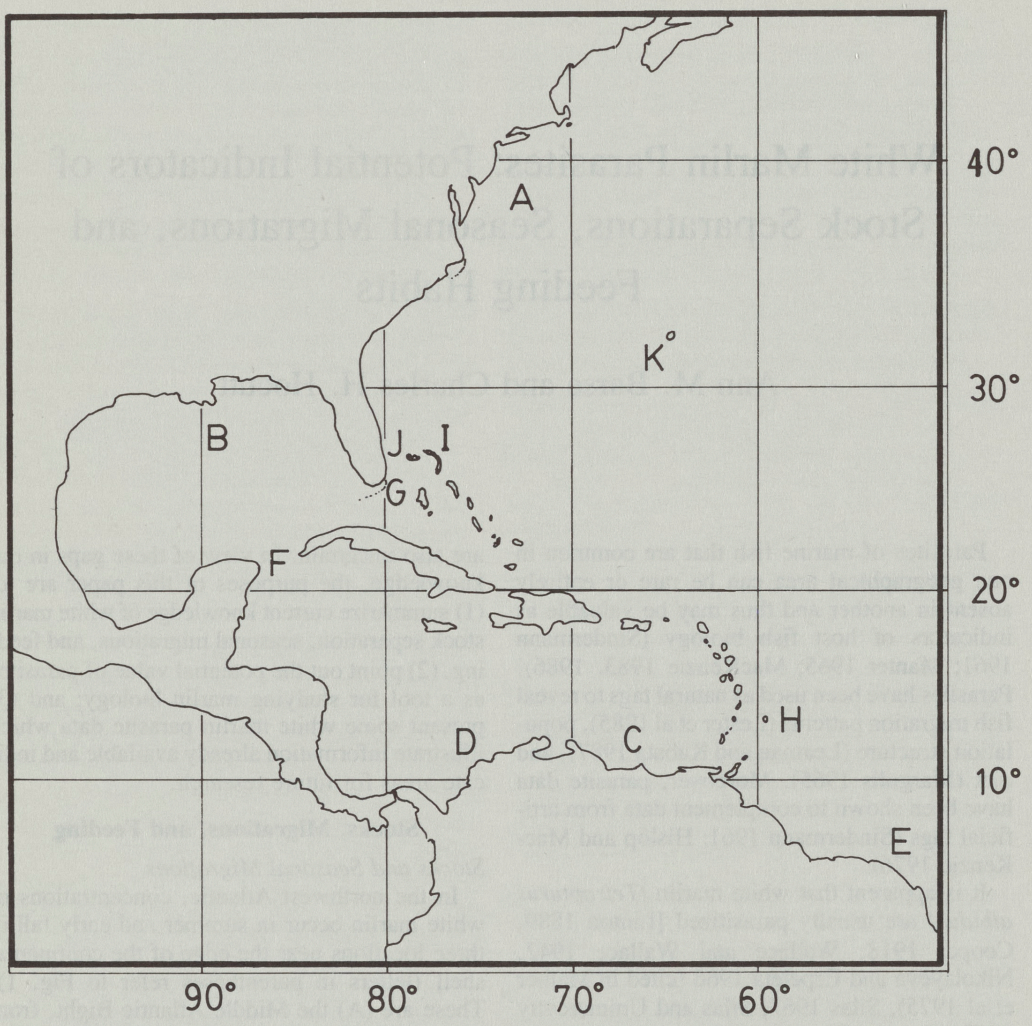

Figure 1. Map showing distribution of white marlin in the northwest Atlantic Ocean (from Mather et al 1972).

Columbia (D) to Guiana (E) in late fall and winter. In spring, the east coast group migrates northward via passages ranging from the Yucatan Channel (F) and Straits of Florida (G) to east of the West Indies (H). This group enters the southern portion of the Cape Cod-Cape Hatteras area in June and migrates northward and eastward during summer (Mather et al 1975).

Movements of the Gulf (B) and Venezuela (C) summer groups are not as well defined. White marlin tagged and released off Venezuela in summer have been recaptured in winter both in the area of release and off Guiana (E) (Mather et al 1975). The Cooperative Game Fish Tagging Program Newsletter (1977) stated that, "several groups of white marlin may be present at one time in the gulf [of Mexico] during summer: those that are year-round residents, those that winter in the Straits of Florida, those that winter in the eastern Caribbean, and those that change summer habitat from the Middle Atlantic Bight." Statistics of the Japanese Atlantic longline fishery (1956-1967) suggested to Mather et al (1972) that a group of white marlin summers in the Gulf of Mexico and winters off the coast of Venezuela.

Differences in length-weight relationships of white marlin caught in the Gulf of Mexico and the Atlantic Ocean suggested to Baglin (1979) that these are two separate breeding stocks.

Artificial tagging, however, has indicated partial interchanges between these groups, suggesting that these fish comprise a single stock (Mather et al 1975, Oceanic Game Fish Investigations 1976, Cooperative Game Fish Tagging Newsletter 1979). Additionally, electrophoretic analyses of selected blood and tissue proteins did not support the existence of subpopulations of white marlin from the Middle Atlantic Bight, the Straits of Florida, the Gulf of Mexico, and the southern Caribbean Sea (Edmunds 1972).

Northwest Atlantic white marlin are thought to spawn in three areas: northeast of Little Bahama Bank (I), northwest of Grand Bahama Island (J), and southwest of Bermuda (K) (Stephens 1965, Mather et al 1975). Although Edmunds (1972) suggested that white marlin spawn homogeneously, degrees of mixing of summer groups on spawning grounds are not known.

Feeding

Studies of white marlin feeding habits have shown that cephalopods (primarily squid, *Lolgio pealei),* are a predominant prey taxon in all areas surveyed (reviewed in Barse 1988). These areas include the Bahamas, Puerto Rico, the Gulf of Mexico, and the middle Atlantic coast. The round herring *(Etrumeus teres)* has also been important prey for white marlin off the Maryland and New Jersey coasts (Wallace and Wallace 1942, de Sylva and Davis 1963); however, only one round herring was observed in a recent study (Barse 1988). Compared to earlier studies, stomachs of 36 white marlin caught off Maryland and Delaware (1985-1986) contained fewer food items but, nevertheless, included a diverse array of cephalopods and teleost fishes (Barse 1988).

Parasites as Natural Tags

Criteria used to assess the value of parasites as tags have been summarized by MacKenzie (1983, 1986). Infection levels should be significantly different among stocks or migratory groups throughout the range of the host. The parasite should be long-lived and conspicuous but not easily dislodged. The method of examination should (ideally) involve a minimum of dissection. Lastly, the parasite should not reduce the likelihood of host survival or induce behavioral changes in infected fish that reduce tag value.

MacKenzie (1986) suggested that the most frequently used parasites as tags for marine fish are larval anisakid nematodes (e.g., Platt 1976, Lester et al 1985, Chenoweth et al 1986). Nevertheless, an adult anisakid nematode *(Hysterothylacium incurvum),* which also occurs in white marlin (Barse 1988), may be useful in discriminating swordfish populations (Hogans and Brattey 1982). Trypanorhynch metacestodes (preadult stage) have also been useful (or potential) indicators of host stocks (e.g., Lubieniecki 1977, Avdeev 1985, Lester et al 1985). MacKenzie (1986) considered adult and larval digenean trematodes to be good tags because they are highly specific to the first intermediate host (e.g., Arthur and Arai 1980, Lester et al 1985, Kabata et al 1988). Monogenean ectoparasites might be useful to distinguish fish populations (Isles 1971, Rohde 1987) as well as copepods (e.g., Leaman and Kabata 1987), fungi, isopods, and protozoans (MacKenzie 1986). The use of parasites as natural tags is a novel approach to provide information on marlin biology.

Many parasites of marine fishes live within the body of the host in areas such as the alimentary tract, liver, and pyloric caecae. Most endoparasites are acquired through feeding on infected intermediate or paratenic hosts (Cheng 1986). If intermediate or paratenic hosts can be identified, long-term marlin feeding habits will be revealed by the endoparasites harbored (e.g., Margolis 1965, Konovalov and Butorina 1985). Such data would also be an important contribution to knowledge of host-parasite relationships (MacKenzie 1986).

White Marlin Parasites

Methods

White marlin were obtained from anglers from Maryland and Delaware (Middle Atlantic Bight), June to September, 1985 and 1986 (Barse 1988). Alimentary tracts (36 stomachs and 33 intestines) were removed and frozen until they could be examined in the laboratory, where parasites were removed from the stomach (S) and the five morphologically distinct sections of the intestine (labeled A to E, Fig. 2) and preserved in 5% buffered formalin. Helminths were counted and identified to species if possible. Identifications were verified through the USDA Agricultural Research Center, Parasitology Institute (Beltsville, Maryland).

Prevalence and mean intensity of white marlin helminth infections were calculated. For cestodes, mean intensity was calculated per decimeter of intestine for each section (A to E) to standardize

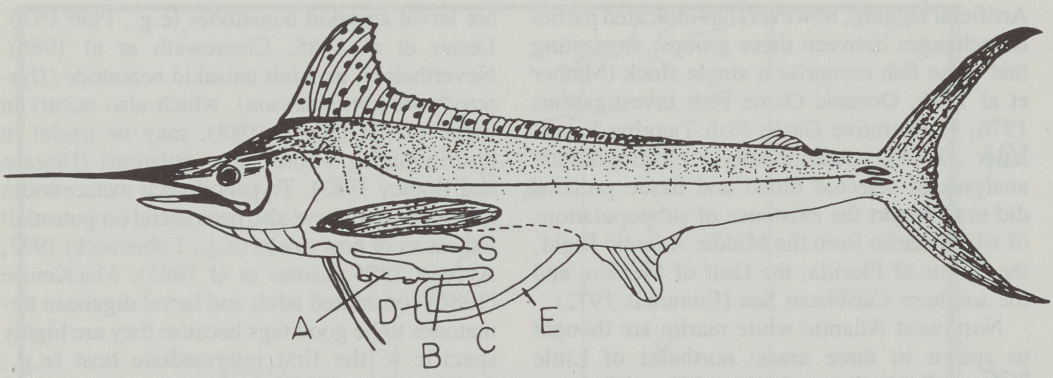

Figure 2. Drawing of a white marlin with the gastrointestinal tract exposed illustrating areas sampled for parasites. S = stomach; A = anteriormost region of intestine showing ducts to mass of pyloric caecae; B = portion of intestine extending posteriorly; C = portion of intestine extending anteriorly after 180° bend; D = short intestine section juxtaposed to pyloric caecae anteriorly and spleen posteriorly; E = long intestine section extending along ventral body wall to vent.

for unequal lengths of sampling regions. Because lengths of cestodes found in white marlin ranged over two orders of magnitude, intensity of cestode infection was also expressed as an estimate of the mean surface area (in square millimeters) of cestode body surface per decimeter of each intestinal section [see Barse (1988) for calculation procedures]. The distribution of cestode length classes (50 mm intervals) was determined for each year of sampling.

The dispersion pattern of each parasite taxon was analysed using the variance/mean ratio of parasite numbers per fish (Anderson and Gordon 1982). The significance level of the observed deviation of the variance/mean ratio from 1.0 was determined by a t-test (Cox 1972). A variance/mean ratio that is significantly greater than 1.0 indicates overdispersion (aggregation), however it does not give a good description of the intensity of aggregation. Therefore, observed frequencies of overdispersed parasites were compared to expected frequencies based on the negative binomial distribution. This distribution is described by the mean number of worms per fish and the parameter k (dispersion parameter) (Southwood 1966). This parameter usually lies between 0.5 and 3.0, with low values indicating high degrees of aggregation (Cox 1972). Agreement between the negative binomial distribution and the observed distribution was tested by a chi-square goodness of fit test (Sokal and Rohlf 1981).

Results and Discussion

Prevalence and mean intensity of helminth parasite infections are summarized in Table 1. Mean number (±1 S.E.) of helminths per alimentary tract (n = 33) was 392.3 (±35.38) worms per fish. Mean number of helminth species per marlin was 2.5 (±0.1) (range = 2 to 4). Frequencies of infections with a digenetic trematode *(Hirudinella marina* Garcin, 1730) and an acanthocephalan *(Rhadinorhynchus* sp.) were relatively low. A nematode *(Hysterothylacium incurvum* Rudolphi, 1819) and a cestode *(Bothriocephalus manubriformis* Linton, 1989)

Table 1. List of helminth species recovered from white marlin caught off Maryland and Delaware (U.S.A.). Number (n) of fish examined = 36 (trematode); n = 33 for other parasite taxa.

Species	% Prevalence	Intensity Range	Intensity Mean (S.E.)	USNM No.[1]
Nematoda: Ascaridoidea				
Hysterothylacium incurvum	100	6-741	231.0 (32.6)	80330
Cestoda: Bothriocephalidae				
Bothriocephalus manubriformis	100	4-463	159.8 (19.8)	80329
Trematoda: Hirundinellidae				
Hirudinella marina	22.2	0-6	0.64 (0.24)	80328
Acanthocephala: Rhadinorhynchidae				
Rhadinorhynchus sp.	27.3	0-3	0.48 (0.16)	80331

[1]National Parasite Collection, United States National Museum number, Beltsville, Maryland, U.S.A.

were present at high levels of infection.

There has been much discussion concerning the use of enteric helminths as natural tags. Lester et al (1985) consider inhabitants of the intestinal lumen to be more easily lost than larval forms encapsulated in the tissues and thus to have less value as tags. MacKenzie (1986) suggests, however, that longevity is not a drawback if recent host-fish history (e.g., seasonal migration) is of interest. Furthermore, it is not clear whether all gut-lumen parasites observed in white marlin are short-lived. For example, cestodes over 50 cm in length were present (see below) that must have been resident in the intestine for an extended period. Hogans and Brattey (1982) found large *Hysterothylacium incurvum* (up to 16 cm) in swordfish and suggested that these nematodes may survive for several years. Therefore, enteric helminths in marlin may yet serve well as natural tags.

The distributions of cestode numbers and estimated surface area per decimeter of intestinal sections A to E are illustrated in Fig. 3. Large numbers of worms were present in D and E where surface area was relatively low, and few worms were found in A and B where surface area was relatively high, thus suggesting a non-random distribution of length classes along the intestine. Indeed, worms 100 mm or less in length were primarily located in section E, worms 101 mm to 300 mm were primarily in Section C, and most worms greater than 300 mm were located in A and B. This pattern may be linked to characteristics of fish in (or from) a particular habitat (e.g., diet, nutritional state of the host, and parasite transmission dynamics). If so, these data might be useful markers of marlin stocks and migrations.

Numbers of *Bothriocephalus manubriformis* in eleven 50 mm length classes are shown in Fig. 4. There was a preponderance of very small worms ($\leq$50 mm) in this cestode population. Demographic characteristics of a parasite population have been used at least once to distinguish fish stocks (Leaman and Kabata 1987), however, as these authors cautioned, population structure can be seasonally dynamic (e.g., Kennedy 1979) and it is important to determine

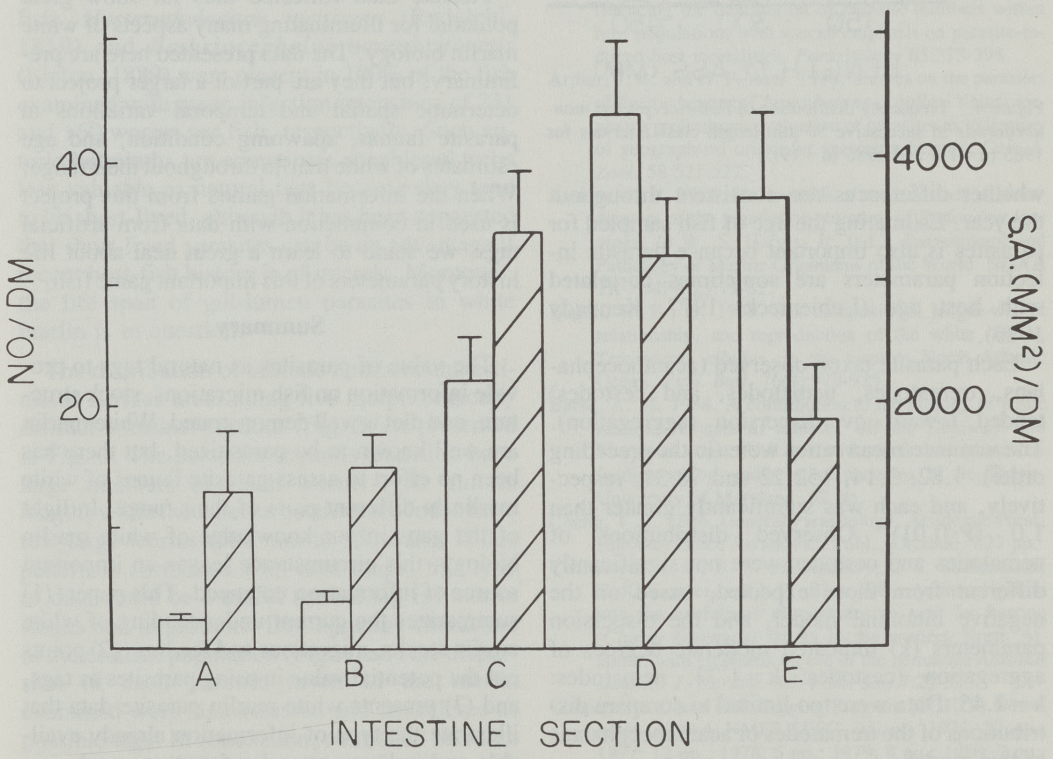

Figure 3. Mean number (+1 S.E.) (open bar) of cestodes per decimeter of intestine (NO./DM) and mean surface area (square millimeters + 1 S.E.) (striped bar) of cestode body surface per decimeter of intestine [S.A. (MM^2)/DM] for each intestine section (A to E).

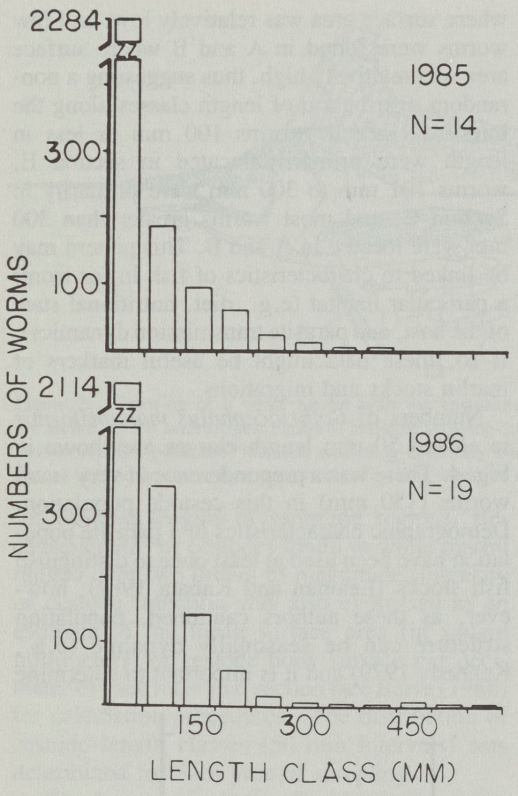

Figure 4. Frequency distribution of *Bothriocephalus manubriformis* in successive 50 mm length class intervals for 1985 (n = 14) and 1986 (n = 19).

whether differences are consistent throughout the year. Estimating the age of fish sampled for parasites is also important because parasite infection parameters are sometimes correlated with host age (Lubieniecki 1977, Kennedy 1979).

Each parasite taxon observed (acanthocephalans, trematodes, nematodes, and cestodes) tended toward overdispersion (aggregation). The variance/mean ratios were (in the preceding order): 1.82, 3.14, 152.22 and 78.31, respectively, and each was significantly greater than 1.0 ($P<0.01$). Observed distributions of nematodes and cestodes were not significantly different from those expected, based on the negative binomial model, and the dispersion parameters (k) indicated moderate degrees of aggregation (cestodes: $k = 1.73$; nematodes: $k = 1.45$. Data were too limited to compare distributions of the trematodes or acanthocephalans to this model.

The majority of helminth distributions have been found to be aggregated in both final and intermediate hosts (Keymer 1982). Kennedy (1979) suggested that underdispersion occasionally arises as a consequence of a low probability of infection and found this to be a useful marker. Consequently, parasite dispersion patterns may also be natural marks for marlin.

Specimens of Didymozoidae (Trematoda) were collected from four white marlin. The poor condition of these tissue-dwelling parasites did not permit identification past the family level (Overstreet, pers. comm.). Lester et al (1985) suggested that Didymozoids live from several months to the life of the host, depending on the species involved, and therefore can be valuable as tags.

Three trypanorhynch (Cestoda) plerocercoid larvae were found in one stomach. All known adult trypanorhynchs are parasitic in the stomach or spiral valve of elasmobranchs (Cheng 1986). Trypanorhynchs have been useful tags for many marine fishes (MacKenzie 1986) but a more thorough investigation of their distribution and abundance in white marlin is necessary to assess their possible value as natural tags.

Parasite data collected thus far show great potential for illuminating many aspects of white marlin biology. The data presented here are preliminary, but they are part of a larger project to determine spatial and temporal variations in parasite faunas, spawning condition, and age estimates of white marlin throughout their range. When the information gained from this project is used in conjunction with data from artificial tags, we stand to learn a great deal about life history parameters of this important game fish.

Summary

The value of parasites as natural tags to provide information on fish migrations, stock structure, and diet is well demonstrated. White marlin are well known to be parasitized, but there has been no effort to assess parasite faunas of white marlin in different parts of their range. In light of the gaps in our knowledge of white marlin biology, this circumstance leaves an important source of information untapped. This paper, (1) summarizes the current understanding of white marlin stocks, migrations and feeding, (2) points out the potential value in using parasites as tags, and (3) presents white marlin parasite data that illustrate the type of information already available and indicate areas for future research.

There are three summer concentations of white marlin in the northwest Atlantic. These

are (Fig. 1) (A) the Middle Atlantic Bight, (B) the northern Gulf of Mexico and (C) waters north of Venezuela. There is some controversy in the interpretation of data derived from the Cooperative Game Fish Tagging Program and from the Japanese Atlantic longline fishery. Some researchers defend a single stock hypothesis while others contend that two or more subpopulations exist. The study of parasites offers a means to improve our understanding of marlin stock structure and seasonal movements. Secondly, if intermediate or paratenic hosts of white marlin parasites can be identified, long-term feeding habits will be revealed by the endo-parasites harbored.

Parasites were collected from the alimentary tracts of white marlin caught by sport fishermen off the Delaware and Maryland coasts during two summers (1985-86) and four helminth taxa were observed. *Hirudinella marina* Garcin, 1730 and *Rhadinorhynchus* sp. were present in 22% and 27%, respectively, of the marlin (n = 36 and 33, respectively) examined at mean intensities of infection of less than 1 worm per fish. *Hysterothylacium incurvum* (Rudolphi, 1819) and *Bothriocephalus manubriformis* (Linton, 1889) were present in 100% of the fish examined with mean infection intensities of 231 and 160 worms per fish, respectively. Such enteric helminths are sometimes considered to be less valuable as natural tags because they tend to be short-lived, although it has been suggested that short-lived parasites can be an advantage if recent host-fish history is of interest. Moreover, the life span of gut-lumen parasites in white marlin is in question.

The distribution of cestode numbers and estimated surface areas along five morphologically distinct intestinal sections (Fig. 2) are presented in Fig. 3. The posterior sections tended to have large numbers of small worms ($\leq$50 mm in length) while the anterior sections tended to have few large worms (301 mm to 550 mm). If this pattern is correlated with host range, this type of data could be a useful natural tag for marlin stocks and migrations. Demographic characters of the cestode population (Fig. 4) and the dispersion of each parasite taxon in the marlin examined were also assessed and considered as possible tags. In conclusion, continued research on white marlin parasites in conjunction with data from artificial tags should elucidate many ecological aspects of this important game fish.

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Movements and Variations in Early Year-Class Strength of Black Marlin *(Makaira indica)* Off Eastern Australia

Julian G. Pepperell

The six species of billfish which inhabit the Pacific ocean have all been captured off the Australian east coast by recreational anglers. These are the black marlin *(Makaira indica)*, the sailfish *(Istiophorus platypterus)*, the striped marlin *(Tetrapturus audax)*, the blue marlin *(Makaira nigricans)*, the shortbill spearfish *(Tetrapturus angustirostris)*, and the broadbill swordfish *(Xiphias gladius)*. The black marlin is the most commonly encountered of these species, having been recorded along the entire length of the east coast.

The first billfish caught on rod and reel in Australian waters was a black marlin of approximately 30 kg (66 lb) taken off Port Stephens, New South Wales, in 1910 (Goadby 1987). Since 1962, a major annual game-fishing tournament has been held at Port Stephens to coincide with the appearance of the species at that latitude in late summer.

Very large black marlin, often exceeding 450 kg (990 lb) in weight, appear at the edge of the Great Barrier Reef north of Cairns, Queensland, each spring, and have attracted anglers from around the world since the early 1960s. During the last decade, recreational fisheries directed toward juvenile black marlin (15-25 kg or 32-55 lb) have been established inside the Great Barrier Reef and off southern Queensland, while the species has been targeted off central and southern New South Wales since the 1930s.

The black marlin is relatively common in coastal waters off eastern Australia, but it is the least common Istiophorid caught by the Japanese tuna longlining fleet in the Pacific (Shomura 1978). Consequently, very few studies of its biology have been undertaken.

Tagging is potentially useful in studying movements and population structure of large pelagic fishes such as the black marlin, but would be prohibitively expensive if undertaken from chartered vessels. Fortunately, the development of the metal-headed streamer tag, in the early 1950s (Mather 1963), has allowed recreational anglers to contribute to collection of biological data through cooperative tagging programs. This system has been so successful that more than 100,000 billfish have now been tagged worldwide.

In Australia, black marlin were first tagged off northern Queensland under the cooperative tagging program of the United States National Marine Fisheries Service (NMFS), Southwest Fisheries Center, La Jolla, California. From 1968 to 1977, over 2,500 black marlin were tagged on that program, and 60 recoveries were reported (Squire and Nielsen 1983).

The Australian cooperative gamefish tagging program, operated through the Fisheries Research Institute of the New South Wales Department of Agriculture and Fisheries, was commenced in late 1973. Since 1977, it has had responsibility for tagging black marlin in northern Queensland. The charter boat fishery in this region has remained essentially similar throughout this period, as have the tags and tagging techniques used. The present study expands considerably on that of Squire and Nielsen (1983) in that a further 6,400 black marlin have been tagged in the same general region, and an addi-

tional 2,500 have been tagged in other areas covering most of the black marlin's range along the eastern Australian coast. In addition, historical catch records from a number of gamefishing clubs have been used to provide insight into seasonality of appearance of different size groups of fish at different locations.

This study, then, brings together data from a number of sources to examine possible movements of black marlin off eastern Australia and in the southwestern Pacific.

Methods

Tagging Operations

Tags used on black marlin in the Australian gamefish tagging program were almost exclusively the steel anchor, plastic streamer type, model FH-69A, manufactured by Floy Tag and Manufacturing Incorporated, Seattle, Washington. Fewer than 100 black marlin were tagged with standard nylon barbed tuna dart tags. Tag distribution and methods of application to large fish are now used on many programs worldwide, and have become quite standardized as a result. Details are given in Pepperell (1981) and Pepperell (1985). First-time taggers received a certificate and jacket patch as incentives to join the program. Those reporting recapture information received a certificate with details of the movements of the recaptured fish, as the original tagger.

Size-Composition of Catch

Size-frequency data on the eastern Australian recreational catch of black marlin were derived from a number of sources.

For fish caught in the Cairns-Lizard Island area, off northern Queensland, weights of boated fish were obtained from the Cairns Game Fishing Club, while estimated weights at release were used for tagged fish. These latter weights were nearly always given in multiples of 50 pounds. Estimated weights at release of fish marked with NMFS tags were kindly supplied by J. Squire, Jr.

For other sites in Queensland, only estimated weights at release were available, since very few billfish are ever boated and weighed in those areas.

For New South Wales ports, actual weights of fish caught during tournaments or normal club activities, and published in club newsletters and annual reports, were used. In all areas other than Cairns — Lizard Island, weights were taken to the nearest 5 pounds. In the case of Port Stephens, estimated weights of tagged fish are included for some recent years, because a minimum size limit of 45 kg (100 lb) was voluntarily imposed in 1985 for the major tournament held from that port.

Location of Main Fishing Grounds

The positions of fishing grounds, and other locations mentioned in this text, are shown in Figure 1. Brief descriptions of the main centres of activity follow:

Cairns to Lizard Island. The charter fishery for black marlin in this region operates from Cairns, Lizard Island, or mother ships. Fishing occurs outside the edge of the barrier reef, concentrating since about 1975 along the Ribbon Reefs (numbers 5 to 10) south of Lizard Island. Nearly all black marlin are caught within several kilometres of the reef drop-off. The fishery operates from September to early December each year, with virtually no activity outside that period.

Pixie Reef. An occasional light-tackle tournament targets on juvenile black marlin in August in an area around Pixie Reef. This is about 40 km north of Cairns and about 35 km inside the outer edge of the barrier reef. At this latitude, the reef edge is about 60 km from the mainland.

Dunk Island. Since 1977, a tournament targeting on sailfish and juvenile black marlin has taken place from Dunk Island during each winter-early spring period (July and September). The charter fleet fishes mainly near Beaver Reef, about 22 km northeast of Dunk Island, and about 50 km inside the edge of the barrier reef. At this latitude, the reef edge is about 78 km from the mainland.

Cape Bowling Green. These grounds, discovered to be a prolific area for sailfish and juvenile black marlin in 1982, are about 200 km southeast of Dunk Island. The area is shallow, averaging about 30 metres (98 ft) in depth, and about 95 km from the edge of the barrier reef. The main fishing grounds are only about 20 km from the mainland, in an area influenced by the Burdekin River. Peak taggings of small black marlin are made in September-October each year.

Cape Moreton. These grounds are near the northern tip of Moreton Island, located off Brisbane. This point marks the southern-most limit of sailfish concentrations on the east coast. The fishing grounds are about 20 km from the

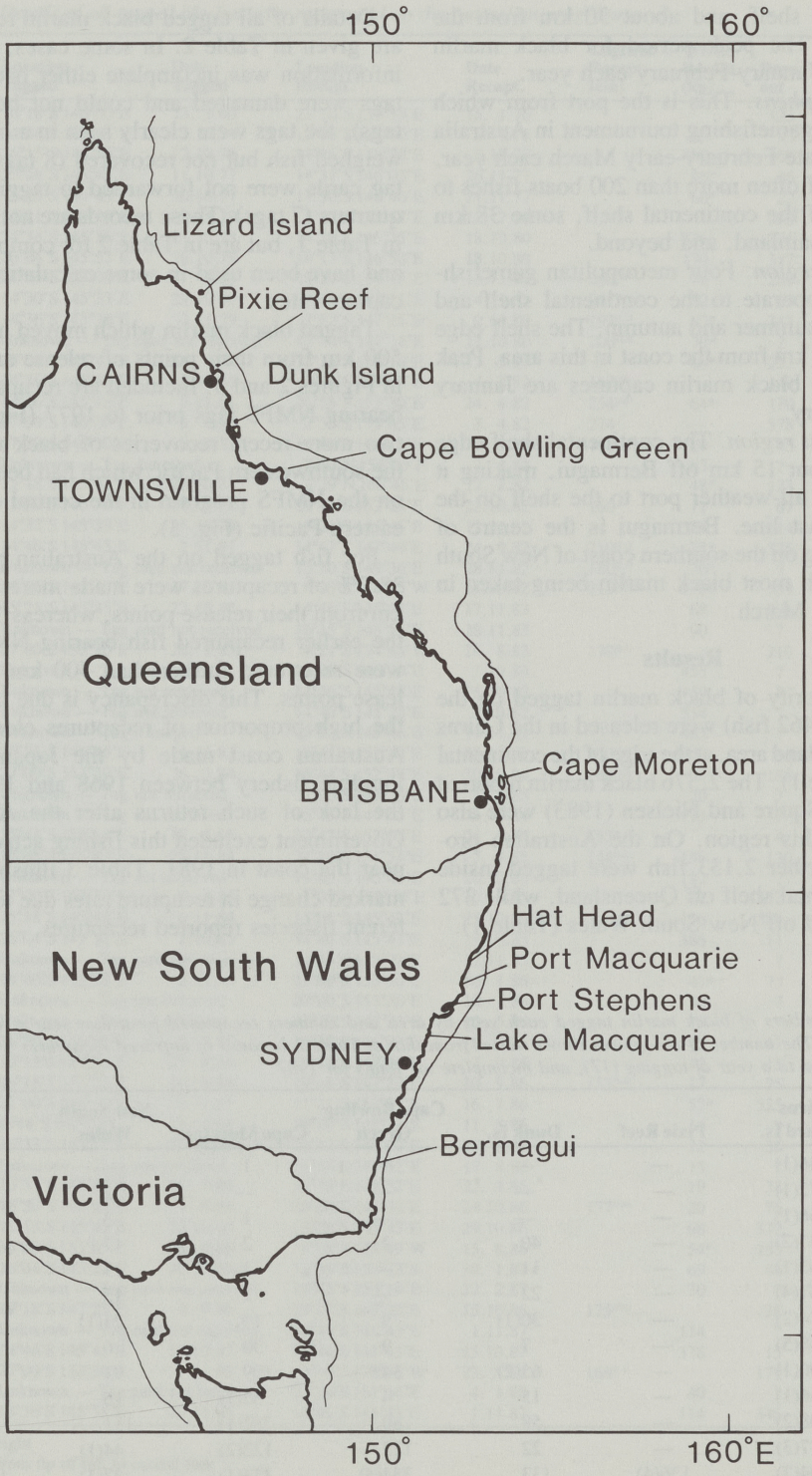

Figure 1. Eastern Australia, showing the positions of the main fishing grounds for black marlin, and other locations mentioned in the text. The 200-metre depth contour is also shown.

continental shelf, and about 30 km from the mainland. The peak period for black marlin catches is January-February each year.

Port Stephens. This is the port from which the largest gamefishing tournament in Australia is held in late February-early March each year. The fleet of often more than 200 boats fishes to the edge of the continental shelf, some 38 km from the mainland, and beyond.

Sydney region. Four metropolitan gamefishing clubs operate to the continental shelf and beyond in summer and autumn. The shelf edge is about 28 km from the coast in this area. Peak months for black marlin captures are January and February.

Bermagui region. The continental shelf edge is only about 15 km off Bermagui, making it the nearest all-weather port to the shelf on the eastern coast line. Bermagui is the centre of gamefishing on the southern coast of New South Wales, with most black marlin being taken in this area in March.

Results

The majority of black marlin tagged on the program (6462 fish) were released in the Cairns — Lizard Island area, at the edge of the continental shelf (Table 1). The 2,576 black marlin reported tagged by Squire and Nielsen (1983) were also tagged in this region. On the Australian program, a further 2,133 fish were tagged inside the continental shelf off Queensland, while 372 were tagged off New South Wales (Table 1).

Details of all tagged black marlin recaptured are given in Table 2. In some cases, recovery information was incomplete either because the tags were damaged and could not be read (3 tags), the tags were clearly seen in a hooked or weighed fish but not recovered (8 tags), or the tag cards were not forwarded to tagging headquarters (7 tags). These records are not included in Table 1, but are in Table 2 for completeness, and have been used in some calculations of recapture rates.

Tagged black marlin which moved more than 500 km from their points of release are shown in Figures 2 and 3. Included are recaptured fish bearing NMFS tags prior to 1977 (Fig. 2) and two more recent recoveries of black marlin in the southwestern Pacific which had been tagged on the NMFS program in the central or northeastern Pacific (Fig. 3).

For fish tagged on the Australian program, 38.7% of recaptures were made more than 500 km from their release points, whereas 18.6% of the earlier recaptured fish bearing NMFS tags were recovered further than 500 km from release points. This discrepancy is due largely to the high proportion of recaptures close to the Australian coast made by the Japanese tuna longline fishery between 1968 and 1980, and the lack of such returns after the Australian Government excluded this fishing activity from near the coast in 1981. Table 3 illustrates this marked change in recapture rates due to the different fisheries reported recaptures.

Table 1. Numbers of black marlin tagged each year by area and numbers recaptured from that year's releases (in parentheses). The number of recaptures shown varies from that of Table 2 because of untraced recaptures which could not be assigned to a year of tagging (17), and incomplete tag totals for 1987.

Year	Cairns–Lizard Is.	Pixie Reef	Dunk Is.	Cape Bowling Green	Cape Moreton	New South Wales	Total
1974	46(1)	—	—	—	1	—	47(1)
1975	72(1)	—	—	—	—	2	74(1)
1976	66(1)	—	—	—	1	3	70(1)
1977	537(2)	—	40	2	2	17	598(2)
1978	503(1)	—	11	—	4	11	529(1)
1979	561(4)	—	22	—	2	13	598(4)
1980	614(2)	—	30(1)	9	19	21(1)	693(4)
1981	548(5)	—	7	9	30	6	600(5)
1982	590(1)	—	65(2)	34	109	91	889(3)
1983	846(1)	—	15	4	35(1)	16	916(2)
1984	808(2)	—	58	80	282(1)	111	1,339(3)
1985	677(3)	—	22	122	122(2)	44(1)	987(6)
1986	594(2)	136(4)	133	354(4)	373(1)	37(1)	1,627(12)
Total	6,462(26)	136(4)	403(3)	614(4)	980(5)	372(3)	8,967(45)

Table 2. Details of all tagged black marlin recaptured on the Australian programme.

Recapt. No.	Location Tagged	Date Tagged	Location Recapt.	Date Recapt.	Lngth at Recapt. (cm)	Wt. at Recapt. (kg)	Days out	Distance & Dir^{n} Moved (km)
1	16°18'S 146°00'E	13. 9.75	21°10'S 153°55'E	15. 1.76			123	900 SE
11	14°46'S 145°43'E	5.10.74	11°30'S 151°00'E	5. 1.75		93	93	800 N
18	16°15'S 145°55'E	12.10.76	14°36'S 145°38'E	7.10.77		480	360	168 N
24	15°26'S 145°45'E	11.10.77	14°37'S 146°02'E	26.11.77		45*	46	86 NE
25	15°25'S 145°45'E	30.10.77	17°30'S 146°46'E	21.11.77		60*	22	186 SE
94	15°21'S 145°45'E	30.11.79	5°17'S 155°57'E	22. 7.80			235	1800 NE
95	14°36'S 145°38'E	23.10.78	14°30'S 145°33'E	18.10.80		136	725	14 NW
97	16°04'S 145°52'E	26.10.79	16°17'S 146°50'E	18.10.80		170	357	105 ESE
99	31°03'S 153°04'E	27. 2.80	18°29'S 151°15'E	15.11.80	260$^{(OA)}$	70	260	1200 NE
103	14°30'S 145°33'E	29.10.80	32°45'S 152°11'E	4. 1.81	207$^{(L1)}$	52	65	2650 S
115	14°36'S 145°38'E	2.11.79	17°22'S 147°21'E	9.10.80	193$^{(L2)}$	67*	343	351 SE
116	Unknown — Tag card not received		17°40'S 147°18'E	11.10.80	200$^{(L2)}$	70*	?	?
152	15°00'S 145°43'E	28. 9.80	7°25'S 152°16'E	13. 5.81		68*	227	1480 NE
223	14°46'S 145°43'E	15.10.81	9°40'S 159°00'E	4. 3.82	163$^{(A)}$		140	1900 NE
239	14°46'S 145°43'E	5.11.81	26°55'S 153°30'E	24. 4.82	254$^{(L1)}$	64*	170	1450 S
252	17°50'S 146°30'E	3. 9.80	2°55'S 175°45'E	3. 4.82	274		578	3812 NE
270	17°50'S 146°30'E	16. 8.82	16°50'S 146°11'E	30. 9.82	152	20	45	120 N
272	Unknown — Tag damaged		7°30'N 158°00'E	7. 8.82		63	?	?
275	15°18'S 145°43'E	27.10.81	3°29'N 160°45'E	27. 2.82		48*	123	3100 NNE
281	17°50'S 146°30'E	16. 8.82	24°42'S 152°25'E	22.10.82	160	11	67	985 S
282	14°33'S 145°35'E	25.10.79	15°21'S 145°45'E	12.11.82		371	1114	85 S
332	14°46'S 145°43'E	2.11.81	14°47'S 147°49'E	24. 9.82	210$^{(L1)}$	75*	326	223 E
333	Unknown — Tag card not received		18°50'S 149°36'E	28.11.82	180$^{(L1)}$	70*	?	?
401	14°46'S 145°43'E	27.10.81	8°23'S 148°15'W	21.10.82	315$^{(OA)}$	170*	359	7200 ENE
464	15°21'S 145°45'E	22.10.82	14°46'S 145°43'E	17.11.83		68	391	59 N
465	Unknown — Tag card not received		16°15'S 145°55'E	28.11.83		90	?	?
477	27°00'S 153°30'E	28. 1.83	4°21'S 174°43'W	26. 8.83	170$^{(L1)}$		210	4200 NE
478	Unknown — Tag damaged		16°30'S 146°00'E	?.10.83		455	?	?
490	Unknown — Tag not retrieved		14°46'S 145°43'E	25.10.83		159	?	?
535	Unknown — Tag not retrieved		14°40'S 145°28'E	?.10.82		554	?	?
536	Unknown — Tag damaged		15°27'S 145°46'E	11.11.83		465	?	?
552	15°21'S 145°45'E	14.11.83	18°45'S 152°42'E	28.11.83	270$^{(L2)}$	250	14	806 SE
715	27°00'S 153°30'E	26. 3.84	18°44'S 152°48'E	30. 9.84	168$^{(L2)}$	68*	188	900 N
748	Unknown — Tag not retrieved		27°00'S 153°30'E	1. 2.85		20	?	?
753	Unknown — Tag not retrieved		15°18'S 145°45'E	5.10.84		113	?	?
755	32°43'S 152°14'E	17. 3.85	32°47'S 152°07'E	21. 3.85	183$^{(L1)}$		4	10 S
772	15°05'S 145°43'E	28.11.84	24°10'S 151°54'E	7. 4.85	244$^{(L1)}$	136	130	950 S
784	Unknown — Tag not retrieved		14°46'S 145°43'E	20.10.84		182	?	?
822	27°00'S 153°30'E	9. 1.85	7°00'N 152°30'E	30. 6.85		31	172	3872 N
824	15°18'S 145°42'E	6.11.84	15°05'S 145°43'E	22.10.85		136	350	5 N
825	16°04'S 145°52'E	2.10.85	14°46'S 145°43'E	13.10.85		386	11	112 N
831	Unknown — Tag card not received		14°46'S 145°28'E	22.11.85			?	?
879	14°40'S 145°28'E	2.11.85	27°00'S 153°30'E	16. 1.86		41*	75	1415 S
909	Unknown — Tag not retrieved		27°00'S 153°30'E	10. 1.86		30	?	?
1037	Unknown — Tag not retrieved		19°18'S 147°23'E	20. 5.86		10	?	?
1102	16°30'S 146°00'E	5. 8.86	16°30'S 146°00'E	16. 8.86		18	11	0
1106	19°18'S 147°23'E	23. 8.86	19°18'S 147°23'E	7. 9.86		12	15	0
1108	19°18'S 147°23'E	16. 8.86	19°18'S 147°23'E	10. 9.86	153$^{(L1)}$	17	25	0
1110	27°00'S 153°30'E	28. 1.85	11°21'S 163°37'E	16. 7.86		57*	535	2000 NE
1112	1918'S 147°23'E	31. 8.86	19°18'S 147°23'E	11. 8.86		14	9	0
1113	16°33'S 145°52'E	26. 7.86	16°33'S 145°52'E	30. 8.86		22	36	0
1114	Unknown — Tag not retrieved		16°33'S 145°52'E	17. 8.87		15	?	?
1116	16°33'S 145°52'E	16. 8.86	16°33'S 145°52'E	22. 9.86		19	38	0
1135	16°30'S 146°00'E	9. 8.86	20°00'S 148°33'E	24.10.86	177$^{(OA)}$	20	76	359 S
1136	15°53'S 145°45'E	22.10.85	15°28'S 145°47'E	29.10.86		68	372	40 N
1142	35°00'S 151°05'E	4. 4.86	4°08'S 178°47'W	15. 8.86		54*	133	4500 NE
1163	16°04'S 145°52'E	18.10.86	33°35'S 151°23'S	10. 1.87		69	84	2390 S
1192	Unknown — Tag card not received		26°45'S 153°19'E	22. 2.87		30	?	?
1232	19°18'S 147°23'E	7. 9.86	19°27'S 147°30'E	15.10.86	175$^{(OA)}$		38	0
1982	Unknown — Tag card not received		14°46'S 145°43'E	1.11.87		114	?	?
1383	14°46'S 145°43'E	10.10.87	14°46'S 145°43'E	25.10.87		376	15	0
1386	27°00'S 153°30'E	27.11.86	3°40'S 176°35'W	23. 5.87	168$^{(L1)}$		177	4000 NE
1541	Unknown — Tag card not received		22°34'S 161°16'E	4. 1.88		40	?	?
1547	14°36'S 145°38'E	20.11.86	14°46'S 145°43'E	1.11.87		114	346	23 S

* dressed weight
L1: Length from tip of bill to caudal fork
L2: Length from tip of lower jaw to caudal fork
OA: Length from tip of bill to tip of tail

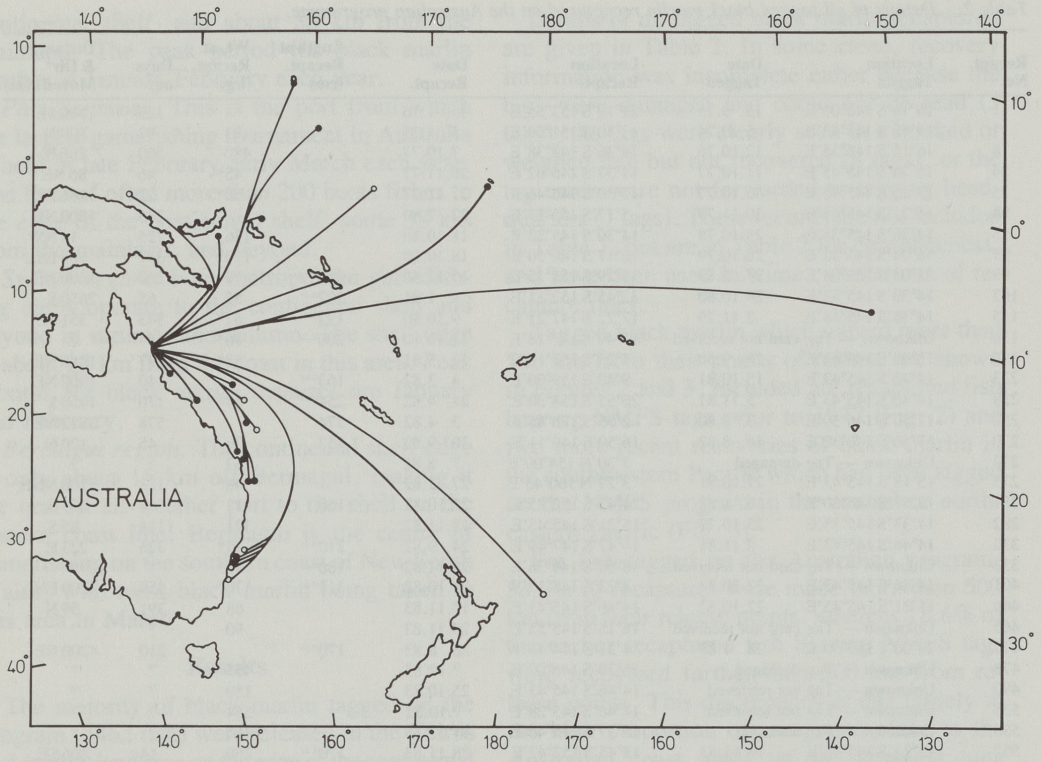

Figure 2. Points of recapture of black marlin tagged in the Cairns-Lizard Island region of northern Queensland, which moved more than 500 km. Open circles represent fish tagged under the NMFS program, closed circles represent fish tagged under the New South Wales program.

Rate of Movement

There was an apparent tendency for fish to move farther from their point of release with time during the first 250 days or so after release (Fig. 4). After approximately one year (330-410 days), however, a number of fish were recaptured very close to or in the same general area of release. This phenomenon also occurred after about 2 years (5 recaptures), 3 years (one recapture) and 4 years (one recapture). All of these cases were recorded in the Cairns — Lizard Island region. No such cases have yet been recorded for juvenile black marlin tagged in other areas.

Determining the maximum rate of movement for tagged black marlin may be useful in considering possible "purposeful" migration, as opposed to random dispersal. Table 4 shows data for recaptured black marlin from both this study and that of Squire and Nielsen (1983) which showed the fastest apparent rates of movement away from their points of release. It is

Table 3. Numbers and overall percentage recaptures (in parentheses) of black marlin recovered inside and outside the Australian 200-mile Fishing Zone (AFZ).

	This study		Squire and Nielsen (1983)	
Method of recapture	**Inside AFZ**	**Outside AFZ**	**Inside AFZ**	**Outside AFZ**
Japanese longline	11(17.7)	6(9.6)	49(84.4)	1(1.7)
Recreational	35(56.5)	1(1.6)	4(6.9)	0
Australian commercial	2(3.2)	0	2(3.4)	0
Korean longline	0	3(4.8)	0	2(3.4)
Other Nation longline	0	1(1.6)	0	0
Pacific artisanal	0	3(4.8)	0	0
Total	48(77.4)	14(22.6)	55(94.8)	3(5.2)

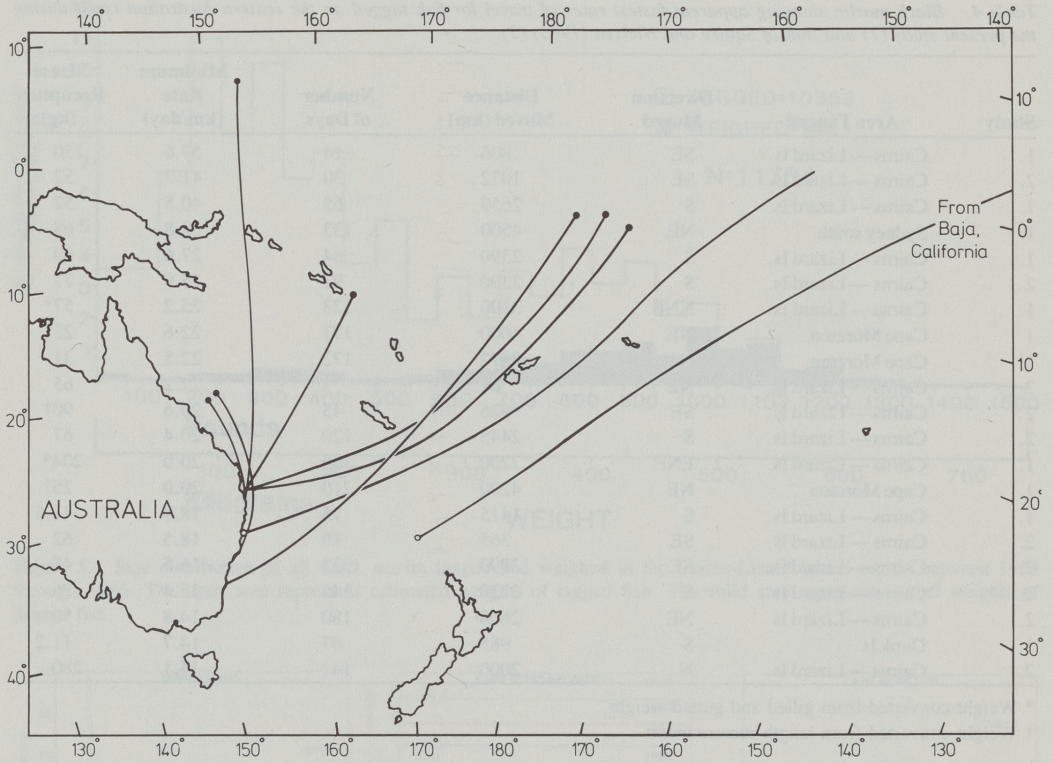

Figure 3. Points of recapture of black marlin tagged in areas other than northern Queensland, which moved more than 500 km. Open and closed circles as for Figure 2.

significant that 18 of the 20 fish included in Table 4 moved distances in excess of 800 km. The fastest moving fish tended to travel in a southward or southeastward direction from northern Queensland.

The two black marlin tagged in the central and eastern Pacific under the NMFS program also recorded relatively fast movements to the western Pacific (Fig. 3). One, tagged off Baja California, Mexico, travelled 5,700 km at an average 9.4 km per day and weighed 58 kg (128 lb) at recapture. The other was tagged at Christmas Island and recaptured on the New South Wales coast after 137 days, an average rate of 24.9 km per day. It weighed about 40 kg (88 lb) at recapture.

Size-Distribution of Recreational Catch

Each year, recreational fishing activity directed towards black marlin occurs over well defined periods in each of the areas mentioned. In the Cairns — Lizard Island region, a wide size range of fish is encountered from September through November each year (Fig. 5). In contrast to this wide range of sizes (and presumably ages) occurring off the outer barrier reef, very narrow size ranges of small fish appear inside the barrier reef, or continental shelf, at other locations (Figs. 6, 7, 8, 9).

Fish within a narrow, unimodal size distribution (presumably one year class) appear near Dunk Island and Cape Bowling Green (both in northern Queensland, well inside the continental shelf) in most years (Fig. 6). At Cape Moreton, in southern Queensland, near the edge of the shelf, a wider size range of fish appears in the catch in some years, but usually a strong apparent year class of small fish is still present, although their modal weight is slightly larger than that of those found in northern Queensland.

Data for Port Stephens (Fig. 7) cover a longer period, and are based on actual weights of individual fish. Here, fish are caught both on and beyond the continental shelf. Again, a strong mode in the size distribution is often apparent for small fish, but larger, presumably older, fish now appear frequently. This circumstance often results in two or sometimes three distinct modes

Table 4. Black marlin showing apparent fastest rates of travel for fish tagged on the eastern Australian coast during the present study (1) and that of Squire and Nielsen (1983) (2).

Study	Area Tagged	Direction Moved	Distance Moved (km)	Number of Days	Minimum Rate (km/day)	Size at Recapture (kg)
1.	Cairns — Lizard Is.	SE	806	14	57.6	250
2.	Cairns — Lizard Is.	SE	1072	30	41.3	52
1.	Cairns — Lizard Is.	S	2650	65	40.8	52
1.	Sydney south	NE	4500	133	33.8	68
1.	Cairns — Lizard Is.	S	2390	84	27.6	69
2.	Cairns — Lizard Is.	S	2390	92	25.9	77
1.	Cairns — Lizard Is.	NNE	3100	123	25.2	57*
1.	Cape Moreton	NE	4000	177	22.6	23†
1.	Cape Moreton	N	3872	172	22.5	31
2.	Cairns — Lizard Is.	NE	67	3	22.2	65
2.	Cairns — Lizard Is.	SE	926	45	20.6	90†
2.	Cairns — Lizard Is.	S	2445	120	20.4	67
1.	Cairns — Lizard Is.	ENE	7200	359	20.0	204*
1.	Cape Moreton	NE	4200	210	20.0	25†
1.	Cairns — Lizard Is.	S	1415	75	18.9	41.5
2.	Cairns — Lizard Is.	SE	365	19	18.5	62
2.	Cairns — Lizard Is.	SE	3890	235	16.5	45
2.	Cairns — Lizard Is.	S	2220	145	15.4	76
2.	Cairns — Lizard Is.	NE	2668	180	14.8	50*
1.	Dunk Is.	S	985	67	14.7	11.2
2.	Cairns — Lizard Is.	N	2000	141	14.1	280

* Weight converted from gilled and gutted weight

† Weight converted from length measurement

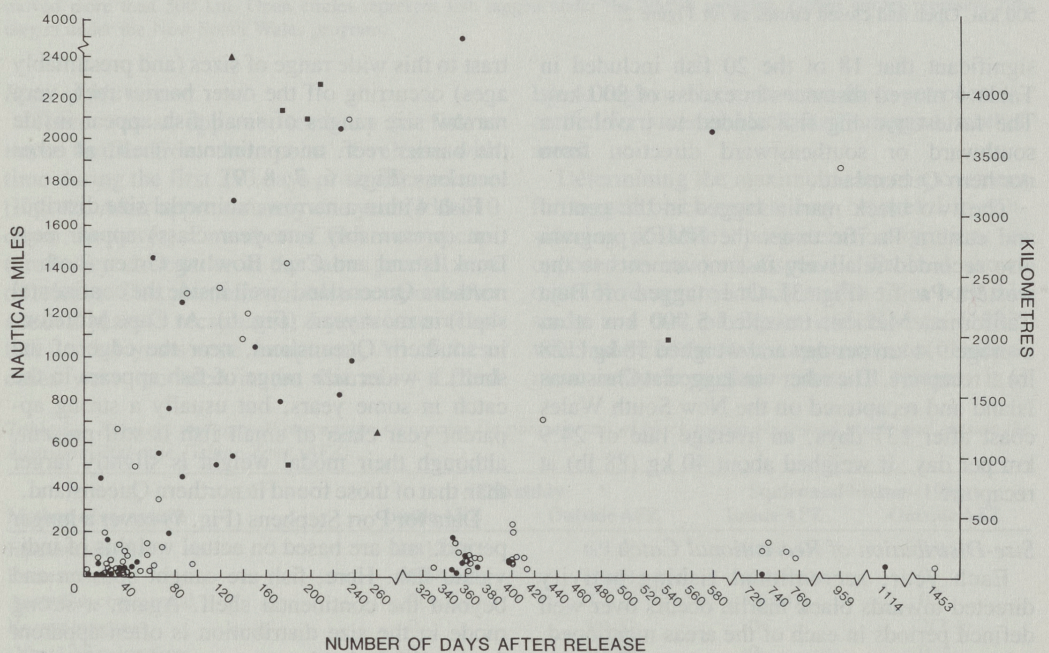

Figure 4. Distance moved and days at liberty for all recaptured black marlin tagged off eastern Australia. Open and closed circles as for Figure 2. Squares represent fish tagged at Cape Moreton, triangles represent fish tagged in New South Wales.

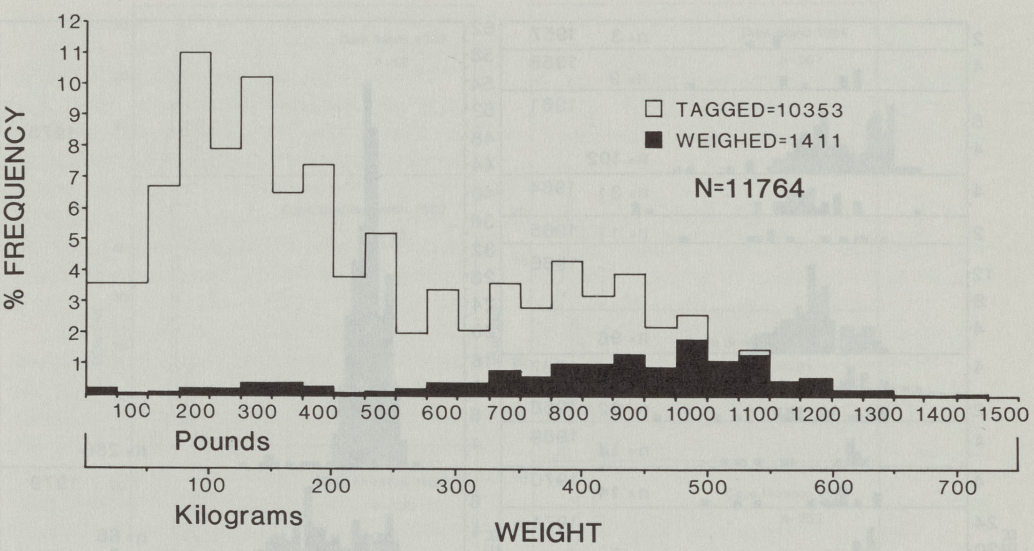

Figure 5. Size distribution of all black marlin tagged and weighed in the Cairns-Lizard Island region between 1968 through 1986. The open area represents estimated weights of tagged fish. The solid area represents actual weights of landed fish.

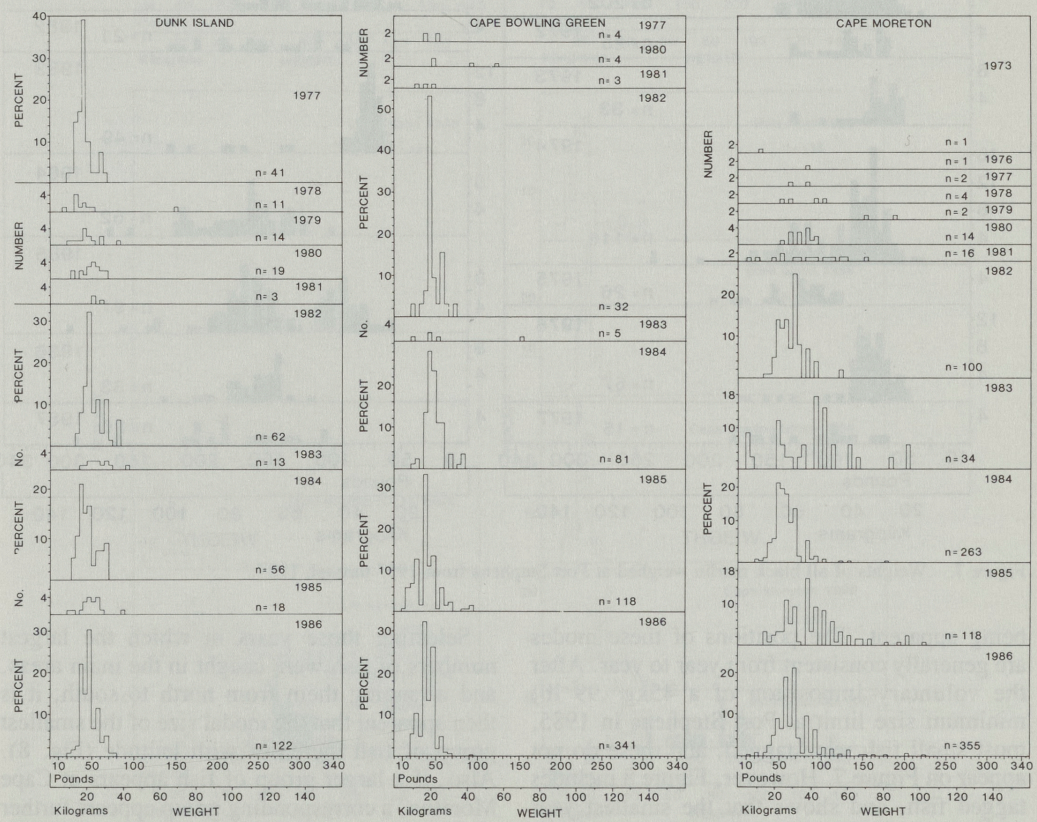

Figure 6. Estimated sizes of all black marlin tagged at Dunk Island, Cape Bowling Green and Cape Moreton throughout the course of the Australian program.

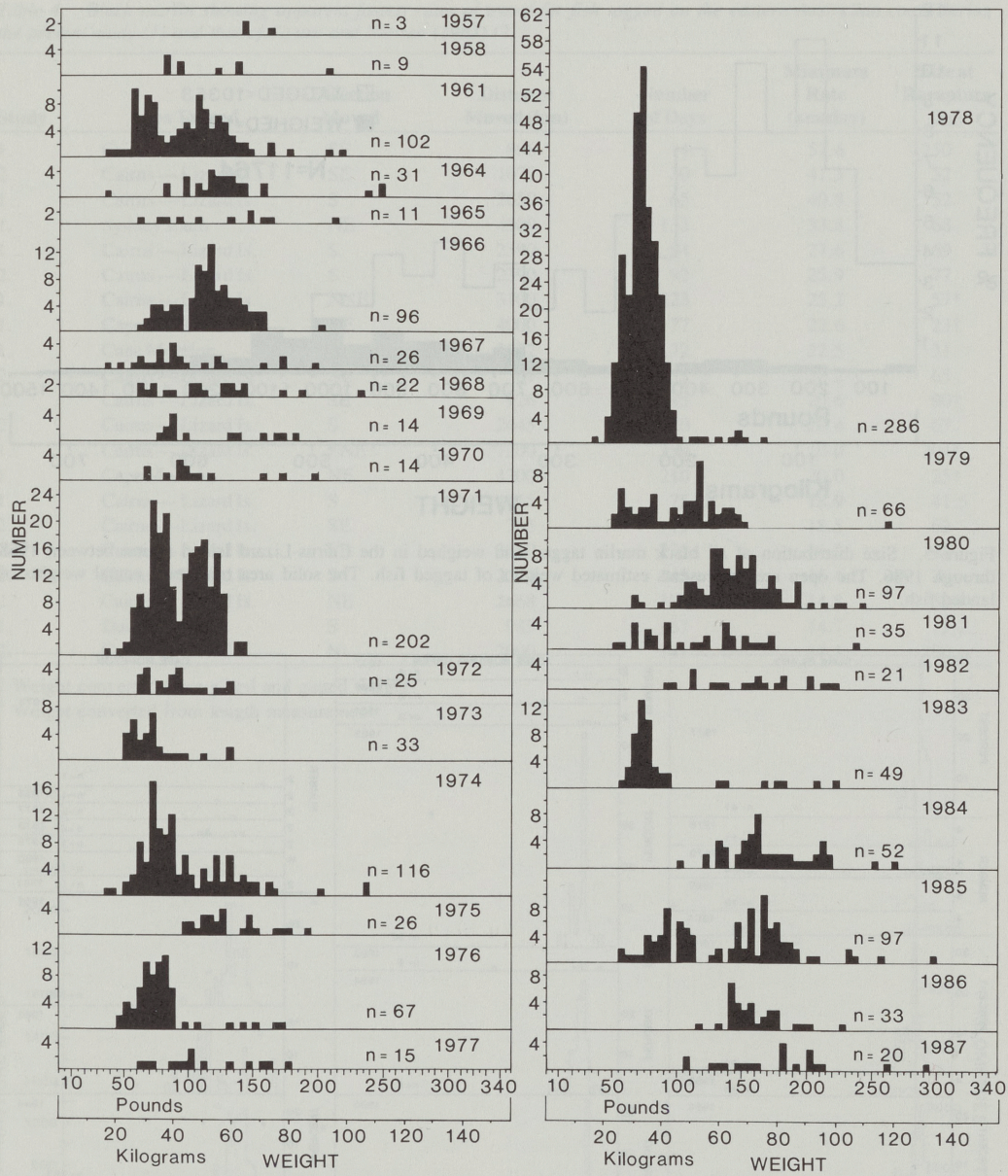

Figure 7. Weights of all black marlin weighed at Port Stephens from 1957 through 1987.

being apparent. The positions of these modes are generally consistent from year to year. After the voluntary imposition of a 45kg (99 lb) minimum size limit at Port Stephens in 1985, most small fish were tagged, and these do not appear on Figure 7. However, Figure 8 includes tagged fish, and shows that the smallest year class was present off Port Stephens in 1987, but not in 1986.

Selecting those years in which the largest numbers of fish were caught in the main areas, and arranging them from north to south, it is then apparent that the modal size of the smallest group of fish increases with latitude (Fig. 8). Also, if a larger group of fish appears at Cape Moreton, a corresponding group appears further south at Port Stephens.

This phenomenon can be better seen by com-

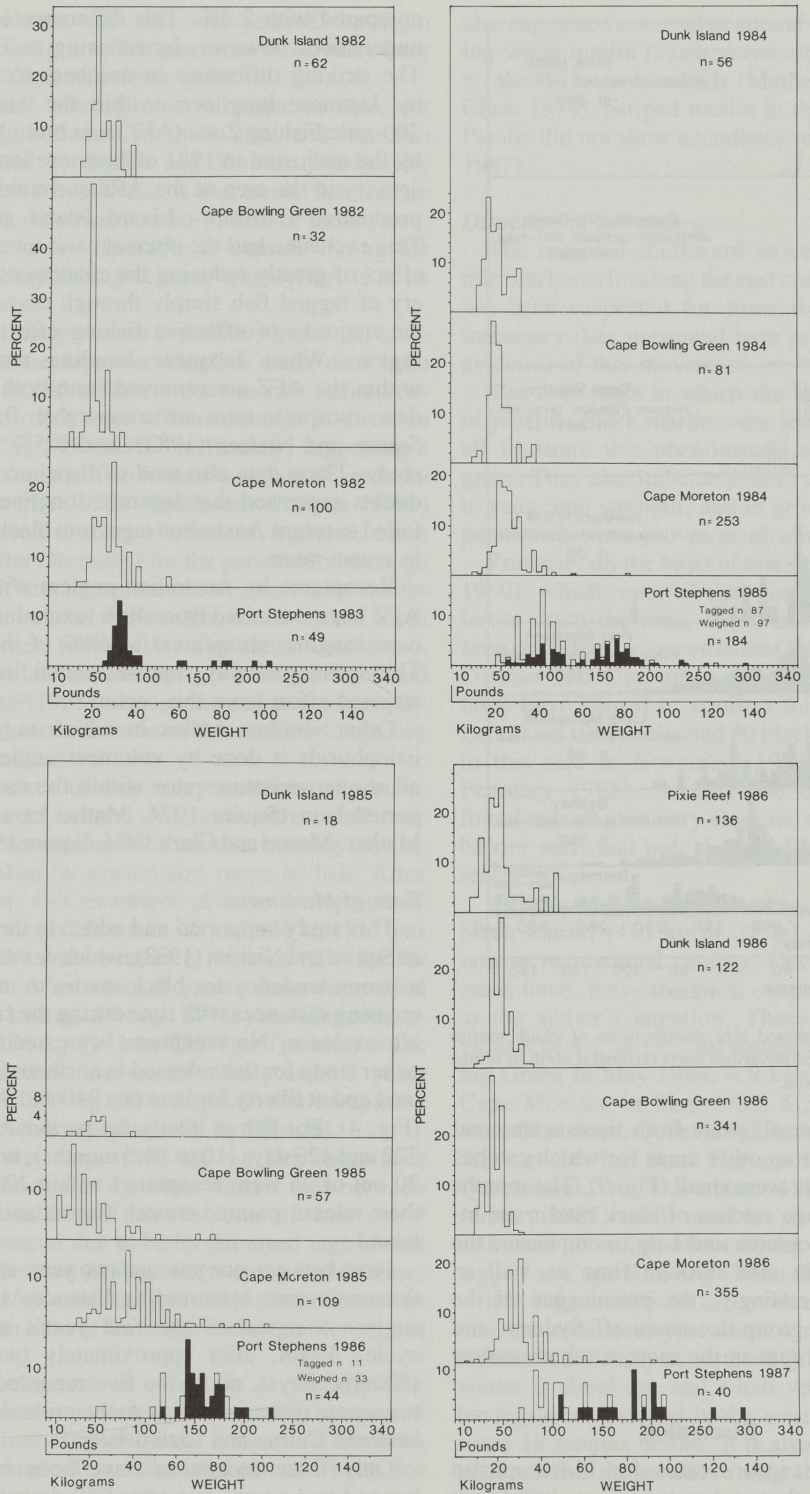

Figure 8. Size distribution of black marlin tagged or weighed at various ports (arranged north to south) in those years showing the greatest numbers caught. Key as for Figure 5.

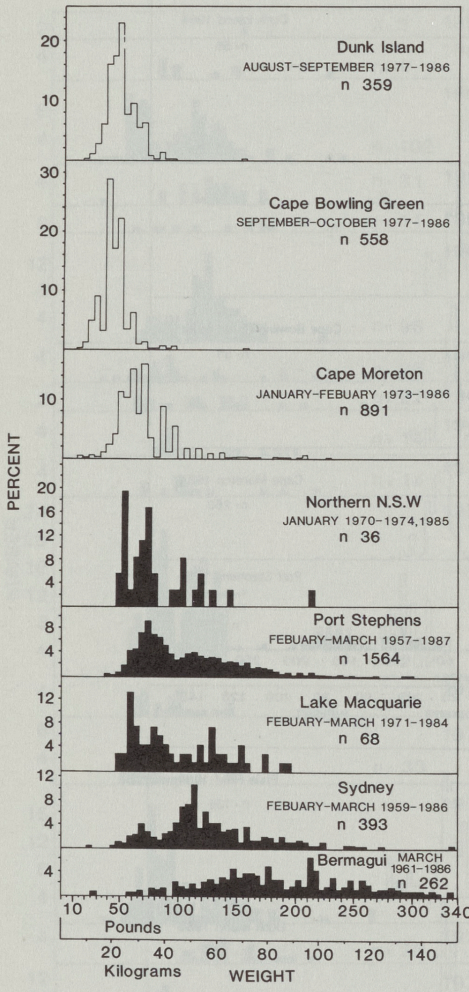

Figure 9. Combined size distributions of black marlin tagged or weighed at various ports (arranged north to south) in eastern Australia.

bining data for all years from these areas, and adding data from other areas for which catches in any one year were small (Fig. 9). The months of peak average catches of black marlin are included for each area and help to emphasize the progression in size through time as well as latitude. Interestingly, the prominence of the smallest size group decreases off Sydney, and is virtually absent in the more southern waters off Bermagui.

Discussion

Overall recapture rates for black marlin tagged during the present study were much lower than those of Squire and Nielsen (1983) — 0.7% compared with 2.3%. This difference is easily understood, however, by referring to Table 3. The striking difference in numbers recaptured by Japanese longliners within the Australian 200-mile Fishing Zone (AFZ) was brought about by the exclusion in 1981 of Japanese longlining activity in the area of the AFZ surrounding the productive Cairns — Lizard Island grounds. This exclusion had the obvious, and immediate, effect of greatly reducing the chances of recovery of tagged fish simply through cessation of the majority of effective fishing effort in the region. When Japanese longline recaptures within the AFZ are removed from both sets of data, recapture rates are comparable: 0.4% for Squire and Nielsen (1983), and 0.5% for this study. These data also tend to dispel occasional doubts expressed that Japanese longliners have failed to return Australian tags from black marlin in recent years.

Recaptures by Australian anglers within the AFZ have increased from 40% (excluding Japanese longline recaptures) to 68% of the total. This quite probably represents real increased targeted effort from this sector.

Other similar studies in which tagging of istiophorids is done by volunteer anglers have all shown recapture rates within the ranges reported here (Squire 1974, Mather et al 1974, Mather, Mason and Clark 1974, Squire 1987).

Rate of Movement

This study supported and added to the results of Squire and Nielsen (1983), which demonstrated a strong tendency for black marlin to move increasing distances with time during the first year after release. No recaptures were recorded in either study for fish released in northern Queensland and at liberty for between 240 and 320 days (Fig. 4). For fish at liberty for periods between 320 and 420 days (10 to 13.5 months), however, 20 out of 25 were recaptured within 200 km of their release points between Cairns and Lizard Island.

From between one year and two years at liberty, three recoveries at increasing distances with time suggest a repeat of the first year's apparent cycle. Again, after approximately two years (720-760 days), all of the five recorded recaptures were taken very close to their release points between Cairns and Lizard Island.

Only three recaptures have been recorded beyond two years; one after 959 days (2 years 7 months) at a considerable distance (3,470 km)

from release, one after 3.05 years 85 km from its release point, and one after 3.98 years only 40 km from its release point.

Annual homing after dispersal is therefore strongly indicated by these data, and was also suggested by Squire and Nielsen (1983). The alternative hypothesis is that some fish remain near the outer barrier reef for one or more years, but are only vulnerable to capture during the late spring fishing season, when effort is at its peak.

This interpretation is probably incorrect, however, since Japanese longline catch data from the early 1950s clearly demonstrate a sharp decline in catch rates of black marlin in this area (10-20°S, 143°-148°E) in January, suggesting a mass exodus of fish from this region (Kamimura and Honma 1959). Squire and Nielsen (1983) also noted a sharp decline in Japanese catch rates after December for the period 1968 through 1977. Their interpretation of catch data in subsequent months was a scattered movement south in summer, followed by a northeastward movement in late autumn-early winter. Howard and Ueyanagi(1965) also postulated a southwardly directed movement from the western Coral Sea after January.

The sizes of fish recaptured near the outer barrier reef around one, two, three, and four years after release indicate that homing may be undertaken by a wide size range of fish. After one year, fish recaptured close to their points of release ranged between 60 and 480 kg (132 and 1,056 lb) with a mean of 108 kg (238 lb) for 20 fish. After about 2 years, those recaptured (5 fish) averaged 94 kg (207 lb) and ranged from 64 to 136 kg (141 to 299 lb). The single fish recaptured in the same vicinity after 3 years weighed 371 kg (816 lb), and that recaptured after 4 years weighed 120 kg (264 lb).

All very large (300 kg +) fish recaptured were taken near the outer barrier reef between Cairns and Lizard Island. Some of these could not be traced due to badly damaged tags (Table 2). Since such damage takes considerable time, it could be assumed that they were released in the same area at least one season earlier, if not before.

The one serious exception to the apparent annual homing tendency was the fish recaptured at the farthest point from release off northern Queensland. This fish had been at liberty for 360 days!

Other tagging studies on istiophorids have also suggested seasonal or annual cycles, including white marlin *(Tetrapturus albidus)* (Mather et al. 1974) and sailfish (Mather, Mason and Clark 1974). Striped marlin in the northeastern Pacific did not show a tendency to home (Squire 1987).

Direction of Movement

The seasonal southward movement of juvenile black marlin along the east coast of Australia has been suspected for some time. The size-frequency data presented here provide the first evidence of this movement.

The four years in which the largest numbers of juvenile black marlin were recorded (Fig. 6) all illustrate this phenomenon to varying degrees. They also indicate year to year variability in year-class strength, and in growth rate as the population wave moves southward.

Primarily on the basis of one study (Ueyanagi 1960), which reported ripe gonads and several larvae from the area, black marlin have long been considered to spawn in the Coral Sea between October and December. Recent larval collections have helped to confirm this proposition. Leis et al (1987) collected 80 black marlin larvae in this area in November 1984 (but none in February 1985). Seventy-five of these were found outside, but very close to, the edge of the barrier reef, and only 5 were found inside the reef.

As indicated by Figures 6 to 9, very small black marlin (<10 kg or 22 lb) are extremely rare in recreational catches. Occasional specimens have, however, been caught and brought to the author's attention. These include individuals of 4.2 kg (9.2 lb) caught at Cape Bowling Green in May 1984, 4.9 kg (10.8 lb) from Cape Moreton in May 1985, 5.3 kg (11.6 lb) from Gladstone, Queensland, in May 1988, and 7.3 kg (16 lb) from Hervey Bay, southern Queensland, in November 1985. Also, in January 1985, small numbers of black marlin, estimated to weigh about 10 kg (22 lb), were tagged at Cape Bowling Green (Fig. 6).

It is suggested from this evidence, therefore, that the consistent year class which enters the recreational fishery in northern Queensland each winter is about one and a half years old (1 +), having been spawned in the western Coral Sea some 18 months before. It is also apparent that younger fish do not move onto the barrier reef from offshore in any numbers before that time.

At the latitude of Cape Moreton, black marlin

have grown to about 28 kg (61 lb) by their second birthday in December, and as 2+ age class fish reach Port Stephens by February of the following year, at a modal weight of about 32 kg (70 lb). This year class appears intermittently off Sydney, but larger, older fish dominate the fishery at this latitude (Fig. 9). The virtual absence of the presumed 2+ year class off Bermagui strongly suggests their departure from the coast before that point.

A group of larger, presumably older, fish enters the fishery at about Cape Moreton (Fig. 6), are present in northern New South Wales (Fig. 9), but are best seen in the data from Port Stephens (Fig. 7). At this latitude, the presumed 2+ age class fish (modal weight about 32 kg or 70 lb) are present in most years. The next obvious size group has a modal weight of about 50-55 kg (110-121 lb), while a third group, showing a less distinct mode at 68-70 kg (150-154 lb), is only occasionally evident (for example, in 1980, 1984, 1985, and 1986). These two larger size-groups of fish could be presumed to represent the 3+ and 4+ year-classes, although an independent method of ageing these fish is needed to validate this interpretation. If these three-size groups are successive year-classes, the data show considerable annual variation in their strengths. In some years, one or more groups failed to appear in the recreational fishery at all. The year 1986/87 was particularly interesting (Fig. 8) in that record numbers of presumed 1+ fish were tagged at all of the main fishing grounds in Queensland, but very few individuals from this strong year class apparently reached the latitude of Port Stephens. In fact, fish appeared later than usual at Dunk Island, Cape Bowling Green, and Cape Moreton that year, with the peak month for catches at Cape Moreton being February (rather than January). It would appear, then, that these fish remained on the Cape Moreton grounds that year, in preference to moving south.

Supporting Data From Tag Recoveries

Do tag recoveries support the presumed southward movement of small and larger fish? Of the 2,000-plus fish released at Pixie Reef, Dunk Island, Cape Bowling Green and Cape Moreton, 16 (less than 1%) have been recaptured. Half (8) were recovered near their release points shortly after tagging, 6 were recaptured to the north or northeast, and 2 moved south (Table 2). Interestingly, the two which moved south were the smallest black marlin recaptured during the study. One of these moved 958 km south from Dunk Island in 67 days and weighed 11.2 kg (25 lb) at recapture, the other moved 359 km south from Pixie Reef in 76 days and weighed 20 kg (44 lb) at recapture. Both were recaptured by recreational anglers well inside the edge of the continental shelf. Although small fish released at Cape Moreton might reasonably be expected to be recaptured in New South Wales (Figs. 8 and 9), as yet none has been. Instead, all 5 recaptured fish tagged at Cape Moreton have been recovered at considerable distances to the north or northeast. At release, all of these fish were small, estimated at 23 kg to 40 kg (50 to 88 lb).

Some of these fish may well have moved into New South Wales waters before departing from the Australian coast, but the absence of supporting data must leave doubts regarding this possibility. Larger numbers of small fish will need to be tagged in northern and southern Queensland if this problem is to be addressed.

On the other hand, far greater numbers of larger, older fish have been released outside the continental shelf in the Cairns — Lizard Island area. Recaptures of tagged fish show that at least some members of the population move south along the shelf in subsequent months (Fig. 2), and that the rate of movement is rapid (Table 4). Others have been recaptured southeast of the Cairns — Lizard Island area, and Squire and Nielsen (1983) also reported two recoveries off northern New Zealand.

Based on the presumed ages of black marlin caught in the Port Stephens recreational fishery, fish tagged off northern Queensland and recaptured off southern Queensland and New South Wales would be 2 to 5 years old.

The continental shelf of eastern Australia appears to play a major role in determining the distribution of small and larger black marlin. Fish presumed to be one year old appear well inside the outer edge of the Great Barrier Reef in northern Queensland, remaining on the continental shelf as they move south. Older, (2 to 5-year-old) fish, however, apparently stay near the outer edge of the shelf, also making a similarly timed movement with the advancing warm water of the east Australian current. Some of these older fish are first contacted by recreational anglers at Cape Moreton, which is much closer to the edge of the continental shelf than the more northern grounds.

The recreational fisheries in New South Wales range out to the continental shelf (due to its proximity) and come into contact with the older fish. No accurate records of exact location of capture of small fish (30-40 kg or 66-88 lb) are available for New South Wales, but personal observations strongly suggest that most are caught inside the shelf.

It is interesting to note that black marlin of the sizes encountered by recreational fishermen on the Australian continental shelf are very rare in records of Japanese longline catches from different areas (Kamimura and Honma 1959, Ueyanagi 1960, Koto and Kodama 1962). Only Takahashi et al (1983) reported numbers of black marlin in the range of 15-25 kg (33-55 lb) caught by longline. Their results were from exploratory longlining in the Gulf of Thailand. Water depth there is less than 200 m, corresponding to the depths where fish of similar sizes are caught off eastern Australia.

Summary

The black marlin is the primary target species of game fishing in eastern Australia. Adults are fished during an apparent pre-spawning aggregation at the edge of the Great Barrier Reef in northern Queensland. Juveniles are targeted at known locations inside the Great Barrier Reef, and along the Continental Shelf to southern New South Wales.

Over 11,000 black marlin have been tagged by volunteer anglers throughout this range, mainly in northern Queensland, from 1968 through 1986, and 120 recaptures have been recorded.

Recaptures indicate a tendency for distance moved to increase with time at liberty during the first year after release. Recaptures of fish near their points of release after one, two, three, and four years, however, strongly suggest annual homing.

Black marlin can be classified as being highly mobile, but not necessarily migratory in that movement is not entirely predictable. A relatively high proportion of recaptured fish have been taken at considerable distances from their points of release, and fish covering a wide size range have moved considerable distances.

A southward directed movement of one- to two-year-old fish, from northern Queensland to central New South Wales, is indicated by an annual appearance of this group in the north, and then at more southern latitudes through time. An increase in modal size of the group also occurs with latitude and time.

One or two older groups of fish also apparently undertake this southward movement, although not every year. These larger fish are normally encountered at the edge of or beyond the continental shelf. Tag-recapture data have not as yet entirely supported this hypothesis, but a number of fish tagged in northern Queensland, and recaptured in southern Queensland and New South Wales, fit the proposed movement route.

Because recapture rates are low, and many gaps still exist in the knowledge of black marlin movements, tagging of large numbers of all sizes throughout their range should continue to be encouraged.

Tetracycline injection of small fish at the time of tagging may help to validate the suggested ages of the younger fish.

In northern Queensland, where a relatively high strike rate of large fish occurs in late Spring each year, the opportunity exists for tracking by means of archival self-release tags. When this technology becomes available, its use in this area should be encouraged.

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Migration Trends of Striped Marlin *(Tetrapturus audax)* in the Pacific Ocean

James L. Squire and Ziro Suzuki

Migration patterns of large pelagic fish such as tunas and billfishes are not well defined in the Pacific Ocean, in spite of extensive tagging programs conducted for some of the species. Information on the potential for trans-oceanic or long-distance migrations has been developed for some species, but how population segments actually move is poorly known.

Investigators can determine migration trends by analyzing tagging data, length frequencies, and other biological differences by geographical areas, as well as the locations and seasonal movements of areas of high catch-per-unit-effort (CPUE). This paper reviews the biological and fishery charcteristics of striped marlin *(Tetrapturus audax)* to develop a hypothesis on their movements throughout the Pacific Ocean.

Development of the Fishery

In the post-World War II era, the Japanese longline fishing fleet expanded its operations until tunas and billfishes were fished in all tropical and temperate oceans of the world. By the early 1950s, the Japanese longline fleet had already explored the western, southwestern, and central Pacific areas for tunas and billfishes. (Honma and Kamimura 1958). By 1956, the Japanese longline fleet had reached into the eastern Pacific (E. of 130°W) (Suda and Schaefer 1965). Expansion continued through 1962, with fishing targeted on yellowfin tuna *(Thunnus albacares)* and bigeye tuna *(Thunnus obesus)* in the equatorial areas. At that time, tunas accounted for about 85% and billfishes for about 15% of the catch by weight. Billfish catches by number consisted of 9% blue marlin *(Makaira nigricans);* 4% striped marlin; and 1% of black marlin *(Makaira indica),* swordfish *(Xiphias gladius),* Pacific sailfish *(Istiophorus platypterus),* and shortbill spearfish *(Tetrapturus angustirostris)* combined.

A further expansion of the fishery occurred north of the equator in the early 1960s, with rapidly increased catches of striped marlin, sailfish, and swordfish. This increase occurred as the hooking rate of bigeye tuna declined in the eastern Pacific (Shiohama 1969). This final expansion completed the eastward exploration of the Pacific by the Japanese longline fleet.

Distribution of Striped Marlin

Fishing log records are maintained by longliners for the Japan Fishery Agency, and this organization has published catch and effort data annually on a worldwide basis for the years 1962 through 1980 (Anon 1962-1980). Biological data on striped marlin for many areas of the Pacific Ocean were also collected by Japanese fishery survey vessels and shore sampling, and these data have been published in various journals and reports.

Based on these Japanese data, various authors have attempted to describe the general distribution of striped marlin in the total Pacific or portions of it (Kume and Schaefer 1966, Kume and Joseph 1969, Howard and Ueyanagi 1965, Suda and Schaefer 1965, Nakamura 1974, Shiohama 1969, Honma and Kamimura 1958, Joseph et al 1974, Shingu et al 1974, Suzuki and Honma[1], Miyabe and Bayliff 1987). The general description of striped marlin distribution

[1]Suzuki, Ziro and M. Honma. 1977. Stock assessment of billfishes in the Pacific. Unpublished.

by Nakamura (1974), when modified to indicate low-catch-rate areas (Fig. 1), suggest that few striped marlin are found in the equatorial areas. Actually, data by Suzuki and Honma indicate low catch rates of <2.0 fish per 1,000 hooks in this area, possibly due to low catchability.

The relative size of the striped marlin population in various areas of the Pacific is of importance to this study. Results of the billfish stock assessment workshop (Shomura 1980) indicate that a considerable difference exists in population size between the north and south Pacific. For assessment purposes, the striped marlin population was divided at the equator. Areas of higher catch rates were observed in the northcentral, northeast, and southeast Pacific. The Pacific-wide stock was assessed as having a yield of 24,000 mt per year and the south Pacific estimate was 6,000 mt, about 1/3 that of the north Pacific yield. This significant difference in population size should be taken into account when comparing statistics for the various areas of the Pacific, particularly those for the southwest Pacific, an area of relatively low catch rate and population strength.

Movements of Striped Marlin

Evidence From Changes in CPUE

To determine how areas in the Pacific having high CPUE rates change, and to ascertain how these changes may relate to fish movements, the striped marlin CPUE data presented by Suzuki and Honma[1] were examined. For the period 1965-1975, the mean monthly CPUE values were ranked for each 5° long. by 5° lat. area. The 1965-75 period would cover years of full areal exploitation of striped marlin. Striped marlin occur as a by-catch in most areas of the

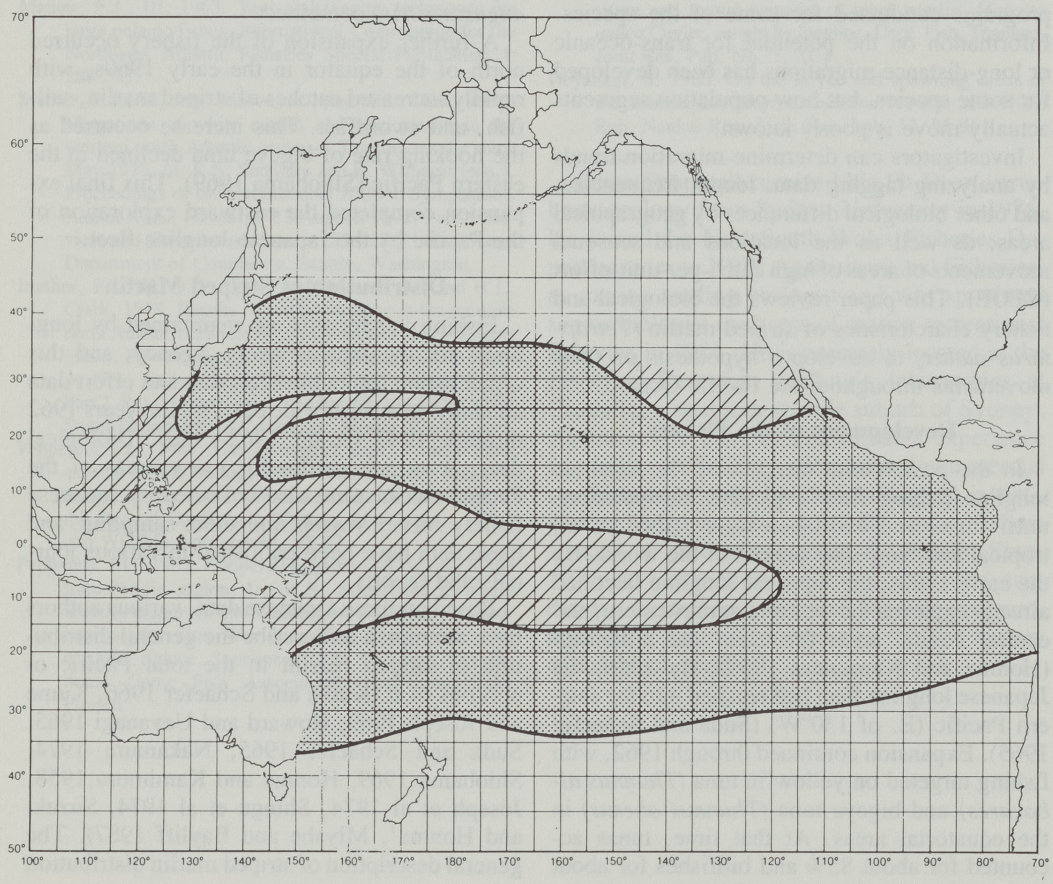

Figure 1. Distribution of good fishing grounds for striped marlin *(T. audax)* based on catch data from the Japanese longline fishery during 1964-1969 (adapted from Nakamura 1974). Light stippled areas indicate striped marlin occurrence, but at low catch levels.

Pacific except the eastern Pacific, where the species is targeted. Changes in catchability that result from targeting or non-targeting the species should not mask main patterns. Areas having an average CPUE value of 2.1 to 5.0 striped marlin per 1,000 hooks fished were assigned a value of 1, and areas having an average CPUE value of 5.1 striped marlin or more were assigned a value of 2. The monthly ranks were summed for all 12 months in each 5° longitude by latitude area where striped marlin catch exceeded 2.1 fish per 1,000 hooks (Fig. 2). The highest CPUE value (24) is found near the southern tip of Baja California, Mexico. The highest value (24) means that an average CPUE level of 5.1 striped marlin or greater occurred for all months during 1965-1975. Smaller numbers represent lesser sums of the ranking of mean monthly CPUE values. The areas to the south and southeast, off Ecuador and near the Galapagos Islands, have high CPUE values, as do areas further southwest, from 10° to 30°S lat. along 100°W long.

The highest CPUE values in the northeast Pacific were observed from June to November, while highest values in the southeast Pacific were apparent from December to March. In the southwest Pacific, CPUE values were highest in the Coral Sea area from October through January. In the north and north-central Pacific, highest CPUE values were observed north and west of the Hawaiian Islands from April to July.

Based in part on information on the movements of striped marlin from Honma and Kamimura (1958) for the southwest Pacific, Shiohama (1969) for the eastern Pacific, and Suzuki and Honma[1] for the total Pacific, we now infer seasonal movements of striped marlin from areal changes of high CPUE (Figs. 3 to 6, wherein arrow length indicates the approximate

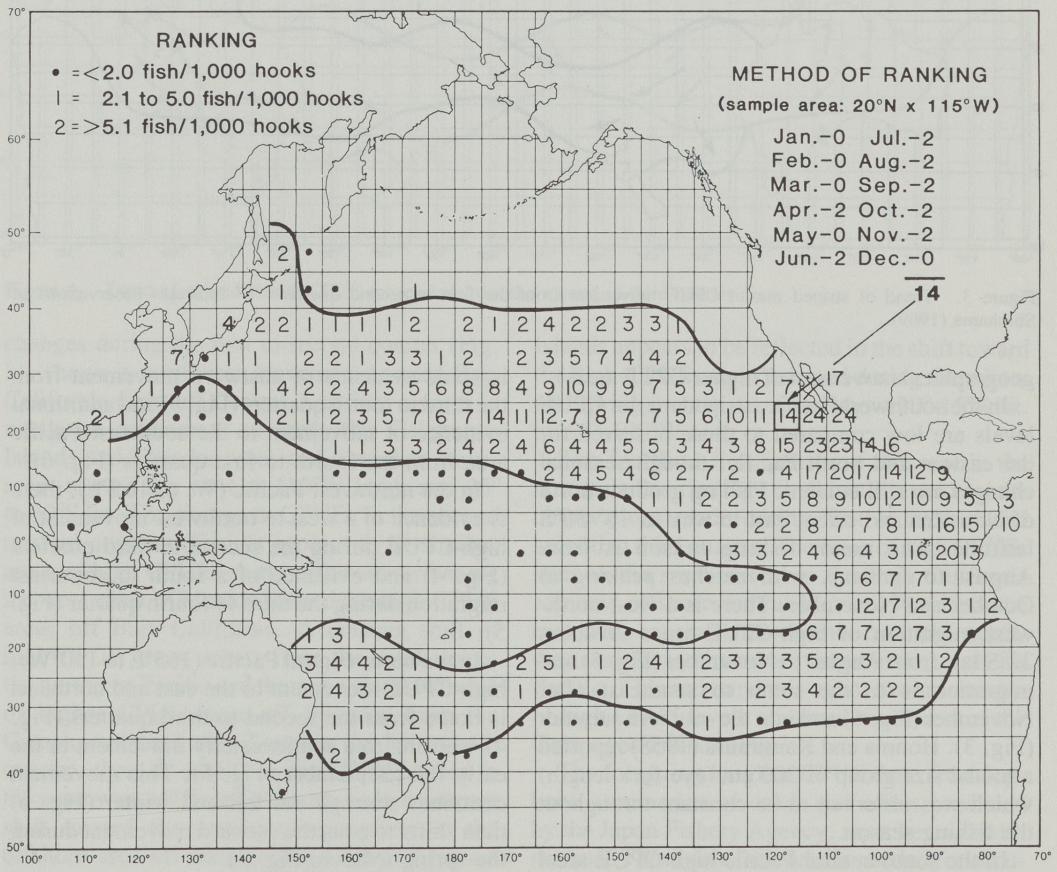

Figure 2. Rank values for hooking rates (CPUE) by Japanese longliners. Numbers represent the sum of mean monthly rank values for CPUE, 1965-1975.

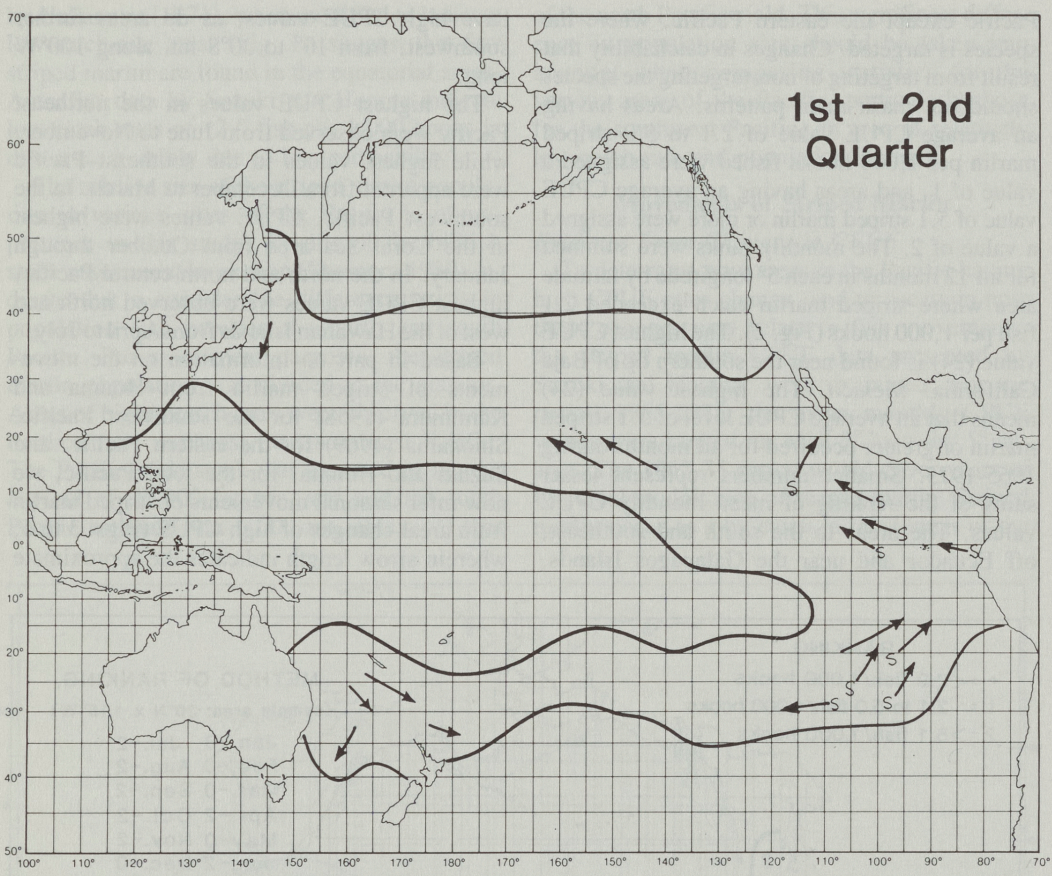

Figure 3. Trend of striped marlin CPUE movement from the first to second quarter. "S" indicates observations of Shiohama (1969).

geographical movement of higher CPUE areas).

In the southwest Pacific, striped marlin CPUE levels are low compared to those observed for the eastern and north Pacific, though seasonal changes are still evident. Fishing grounds north of New Zealand orient east to west at 16°-30°S latitude. The major fishing season is from August to January, with catches peaking in October and November. There is a west-northwest migration of high-CPUE areas to about 22°S lat. from August to November (Fig. 5) and migration is to the south to southeast after November (Fig. 6) and into the southern summer (Fig. 3). Honma and Kamimura (1958) reported a modal size group of 200 cm (eye-fork length) which was observed to be constant throughout the fishing season.

In the south-central Pacific high-CPUE areal movement to higher latitudes during the second and third quarters (Fig. 4) can be detected. There is some evidence of eastward movement from the third to fourth quarters (Fig. 5) and additional evidence of movement to the southeast Pacific area from the fourth to first quarters (Fig. 6).

In the northwest Pacific (W. of 165°E), there is evidence of a west to northwest movement of high-CPUE during the second to third quarters (Fig. 4) and evidence of a south to southeast migration during the third to fourth quarter (Fig. 5).

In the north-central Pacific (165°E to 130°W), high-CPUE movement to the east and northeast is noted from the second to third quarters (Fig. 4), shifting to a southwesterly movement in the early fall (September, Fig. 5). This movement continues through the fall and winter (Fig. 6) then shifts to a northwestward movement during the spring (March; Fig. 3).

In the eastern Pacific (E. of 130°), three areas have high CPUE levels (Fig. 2). Their areal

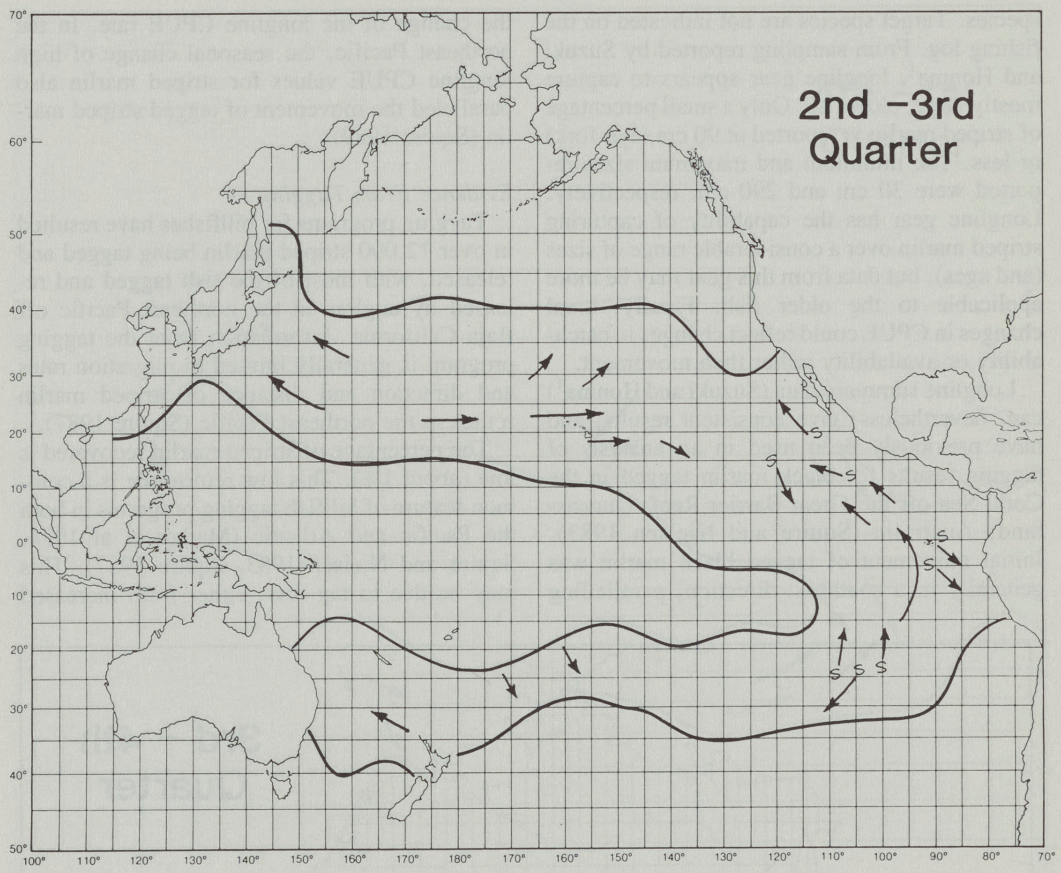

Figure 4. Trend of striped marlin CPUE movement from the second to third quarter.

changes during the first to second quarter (Fig. 3), shows a northwest movement toward Baja California from off Central America, a north to northeast movement towards the Galapagos Islands and Ecuador area, and a weaker movement toward the west at 110°W long, and 25° to 30°S lat. The change in CPUEs in the second to third quarters (Fig. 4) appears to be similar; areas of high CPUEs shift northwestward along the west coast of Mexico toward the high-CPUE areas off Baja California. A definite shift of high-CPUE areas occurs from the southeast to the northeast Pacific and there is a shift southeast of higher CPUE rates off Ecuador from the Galapagos Island area. Between the 3rd and 4th quarter, there is a shift in high-CPUE areas to the southwest off Baja California and a southeast shift toward the southern hemisphere in the offshore area off Mexico and Central America (90°-100°W long. by 5°-15°N lat.) (Fig. 5). The migration pattern southwest of the Galapagos Islands appears to be reflected in the shift toward the high-CPUE areas observed during the winter and spring months, centered about 10°-15°S lat. by 95°-100°W long.

The fourth to first quarter of the year in the northeast Pacific (Fig. 6) shows a reverse of the observations made during first to second and second to third quarter. The areas of high CPUEs shift to the southeast from the Baja California area and offshore central Mexico. A shift to the east with separate movements from the northwest and the southwest is evident in the southeast Pacific. This movement is again toward an area of high CPUE levels observed southwest of the Galapagos Islands (Fig. 2).

The foregoing longline CPUE data, from logbook summaries of catch and effort produced by the Japan Fishery Agency, must be used with caution. These data lack details needed for accurate interpretation of CPUE. Longline gear may be fished in many ways to target on specific

species. Target species are not indicated on the fishing log. From sampling reported by Suzuki and Honma[1], longline gear appears to capture mostly large, older fish. Only a small percentage of striped marlin is reported at 90 cm (eye-fork) or less. The minimum and maximum sizes reported were 30 cm and 290 cm, respectively. Longline gear has the capability of capturing striped marlin over a considerable range of sizes (and ages), but data from this gear may be more applicable to the older fish. Finally, areal changes in CPUE could reflect changes in catchability or availability rather than movement.

Longline summary data (Suzuki and Honma[1]) can, nevertheless, give consistent results, and have previously been used in an analysis of tagging results for black marlin tagged in the Coral Sea off the Great Barrier Reef, Queensland, Australia (Squire and Nielsen 1983). Initial movement of tagged black marlin was generally in a southeast direction, parallelling the change of the longline CPUE rate. In the northeast Pacific, the seasonal change of high longline CPUE values for striped marlin also paralleled the movement of tagged striped marlin (Squire 1987).

Evidence From Tagging

Tagging programs for billfishes have resulted in over 12,000 striped marlin being tagged and released, with most of the fish tagged and released by anglers in the northeast Pacific off Baja California. Information from the tagging program is generally limited to migration rates and direction and distance of striped marlin routes in the northeast Pacific (Squire 1987).

The percentage of striped marlin recovered is low (about 1%). This low return rate is a common feature of billfish tagging programs in both the Pacific and Atlantic (Mather et al 1974, Squire and Nielsen 1983, Squire 1987). This may be due to tag loss, either from increased

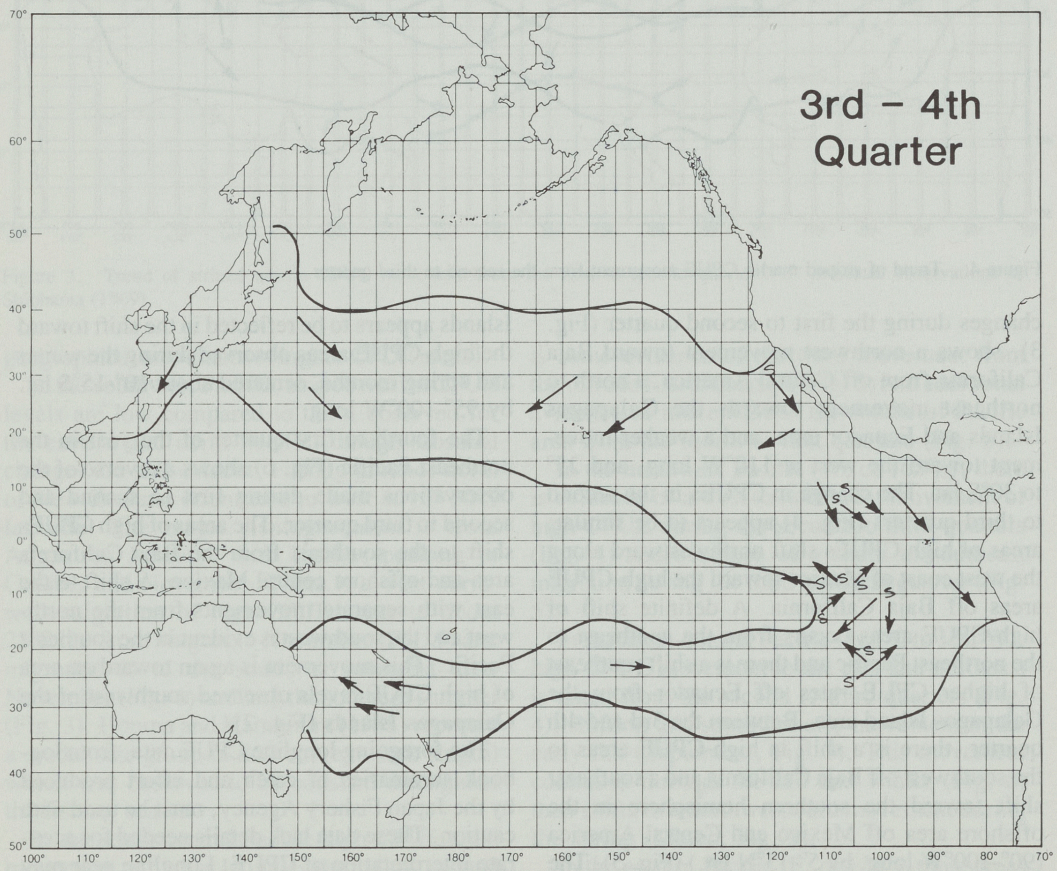

Figure 5. Trend of striped marlin CPUE movement third to fourth quarter.

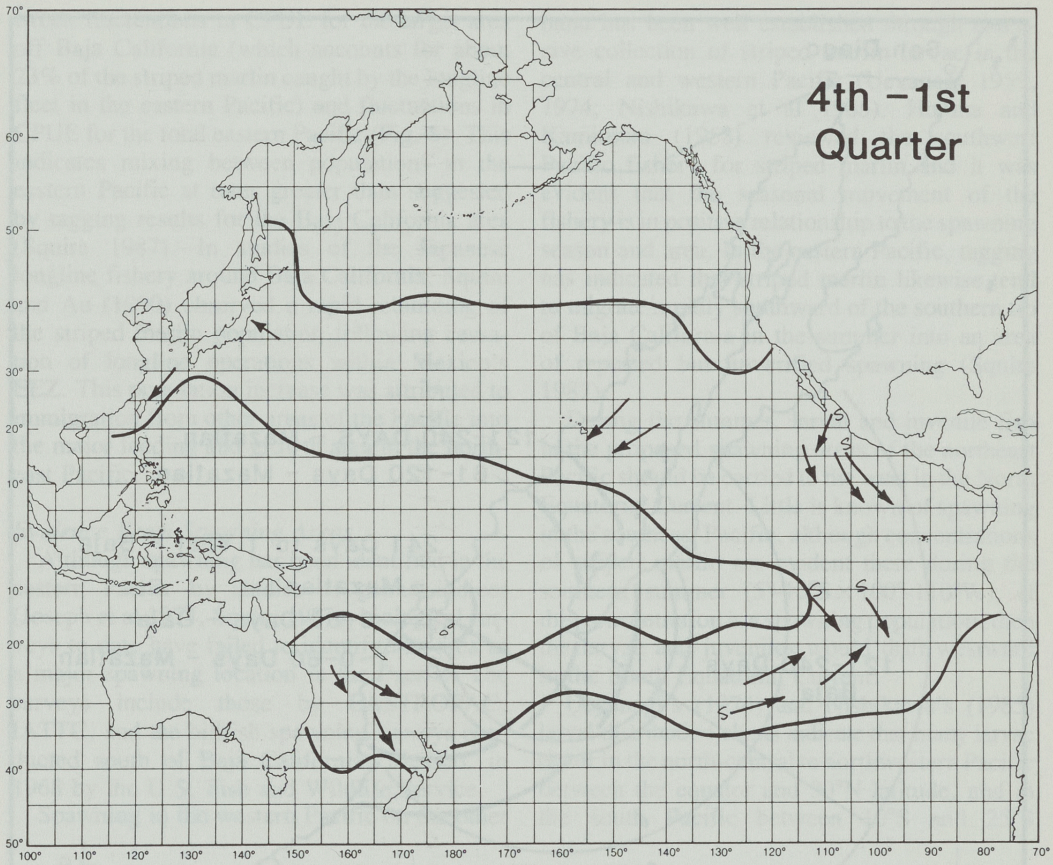

Figure 6. Trend of striped marlin CPUE movement fourth to first quarter.

mortality due to hooking, or from tag shedding, or to a combination of factors. Another unknown in evaluating the frequency of long-term recoveries is behavioral changes in migration patterns related to age. As striped marlin become older, they may move away from the highly productive "target fishing areas" into less frequently fished areas. This would tend to reduce the chance of recapture. In the northeast Pacific, length-frequency data (1965-1976 and 1980-1983) from the longline fishery (Suzuki and Honma[1]; M. Comparan, pers. comm.) would indicate that the larger size fish (older year classes) are not represented in the catch as they are in other areas of the Pacific. These factors may limit the ability of billfish tagging results to describe accurately the interactions between populations observed in various geographical areas of the Pacific.

A hypothesis describing the seasonal trend of striped marlin migration in the northeast Pacific was given by Squire (1987). Using plots of tag and recovery points, migration direction and rate analyses, movements of high-CPUE areas in the commercial longline fishery over time, and the spawning behavior exhibited in the northeast Pacific, he developed a schematic of seasonal migration. The movements can be shown in the form of time periods and distance of recovery points from the tagging site (Fig. 7) for time periods 0-60, 61-120, 121-240, and 241-360 days after tagging and release to recapture. Some of the tagged fish return to the tagging area; however, most returns were short-term (<1 year).

Long-range and non-seasonal movements from one area of the Pacific to another has been shown for some striped marlin tagged off Baja California, but a greater percentage of distant-water recoveries to the west and southwest has resulted from the limited tagging off southern California. Most recoveries from southern

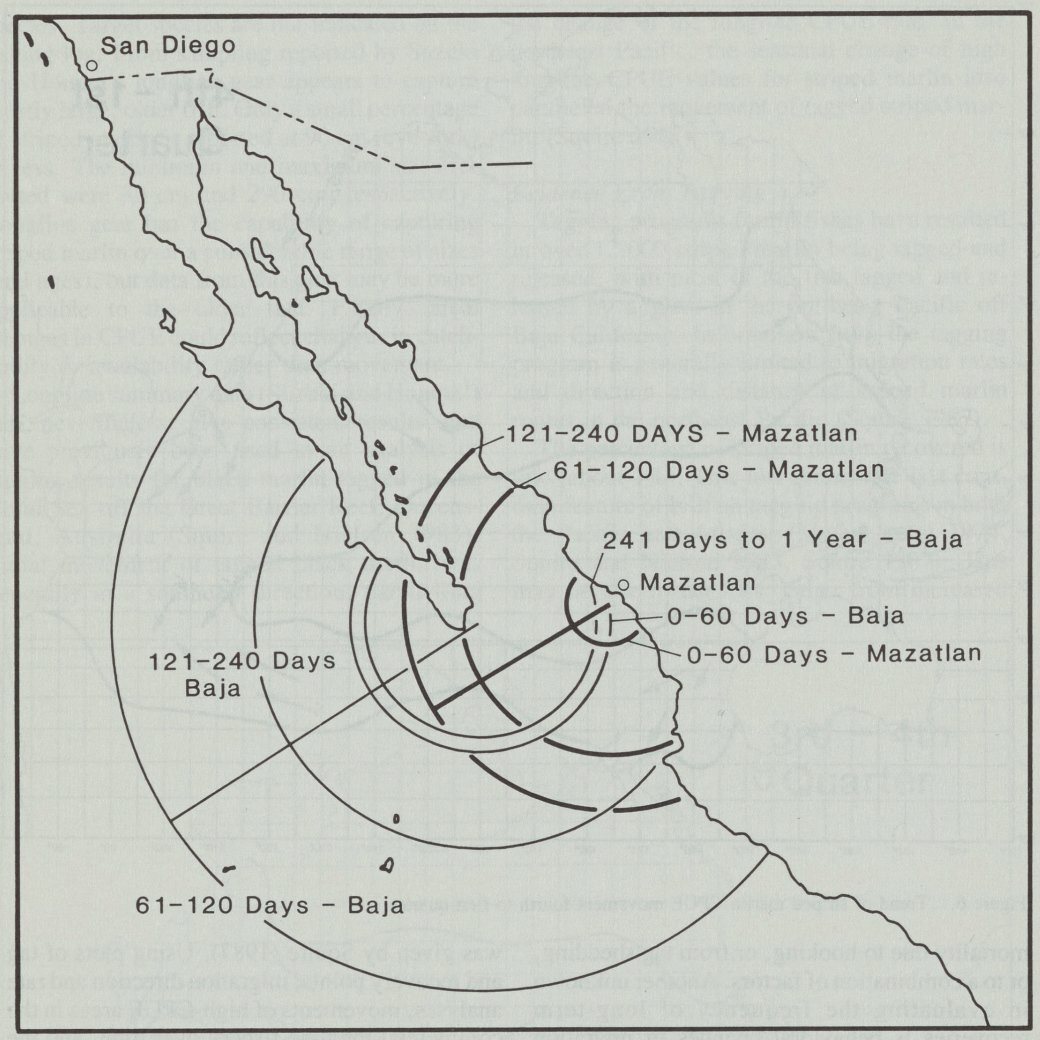

Figure 7. Average midpoint migration distances from tagging areas off Baja California Sur and Mazatlán to recapture points for time periods, tagging to recapture, 0-60, 61-120, 121-240, and 241 days to 1 year.

California tagging have been made to the southeast off Baja California, the most distant at 113°W long. by 20°S lat. Several recoveries have been made near the Hawaiian Islands, indicating that some movement is to both the north-central and southeastern Pacific from off southern California.

In January 1983, a striped marlin was reported tagged off Cabo San Lucas, Mexico, and was recovered near Norfolk Island, north of New Zealand, in September 1984. This fish was identified by the angler and charter boat captain at the time of tagging as a striped marlin; upon recapture, it was reported by the vessel's agent in New Zealand as a black marlin. The body and dorsal fin differences between a striped marlin and a blue marlin or black marlin are sufficient for identification at the time of tagging; therefore, this recovery was assumed to have been a striped marlin.

Further to examine the relationship of striped marlin tagged in the northeast Pacific to the remainder of the eastern Pacific population, the CPUE trend was compared over time between the major "target areas" for commercial and recreational fishing (and tagging) of striped marlin off Baja California (20°N lat. by 105° and 110°W long.) and the longline CPUE trend observed for the total eastern Pacific (east of 130°W long.). There is a good association be-

tween fluctuations in CPUE for the target area off Baja California (which accounts for about 23% of the striped marlin caught by the longline fleet in the eastern Pacific) and fluctuations in CPUE for the total eastern Pacific (Fig. 8). This indicates mixing between populations in the eastern Pacific at rates greater than suggested by tagging results for the Baja California area (Squire 1987). In studies of the Japanese longline fishery around Baja California, Squire and Au (1990) observed a rapid rebuilding of the striped marlin population following cessation of longline operations within Mexico's EEZ. This population increase was attributed to immigration from other areas of the Pacific into the major feeding and growth area in the northeast Pacific.

Evidence From Spawning Areas

Although spawning has been identified in the eastern Pacific by studies of gonad indices (Joseph et al 1974, Squire 1987), biological surveys to date have failed to identify this area as a major spawning location in the Pacific. The surveys include those by EASTROPAC, IATTC, and the billfish spawning surveys conducted south of Baja California, Mexico, in 1968 by the U.S. Fish and Wildlife Service.

Spawning in the western Pacific on the other hand has been well established through extensive collection of striped marlin larvae in the central and western Pacific (Ueyanagi 1959, 1974; Nishikawa et al 1985). Honma and Kamimura (1958) reviewed the southwest Pacific fishery for striped marlin and it was evident that the seasonal movement of the fishery is in positive relationship to the spawning season and area. In the eastern Pacific, tagging has indicated that striped marlin likewise tend to migrate rapidly southward of the southern tip of Baja California in the summer into an area of reported but unverified spawning (Squire 1987).

During the summer, larval and juvenile fish in the proposed spawning areas of the northeast Pacific should be carried to the west in the North Equatorial Current. Little is known of spawning in the southeast Pacific, although concentrations of striped marlin are evident there during the southern summer (5°-10°S × 100°-110°W). If this concentration is a spawning population, then the larvae and juveniles would drift westward in the South Equatorial Current.

Ueyanagi's (1974) and Nishikawa's (1985) larval distribution charts indicate that many larvae occur in the north-central to northwestern Pacific between the equator and 30°N latitude, and in the south Pacific between 10°S and 25°S

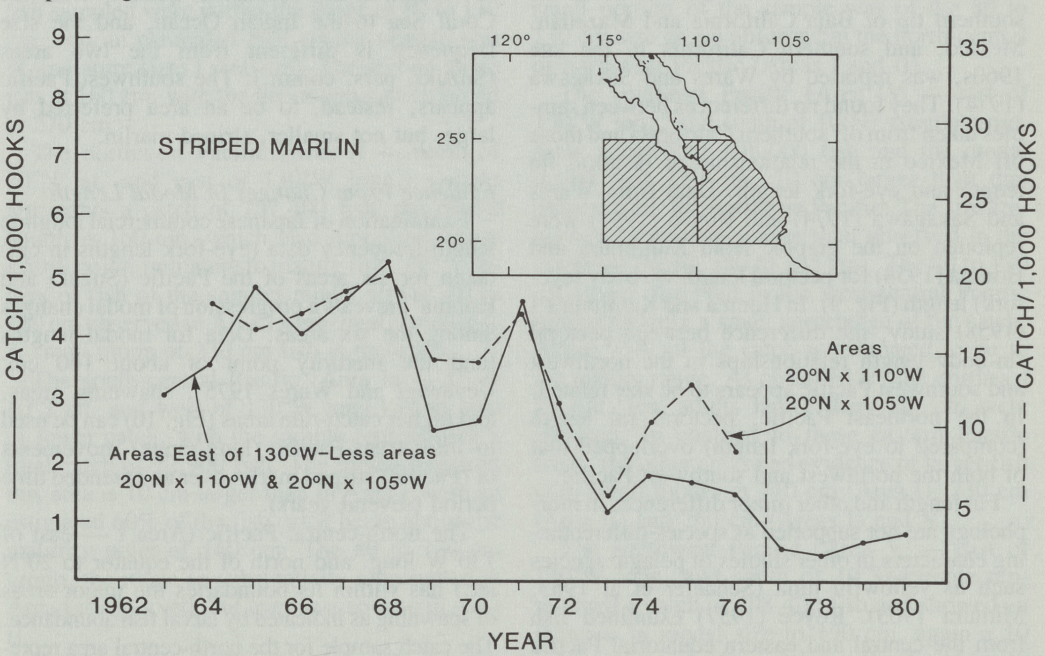

Figure 8. Comparison of CPUE trends for areas around Baja California (20°N × 105° and 110°W) and for the total eastern Pacific, less these areas.

latitude. No collections of larvae are reported east of 135°W longitude. During the summer, the current and larval drift there is westward in the North Equatorial Current, although some larvae and juveniles may drift to the east in the lower latitudes in the North Equatorial Countercurrent. In the southern hemisphere, spawning during the southern summer should result in larval and juvenile drift to the northwest.

Data from the fishery indicate that younger fish (<110 cm eye-fork) are concentrated in the north-central Pacific area, with lesser concentrations in the northwest and south central Pacific. These data, plus the dearth of larvae in the eastern Pacific — even when considering westward transport of larvae by the currents — suggest that mature fish are less likely to reside in the eastern Pacific.

Evidence From Biometrics

In 1956, Kamimura and Honma (1958) made a biometric comparison of the external characteristics of striped marlin from the north Pacific (30°-35°N) and the south Pacific (18°-25°S). Among five morphometric characters measured, a noticeable difference was observed only in pectoral fin length relative to the eye-fork length. Biological sampling (morphometrics) of striped marlin in the eastern Pacific, about the southern tip of Baja California and Mazatlan, Mexico, and southern California in the late 1960s, was reported by Wares and Sakagawa (1974). They found no differences between samples taken from off southern California and those off Mexico in the relationship of pectoral fin length and eye-fork length. Data from Wares and Sakagawa (1974) and Royce (1957) were replotted on the graphic from Kamimura and Honma (1958) for pectoral length vs. body (eye-fork) length (Fig. 9). In Honma and Kamimura's (1958) study, the difference between pectoral fin-body length relationships in the northwest and southwest Pacific appears to be size related. In the northeast Pacific, pectoral fin length (compared to eye-fork length) overlapped that of both the northwest and southwest Pacific.

Fin length and other minor differences in morphology are not supported as species-differentiating characters in other studies of pelagic species such as yellowfin tuna (Schaefer et al 1963, Mimura 1963). Royce (1957) examined fish from the central and eastern equatorial Pacific (Fig. 9). Wares and Sakagawa (1974), in reporting the findings of Kamimura and Honma (1958) and Royce (1957), concluded that there appears to be "mixing in the central Pacific of the presumed south and north stocks, of striped marlin, or Kamimura and Honma's samples did not adequately reflect the degree of variability in length of pectoral fin of fish from the north and south Pacific." It is possible that striped marlin exhibit allometric growth, and that the larger sizes have longer pectorals relative to eye-fork length. Data on pectoral fin lengths presented to date would indicate the possibility of a cline in the Pacific between the northwest and southwestern Pacific, with broad overlap into the eastern Pacific.

The concept of a stock cline seems appropriate for two reasons: the distributon of striped marlin in the Pacific is of a continuous "horseshoe shape" (north Pacific, eastern Pacific, and south Pacific); and the population in the northeast Pacific has characteristics that are representative of both the northwest and southwest Pacific (Wares and Sakagawa 1974). It appears unlikely, for reasons of proximity alone, that the southwestern population is distinct or separated from the remainder of the Pacific. However, it is possible that the population in the southwest Pacific is associated with the populations in the Indian Ocean, even though striped marlin are not caught in any substantial quantity from the Coral Sea to the Indian Ocean, and the size frequency is different from the two areas (Suzuki, pers. comm.). The southwest Pacific appears, instead, to be an area preferred by large, but not smaller, striped marlin.

Evidence From Changes In Modal Length

Examination of Japanese commercial longline length-frequency data (eye-fork lengths in cm) taken for six areas of the Pacific (Suzuki and Honma[1]) reveals a progression of modal changes among the six areas. Data for modal lengths (and the maturity point of about 160 cm; Ueyanagi and Wares 1975), spawning areas, and higher catch-rate areas (Fig. 10) can be used to infer trans-Pacific (long-range) movements of (Pacific) striped marlin over an extended time period (several years).

The north-central Pacific (Area I — east of 130°W long. and north of the equator to 20°N lat.) has within its boundaries the major areas of spawning as indicated by larval fish abundance. The catch sample for the north-central area represents 212,600 striped marlin. Only this area shows a bimodal frequency distribution with

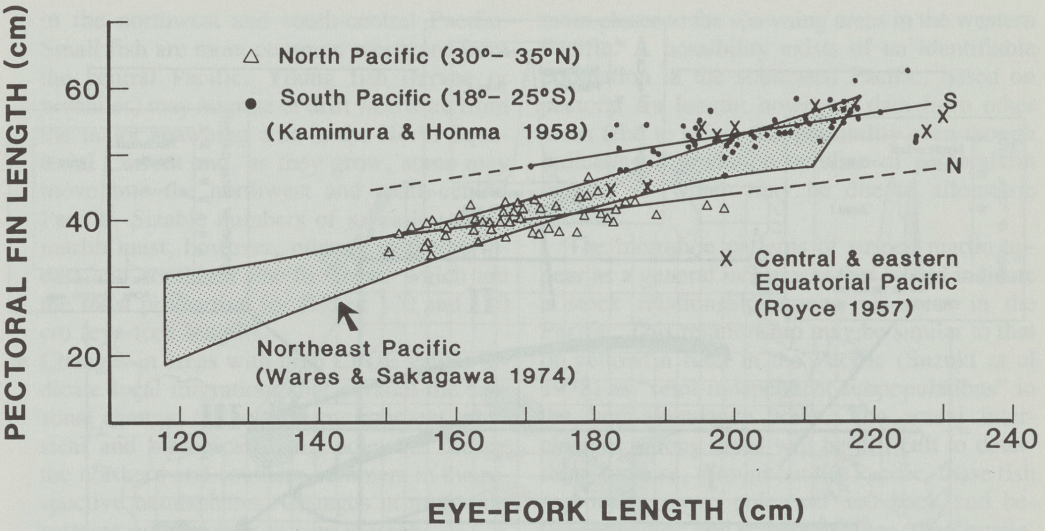

Figure 9. Relations between striped marlin pectoral fin length and body length in the north and south Pacific (Kamimura and Honma 1958), in the northeast Pacific (Wares and Sakagawa 1974), and in the central and eastern Equatorial Pacific (Royce 1957).

young fish (mode 110 cm) nearly equaling the abundance of older fish (mode 160 cm). The first mode at 110 cm (=10-18 kg fish) was composed of fish ranging in size from 80 to 130 cm, representing immature fish seldom observed in the other areas, except Area II and Area Ia to a lesser degree. Approximately 25% of the fish sampled were within the range of 80 to 130 cm, and an estimated 55% of the sample was of immature sizes (<160 cm). The second mode was at 160 cm, with the maximum size recorded at 270 cm.

The northwest Pacific (Area II — north of 20°N lat. and east of 130°W long.) sample represents a catch of 757,400 fish; the modal length is 160 cm, which also represents about a 50% point, immature to mature fish. The numbers of fish of the smaller modal size of 80 to 130 cm observed in Area I were greatly reduced. A small mode of 230 cm fish is recorded.

The south-central Pacific (Area Ia — 0° to 10°S lat. and west of 130°W long.) is an area of lower catch, with the sample representing a total catch of 22,900 fish. The modal length in this area is 10 cm larger than in Area I, with an estimated 60% of the fish catch being above the maturity point of 160 cm. The 80 to 130 cm group, the range so substantially represented in Area I is observed, but even less so than in Area II.

For the northeast Pacific (Area III — north of 10°N lat. and east of 130°W long.), the sample represents a catch of 611,900 fish and the modal size was 170 cm, 10 cm larger than that observed for the northwest Pacific (Area II). About 65% of the fish catch is within the mature range ≥160 cm), but fish under 95 cm and fish over 210 cm were not observed, making this area the most constricted in length-frequency range. Only a small portion of the sample was of the 80 to 130 cm size group observed in the north-central or northwest Pacific (Areas I and II).

The southeast Pacific (Area IV — east of 130°W long. and south of 10°N) sample represents a catch of 498,000 fish and the modal length was 180 cm, 10 cm larger than that observed for the northeast Pacific. The size frequency range was greater than observed in the northeast Pacific (80 to 265 cm). The 80 to 130 cm group observed in the west-central Pacific represents only a small percentage of the catch. About 75% of the catch is estimated to be in the mature range. As observed for the northeast Pacific, few adults larger than 210 cm were sampled. In contrast to these eastern Pacific areas, the other areas had evidence of larger fish with small modes at 210 cm (Area I), 230 cm (Area II) and 260 cm (Areas Ia and V).

The southwest Pacific (Area V — east of 130°W long. and south of 10°S) sample represented a catch of 498,400 fish and showed an increase in modal size to 190 cm, again a 10 cm increase over the southeast Pacific and a 20 cm increase over the south-central Pacific. Only

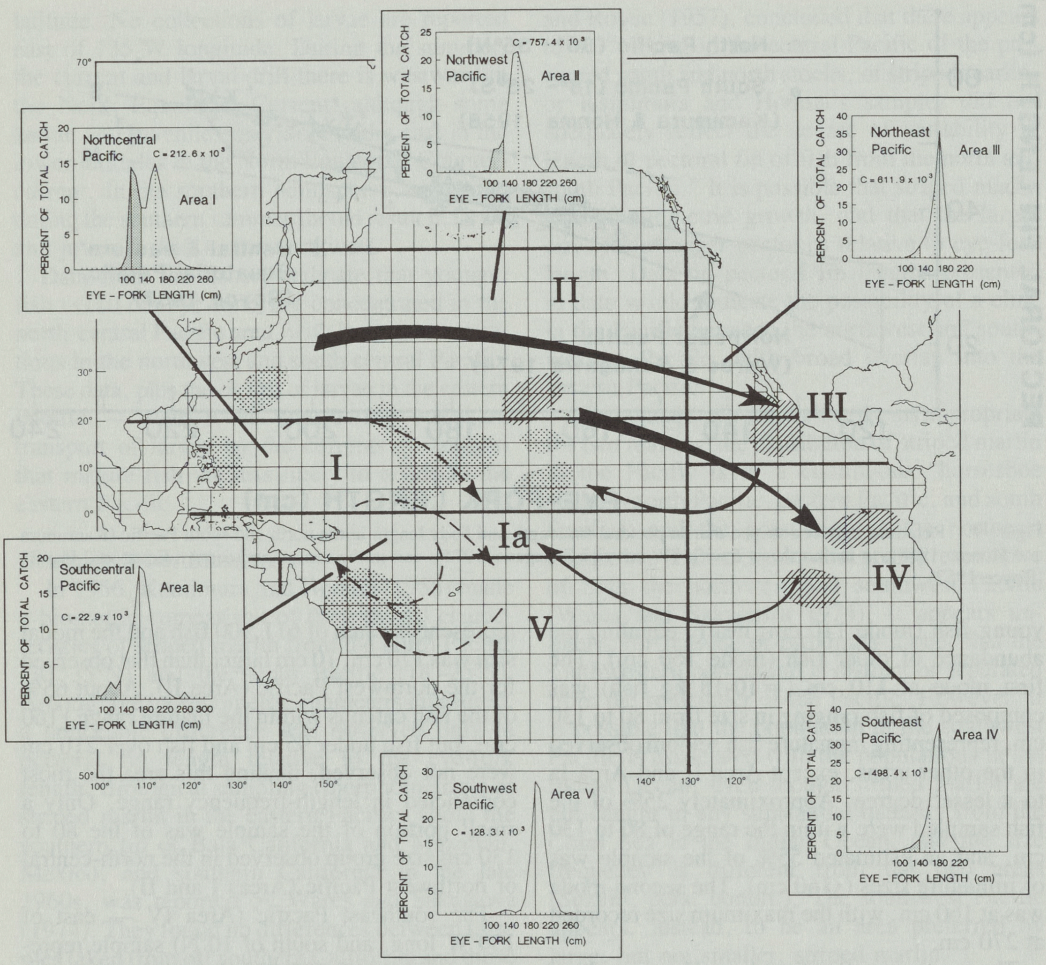

Figure 10. Distribution of length frequencies (eye-fork lengths) observed 1967-1973 in 6 areas of the Pacific Ocean, and a general scheme of movement. Heavy arrows indicate, for younger fish, the eastward clockwise movements for feeding and growth and the westward return to the spawning areas. Dashed arrows indicate similar movements of large, older fish. Movements of intermediate-aged fish would be intermediate between the patterns shown.

a small percentage of fish were observed in the 80 to 130 cm size and an estimated 85% of the fish were above the maturity breakpoint of 160 cm.

The increase in modal lengths from the north-central to northwestern and south-central, and from the northwestern to northeastern and south-eastern and to the southwest Pacific, would appear to be a reflection of the effects of long term defusive migration between the various geographical areas (Fig. 10.

Summary

From examination of the geographical locations of the major known spawning areas, the distribution of length-frequency modes, differences in morphometrics, and changes of high-CPUE areas in the commercial longline fishery, a generalized migration pattern can be hypothesized:

- The major spawning area is in the western Pacific (north-central to western). Some spawning may occur in the eastern Pacific but few larvae have been caught there. There is also spawning in the southwest Pacific. Only a small percentage of young fish is caught in the northeast, southeast, and southwest Pacific, whereas a large percentage of small fish are observed in the catch in the north-central Pacific; the percentage declines

in the northwest and south-central Pacific. Small fish are more common westward from the central Pacific. Young fish (larvae or juveniles) may migrate or drift westward from the major spawning area in the North Equatorial Current and, as they grow, some may move into the northwest and south-central Pacific. Sizable numbers of juvenile striped marlin must, however, migrate to the northeast and southeast Pacific areas, which are the most productive for fish of 170 and 180 cm (eye-fork length).

- Changes in areas with high CPUE values indicate local migrations that parallel the seasonal changes of the total environment (physical and biological); i.e., poleward during the northern and southern summers in the respective hemispheres. Changes in migration patterns with growth in size is likely.
- Modal shifts in eye-fork length can be observed from length-frequency data (Fig. 10), which indicate a shifting of individuals over time from the north-central to the northwest and south-central Pacific, and to the north and southeast Pacific, and then to the southwest Pacific. Modal data indicate that the north-central, northwestern, and south-central areas have populations of both old and young fish, while the northeastern and southeastern areas have intermediate-sized individuals.

In their publication on tunas and billfishes, Joseph et al (1979) describe tunas as "wandering fish," and this description could also be applied to striped marlin. From tagging evidence, however, striped marlin cannot be described as "highly migratory" in the sense that rapid trans-ocean migrations are as common as for such species as bluefin tuna *(Thunnus thynnus)* and albacore tuna *(Thunnus alalunga)*.

Evidence suggests that a net long-term movement occurs from areas having high percentages of smaller fish to areas with larger fish. The indicated long-term movement between the north-central Pacific, an area with small fish, to the southeast and northeast Pacific, and the movement of fish back to the west as they grow, appears to be slow. The larger sizes (>200 cm) are not present in the northeast and southeast Pacific, indicating that these areas are more important as feeding than as spawning areas for intermediate size fish. After a period of time in the eastern Pacific, the maturing fish probably wander back westward to the major spawning areas, and the larger sizes thereafter tend to remain closer to the spawning areas in the western Pacific. A possibility exists of an identifiable population in the southwest Pacific, based on pectoral fin length; however, data from other areas tend to refute this possibility even though indicating a gradation or cline of pectoral fin lengths — which may be due to allometric growth.

The migration patterns of striped marlin appear as a general movement that would indicate a stock relationship among all areas in the Pacific. This relationship may be similar to that of yellowfin tuna in the Pacific (Suzuki et al 1978) as "semi-independent subpopulations" in the high-abundance areas. The actual interchanges among areas will be difficult to determine because, throughout the Pacific, these fish seasonally move poleward and back and between feeding and spawning areas, their availability alternately increasing and decreasing in the geographical areas that are centers for feeding or spawning. Depending upon maturity and feeding conditions, some fish will range farther than others, and it is possible that most may move, in time, to most other areas of the Pacific. Overall movements, however, are diffusive over years rather than highly migratory, and this circumstance should permit management by "stocks."

Acknowledgement

The authors wish to recognize the assistance of Dr. David Au in the preparation of this paper. His perception of behavior characteristics of pelagic species has been of great help in preparation of this hypothesis of striped marlin migration.

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Activity Patterns of Striped Marlin in the Southern California Bight

David Holts and Dennis Bedford

The billfish resource along the west coast of Mexico and California is important to both commercial and recreational fisheries. In Mexico, the striped marlin *(Tetrapturus audax),* is taken in large quantities by commercial longline vessels and by recreational fishermen (Squire and Au 1989). In California, the striped marlin is considered to be among the most desirable of big-game fishes. Although not taken off California in numbers comparable to landings from Mexican waters, it nevertheless supports a very valuable recreational industry (Squire 1987a). In recognition of its value to California's sport fishing public, the striped marlin has been legally designated as a game fish for "sport only" utilization and cannot be taken or possessed by commercial fishermen, or imported into California fish markets. The California Department of Fish and Game (CDFG) has documented increased fishery interactions and conflicts in recent years between recreational and commercial fishermen. Tensions between recreational groups and the commercial fishing industry have increased with the expansion of the drift gill-net fisheries for thresher shark *(Alopias vulpinus)* and swordfish *(Xiphias gladius)* in the late 1970s and early 1980s (Beford and Hagerman 1983, Beford 1987).

Knowledge of striped marlin activity patterns, such as vertical and horizontal swimming patterns, variability of swimming speeds, and temperature-depth preferences, can provide fisheries managers with essential information needed for resolving user conflicts. Acoustic telemetry has been used to monitor the behavior patterns and physiological characteristics that influence habitat preference of large free-swimming pelagic fish (Holland et al 1986, Yuen 1970, Yuen et al 1974, Carey and Robison 1981, Carey and Olson 1981, Yonemori 1982). The current studies with striped marlin are, in part, designed to determine their behavior and vulnerability to various types of commercial and recreational fishing gears and to gain information on the availability of striped marlin off southern California. The correlation of behavioral patterns with various environmental parameters can also be valuable in stock assessment and distribution studies.

During September, 1982, biologists with the National Marine Fisheries Service (NMFS) succeeded in tagging with a sonic tag and tracking a striped marlin (SM82-1) for a period of 24 hours off the coast of southern California. Four years passed before another attempt was made. In 1986, the CDFG recognized the need for information on the behavior of striped marlin as part of studies concerned with incidental catches by the drift gill-net fishery for swordfish. A cooperative research project between the CDFG's Marine Resources Division and the NMFS' Southwest Fisheries Center's Pelagic Fisheries Resources Division was established in 1986 to track striped marlin off southern California. During the summers of 1986 and 1987, ten striped marlin were tagged with sonic transmitting tags and their movements tracked. Results of this project to date are reported herein.

Methods

The tracking vessel was the 59-foot sport fishing boat, *"Pacific Clipper,"* under contract to the CDFG. It accommodated a scientific crew of up to six, with ample space for fishing,

tagging, and tracking equipment. Our tagging and tracking equipment consisted of Vemco* V4P sonic transmitter tags, CS-40 directional hydrophone and a VR-60 receiver-decoder, all similar to that described by Holland et al (1986).

The depth transmitters came in two full-scale pressure ranges of 0 to 100 psi and 0 to 1,000 psi. Depth sensitivity was subject to 2 percent error at full scale. The 1,000 psi tags were used initially, until we established that striped marlin tended to stay in the upper portion of the water column. Output frequencies were set at 29.00 and 34.00 kHz; anticipated battery life was 7 to 14 days, depending on the depth of the fish. The transmitted signal was received through a directional hydrophone, bolted to a rotatable shaft, and was attached to a control motor which turned the hydrophone up to 180 degrees in either direction. This assembly was mounted amidships on the starboard side of the vessel's hull. The rotational control unit for the hydrophone was operated from inside the cabin. A plastic PVC faring was mounted over the hydrophone to reduce external noise while underway at speeds of up to 6 knots.

The receiver digitized the telemetered pulses and stored both time and depth data for later transfer to a computer. The receiver's audible signal was recorded on cassette data tapes as a back up in case any problems ocurred with the internal data storage memory. The strength of the signal received was used to estimate the distance to the target, thus allowing the tracking team to maintain a desired distance from the tagged fish. We estimate our normal operating distance from the fish was approximately 200 to 400 m (650 to 1,300 ft) and our maximum range from which we could receive the signal was about 800 m (2,600 ft).

During tracking, the vessel's location was recorded at 15 minute intervals through the use of Loran-C. Since the distance from the vessel to the fish was routinely kept under 400 m (1,300 ft), the location of the vessel was assumed to be the same as the fish.

During tracking, XBT (expendable bathythermograph) casts were taken to obtain water temperature profiles at intervals of approximately 6 hours.

Fishing and tracking operations were conducted in the most promising areas as determined by daily angler success rates. Cruise dates were scheduled to coincide with recreational marlin tournaments whenever possible. Sport fishing clubs and tournament organizers were asked for assistance in catching marlin for tagging. All but two of the fish were caught and donated by sport fishermen.

When an angler notified the *"Pacific Clipper"* that a fish was hooked-up, and would be donated, a course and distance to the donor vessel was plotted. If we could reach the donor vessel in the time it would take to bring the marlin alongside the catcher vessel we would proceed at top cruising speed to that location. Once alongside, a tagging team would be sent by rubber raft to board the donor vessel and tag and release the fish. The weight of each fish was estiamted at the time of release.

Results

In all, 11 striped marlin were tagged and tracked (including the fish tracked in 1982; SM82-1). Three of the marlin were tracked for less than 5 hours and eight were tracked from 20 to 48 hours (Table 1). Only those tracks with durations of 20 hours and longer are included in the analysis. Marlin tracks lasting 20 hours

Table 1. Tagging and tracking statistics for 11 striped marlin.

Fish	Date	Weight (estimated) kg	Location	Time tracked hrs	Distance traveled nm	dir	Donated by skipper
SM82-1	9/22/82	55	425 spot	24	24	WSW	NMFS
SM86-1	9/27/86	50	Avalon	24	37	S	H. Sutton
SM86-2	10/01/86	55	Mackerel Bank	3	5.5	S	—
SM87-1	9/13/87	50	East of Slide	3.5	4	E	G. Stotesbury
SM87-2	9/16/87	70	East of Slide	20	22	SE	NMFS/CDFG
SM87-3	9/17/87	70	East of Slide	48	57	SE	J. Belus
SM87-4	9/25/87	55	14-mile Bank	24.5	31	E	W. Woodard
SM87-5	10/02/87	80	267 spot	30.5	44	S	G. Jasper
SM87-6	10/04/87	—	267 spot	24	23	NW	G. Jasper
SM87-7	10/17/87	—	267 spot	4.5	6	SW	D. Denholm
SM87-8	10/19/87	65	Dana Point	24.5	16	S	R. Rafkin

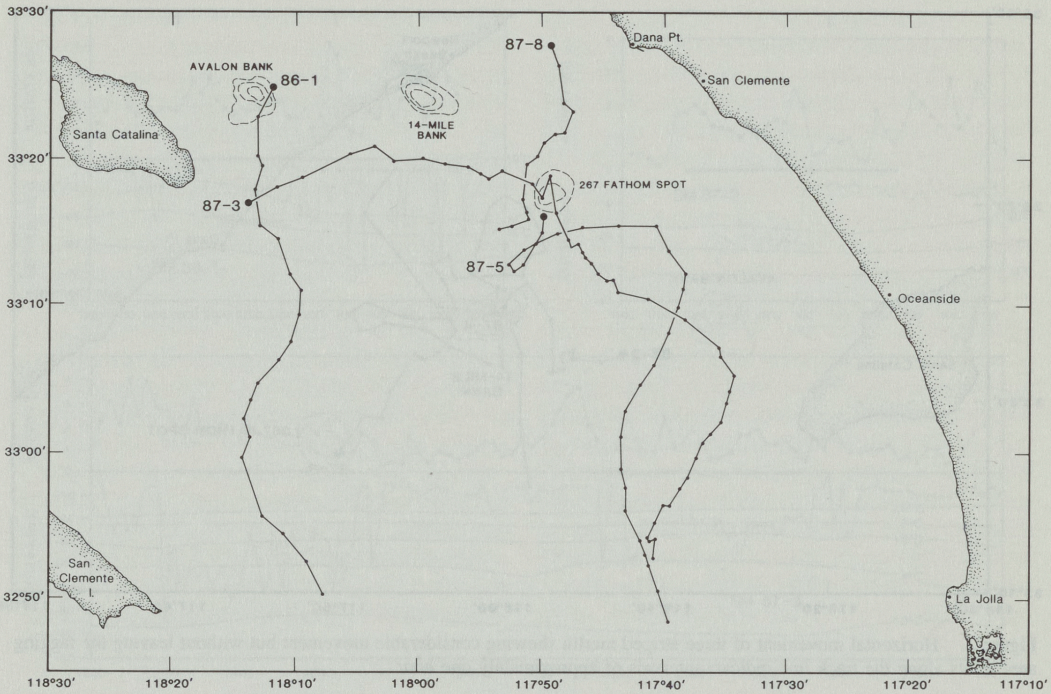

Figure 1. Horizontal movement of four striped marlin generally showing a predominant movement away from the tagging area and in a southward direction. Dots along the track lines indicate intervals of approximately one hour.

or more totaled 219.5 hours and covered 258 nautical miles within the southern California Bight (Figs. 1 and 2). Individual activity and depth profiles for seven of the striped marlin tracked are shown in Figure 3.

Summary of Striped Marlin Tracks

SM82-1. This 55-kg (120 lb) fish was caught on an artificial lure trolled from the tracking vessel 28 miles southwest of Point Loma, San Diego, on September 22, 1982. This marlin was brought to the vessel in 23 minutes, tagged just below the dorsal fin, and released at 1130 hrs in excellent condition. It immediately descended to 25 m (80 ft) and moved north 1.5 nm in the next hour. The fish continued traveling north at a depth of 8 to 10 m (26 to 32 ft) for three more hours. It became relatively inactive at sunset, until shortly after 2100 hrs when it made a short dive to 30 m (100 ft) and began moving west to southwest at about 1.0 knot (kt). The fish stayed at 5 to 10 m (16 to 32 ft) and continued in the same westward direction for the next 17 hours. It made four dives to at least 35 m (104 ft) between midnight and sunrise. The fish traveled an average of 1.0 kts while moving 24 nm in the 24-hour track. Its maximum speed was recorded at 2.0 kts during the midmorning hours. The fish remained in 21°C (70°F) water throughout most of the track. Nearly 86% of the tracking time was spent in the well-mixed surface water above 10 m (32 ft). Its deepest dive to 75 m (244 ft) occurred just after 0200 hrs. The temperature was 12.5°C (54.5°F). Only 3% of the tracking time was spent below 40 m (130 ft).

SM86-1. This 50-kg (110 lb) marlin was caught September 27, 1986, on an artificial lure and donated to our research by a tournament participant. It was tagged and released in good condition at 1230 hrs on the Avalon Bank, located six miles east of Avalon, Santa Catalina Island. This fish remained within 5 m (16 ft) of the surface as it began moving south. The fish continued south for 37 nm at an average speed of 1.5 kts, varying between 0.5 and 3.5 kts. Just after sunset, this marlin descended to 20 m (65 ft) and maintained that depth for 6 hours. Between 0100 and 0400 hrs it made a series of dives between 5 and 30 m (16 and 98 ft). It spent 63% of the tracking period at or above 12 m (39 ft). During the daylight hours, only 10% of its time was below 12 m (39 ft). During nighttime hours, it spent nearly 80% of the time

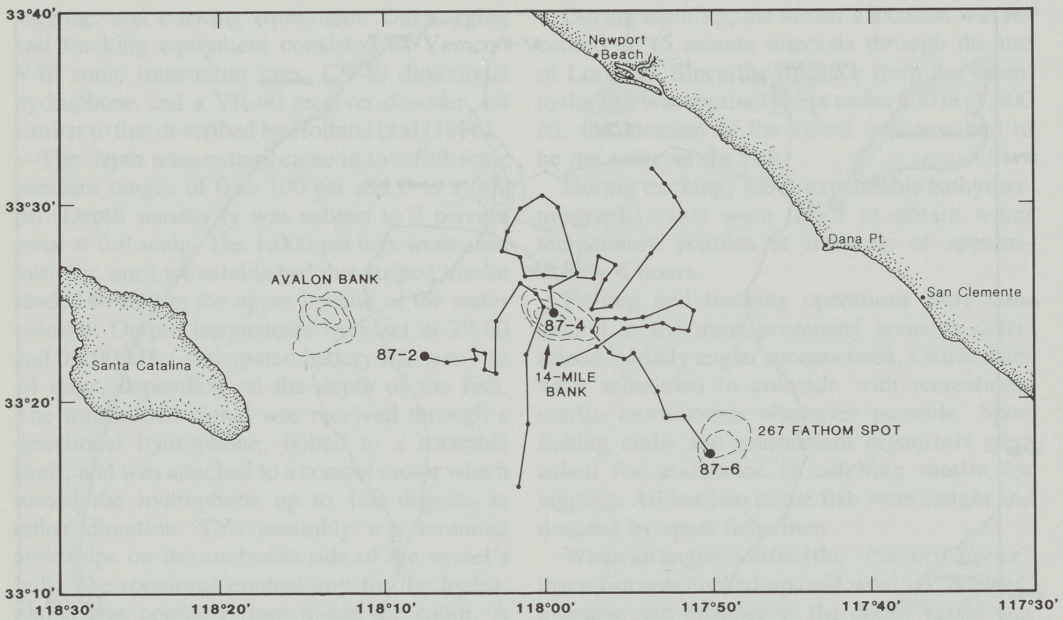

Figure 2. Horizontal movement of three striped marlin showing considerable movement but without leaving the tagging area. Dots along the track line indicate intervals of approximately one hour.

below 12 m (39 ft), with four short descents below 40 m (130 ft). The period of least movement occurred between the hours of 0400 and 0700, although it made two short dives to 40 m (130 ft). The fastest sustained speed was 2.0 and 3.5 kts during the last 6 hours of the track.

SM86-2. This 55-kg (121-lb) fish was tagged and released near the west end of San Clemente Island at 1100 hrs on August 1, 1986. It was tracked for only 13 hours, when the signal was lost due to a damaged hydrophone wire. Replacement of the defective hydrophone took approximately 30 minutes, but efforts to relocate the fish were unsuccessful. This striped marlin traveled 5.5 nm in a southward direction and stayed very near the surface during the tracking period.

SM87-1. This 50-kg (110-lb) fish was donated by a tournament participant and tagged and released off the east end of Catalina Island at 1143 hrs, September 13, 1987. This fish was exhausted when released but otherwise in good condition. It was tracked for just over 3 hours in an eastern direction before it was lost due to a malfunctioning hydrophone. The average speed was 1.2 kts over the period.

SM87-2. This 70-kg (155-lb) marlin was caught on a jig trolled behind the tracking vessel, and was tagged and released in good condition at 1530 hrs near the east end of Catalina Island on September 16, 1987. It was tracked for 22 nm over the next 20 hours. For the first 2 hours of the track it remained within 1 mile from the point of release at a depth of 10 m (33 ft). It then began moving east by northeast at about 1 kt, at a depth varying between 20 and 33 m (65 and 107 ft). Between midnight and sunrise, it passed slowly (0.6 kts) over the top of the "14-Mile Bank," also known as Lasuen Knoll, at a depth of 10 m (33 ft). It turned south in the early morning and maintained 2.3 kts for over 2 hours. Its deepest dive was to 55 m (180 ft) just after sunset. It spent 100% of its daytime hours in the mixed layer, but only 61% of its nighttime hours were in the mixed layer.

This marlin was observed twice during the track. It was seen jumping or "greyhounding" just 4 hours after release, presumably in an attempt to shake the tag off its back. At 1100 hrs the following morning, we observed the fish actively feeding on surface schools of anchovies for over 20 minutes. The fish began swimming south after feeding. The track had to be terminated when the fish entered a military restricted zone.

SM87-3. This 70-kg (154 lb) marlin was donated by a tournament participant 3 miles off the east end of Catalina Island. It was released

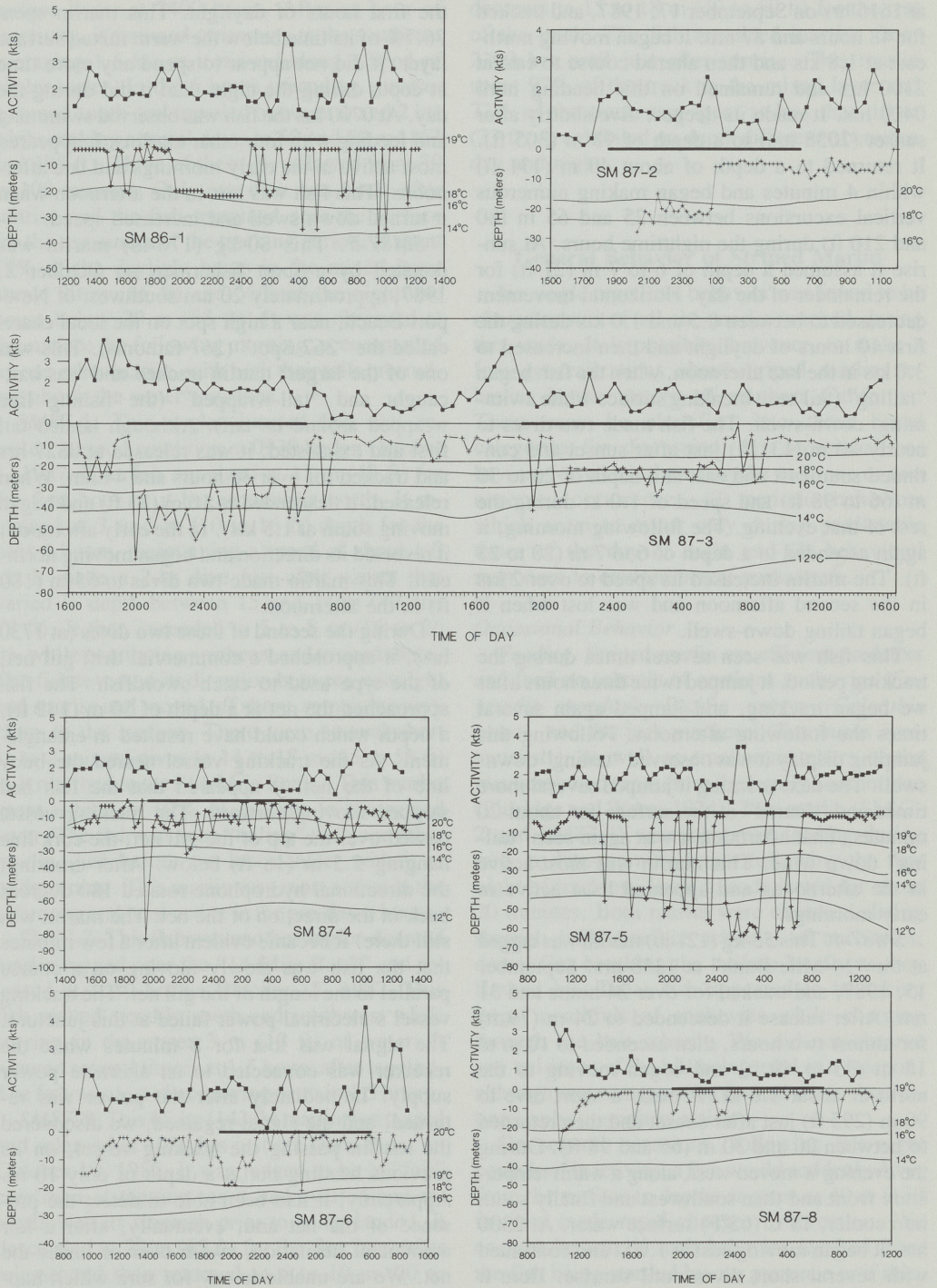

Figure 3. Activity and depth profiles for seven striped marlin tracked at least 20 hours. Activity data (knots) were taken from position data every 15 minutes and smoothed with a running average over 45-minute periods. Depth data were likewise smoothed over 15-minute periods to accommodate computer graphics and may not indicate precise depths attained by individual fish.

at 1615 hrs on September 17, 1987, and tracked for 48 hours and 57 nm. It began moving northeast at 1.8 kts and then altered course to east at 2100 hrs and remained on this heading until 0400 hrs. It made its deepest dive shortly after sunset (2038 hrs) to a depth of 93 m (305 ft). It returned to a depth of about 40 m (131 ft) within 4 minutes and began making numerous vertical excursions between 25 and 65 m (80 and 210 ft) during the nighttime hours. At sunrise it assumed a depth of 6 to 7 m (21 ft) for the remainder of the day. Horizontal movement decreased to between 0.5 and 1.0 kts during the first 10 hours of daylight and then increased to 3.0 kts in the late afternoon, when the fish began "tailing" (tail seen breaking surface while swimming) down-swell. The fish made two dives to nearly 40 m (131 ft) just after sunset and continued southeast and east at a depth of 20 to 30 m (66 to 98 ft) and speed of 1.0 kt during the rest of that evening. The following morning, it again ascended to a depth of 6 to 7 m (20 to 23 ft). The marlin increased its speed to over 2 kts in the second afternoon and was lost when it began tailing down-swell.

This fish was seen several times during the tracking period. It jumped twice three hours after we began tracking, and jumped again several times the following afternoon. Following this jumping display it was observed "tailing" down-swell. The next morning it jumped several more times and "finned" at the surface for about 20 minutes. That afternoon it was again seen "tailing" down wind. This marlin was most active in the afternoons and appeared least active in early mornings.

SM87-4. This 55-kg (121 lb) marlin was tagged at the "14-Mile Bank" at 1358 hrs, September 15, 1987, and tracked for over 24 hours and 31 nm. After release it descended to 24 m (79 ft) for almost two hours, then ascended to 10 m to 15 m (33 to 49 ft) and began moving to the north at about 1.0 kt. It made a short dive to 90 m (295 ft) just after sunset and then returned to between 20 and 30 m (66 and 98 ft). During the evening it moved west, along a warm temperature front and then southwest and finally south into cooler, 18°C (65°F) surface water. At 2300 hrs, it began moving east at 1.0 kt and continued with several short dives until sunrise. Here it remained inactive for an hour and then proceeded north in the warmer surface waters and within 3 nm of the beach. The time spent between 20 to 30 m (66 to 98 ft) increased during the first hours of daylight. This marlin spent 76.7% of its time below the warm mixed surface layer. It did not appear to spend any more time at depth during the night than it did during the day. At 0700 hrs the fish was observed swimming and feeding with four other marlins. It appeared most active in the early mornings and late afternoons. This fish was lost in the afternoon when it turned down-swell and increased speed.

SM87-5. This 80-kg (176-lb) marlin was donated by a sport fishermen on October 2, 1987, approximately 20 nm southwest of Newport Beach, near a high spot on the local charts called the "267 Spot" (267 fathoms). This was one of the largest marlin tracked and was bait-caught and "tail-wrapped" (the fishing line wrapped around its tail). Although landed tail first and exhausted, it was released at 0827 hrs and tracked for over 30 hours and 44 nm. When released, it descended to 10 m (33 ft) and began moving south at 1.5 kts). In the early afternoon, it reversed its direction and began moving northeast. This marlin made two dives to 55 m (180 ft) in the afternoon.

During the second of these two dives (at 1730 hrs), it approached a commercial drift gill net, of the type used to catch swordfish. The fish approached the net at a depth of 50 m (162 ft), a depth which could have resulted in entanglement. As the tracking vessel neared the buoy line of the net, it appeared that the fish had stopped moving forward. The tracking vessel passed over the top of the gill net, the cork line hanging 5.5 m (18 ft) below. After crossing, the directional hydrophone rotated 180 degrees back in the direction of the net. The marlin was still there. It became evident after a few minutes that the fish was slowly moving on a course parallel to the length of the gill net. The tracking vessel's electrical power failed at this juncture. The signal was lost for 8 minutes while the receiver was connected to an alternate power supply. Immediately after the power was returned, and the signal regained, we discovered the marlin passing the tracking vessel, on its previous heading but at a depth of only 10 m. Apparently, it had been able to detect the presence of the net and, eventually, after a fair amount of hesitation, swam over or under the net. We are unable to say for sure which happened, as the signal and fish were lost during this critical period.

The marlin turned east at sunset and maintained a speed of 2 kts until it encountered cooler

surface water at 2400 hours. After an hour of inactivity, it resumed swimming to the southeast averaging 1.6 kts as it moved along a band of cooler water. In the 4 hours preceding sunrise, it turned south and traveled between 1 and 2 kts while making several dives to 50 and 60 m (163 and 195 ft). Three of these dives lasted from 30 to 100 minutes. Only one dive was made after sunrise and the fish remained near the surface for the remainder of the tracking period. It spent 79% of the daylight hours in the mixed layer above 20 m (65 ft) and 56% of the nighttime hours below 20 m (65 ft). It was observed at the surface the following morning, accompanied by one other marlin, with both their tails protruding above the water's surface.

SM87-6. This angler-donated fish was released in good condition at 0930 hrs on October 4, 1987. The fish remained at 13 m (42 ft) for the first hour as it began moving north. It remained at 3 to 5 m (10 to 16 ft) depth for the next 4 hours, maintaining a speed of about 1.0 kt. It made a 2-hr dive just after sunset that varied in depth between 15 and 24 m (49 and 78 ft). It then ascended to 5 to 8 m (16 to 26 ft), while continuing northeast and toward shore. The fish reversed its direction between midnight and sunrise and moved off shore, remaining very close to the surface. There were several short 1- to 2-minute dives to 14 to 18 m (45 to 58 ft) as it returned to the "14-Mile Bank." This marlin spent a total of 97% of its time in the mixed layer. The fish was seen "tailing" with one other marlin, just before we lost contact with it at midmorning. This marlin was most active in the afternoon and least active in the pre-dawn hours.

SM87-7. This fish was another angler-donated marlin tagged near the "14-Mile Bank" and released at 1030 hrs on October 17, 1987. This fish moved steadily south and southwest while staying in the upper 3 m (10 ft) of water. It jumped several times, at 1.5 hours after tagging. The fish was lost after moving 6 nm in 4.5 hours.

SM87-8. This 65-kg (143 lb) marlin was tagged and released at 1020 hrs just off Dana Point on October 19, 1987. It was judged to be in "fair" condition at tagging, as it had everted and reswallowed its stomach prior to being landed. It descended to 20 m (65 ft) for the first hour after release and then returned to 6 to 10 m (20 to 33 ft) for the following 2 hours, all the while moving at 1.4 kts to the south-southwest. Turning south at 1500 hrs, it continued at 1.0 kt and a depth of 2 to 4 m (6 to 10 ft) with occasional descents to 15 to 18 m (49 to 59 ft) for the rest of the track. The fish remained inactive from 2300 hrs until just after sunrise. This marlin spent 97% of the track in the mixed layer and 77% of the track was spent at less than 10 m (33 ft). It exhibited no depth difference between day and night.

General Behavior of Striped Marlin

No single repetitive behavior was found to be characteristic of all the marlin tracked during this study. It is possible, however, to make a few generalizations about striped marlin behavior in the waters off southern California. These may be classified into three broad categories for discussion: (1) occasional behaviors for which there may be only one or two observed occurrences, (2) periodic behaviors which seem to occur only during predictable times of the day or night and (3) behavioral responses to environmental parameters.

Occasional Behavior

Feeding. Striped marlin are efficient predators and feed on schools of northern anchovies *(Engraulis mordax),* Pacific saurys *(Cololabis saira),* and the jack mackerel *(Trachurus symmetricus),* as well as smaller members of the mackerels and tunas from the family Scombridae (Eldridge and Wares 1974). Two marlin (SM87-2 and SM87-4) were observed feeding during mid- to late-morning hours following the first night of tracking. Each episode lasted for about 20 minutes. Both marlin were observed slicing through balls (surface schools) of anchovies, dorsal fins breaking the surface briefly as they flashed by. These fish appeared to be taking large mouthfuls of anchovies while charging through the bait schools. We did not observe any evidence of the bill being used as a weapon, although our vantage point limited these observations only to surface activity.

On several occasions, following late-night periods of inactivity, a fish would suddenly dive, from the surface to depths as great as 40 m (130 ft), and made rapid changes in direction. We can not be sure if such behavior resulted from the fish being startled by our presence or if this, too, could have been actual feeding. Since none of these fish were subsequently recovered for examination of stomach content, we are left to speculate as to the true nature of this behavior.

Periodic Behaviors

Breezing. On several occasions we observed a behavior from both tagged and non-tagged marlin which has been described by fishermen as "breezing" or "tailing." The first name is derived from the fact that this behavior seems to occur only when the wind is blowing, usually in the afternoon. In the Southern California Bight there usually is an onshore breeze in the afternoon during the summer. The second name describes what the observer actually sees as the fish swims by.

During the afternoon breeze, marlin can be seen swimming rapidly down-wind and down-swell. This is characterized by significantly increased speed and a change in direction to correspond roughly to the wind direction. The fish can be seen swimming down-swell at the leading edge of a wind wave, with the upper portions of their caudal fins protruding from the water. While they can only be seen gliding down-swell for up to a couple minutes at a time, this activity may continue for as long as 4 hours and include occasional dives to 20 m (SM86-1 and SM87-5). Swimming speeds as great as 5 or 6 kts may be sustained for short periods. Not coincidentally, most of the tagged fish which evaded our tracking efforts were lost during this activity. A miscalculation of distance from the fish, or a wrong turn, provided the crew with little time to recognize and correct the error before the fish was no longer within signal range.

Sleeping. During the late night and early morning hours, including the period just after sunrise, some fish went through periods of inactivity which we termed "sleeping" behavior. This is characterized by little or no horizontal movement or vertical excursions beyond 5 to 10 m. During these periods, lasting from one to several hours, the fish would remain motionless, just below the surface of the water. Occasionally at sunrise, the tail and dorsal fin could be seen on non-tagged marlin as well as the tagged fish. All fish displayed some slowing of activity during the night hours, although not all fish went through periods of complete inactivity. One fish (SM87-3) exhibited this behavior between 0800 and 1200 hrs, an exception to the time this behavior was generally observed. One other fish exhibited a marginal form of this behavior. Marlin SM87-4 reduced its activity for 4 hours but made three vertical dives to at least 30 m (98 ft) during the period.

Social behavior. Small aggregations of marlin were observed displaying the behavior we previously described as "sleeping." We noted such aggregations during fishing operations, and on two occasions the tagged marlin joined other non-tagged marlin, forming a small group. Once, while we were tracking it, SM87-4 was joined by three other marlin. Several groups of up to 10 marlin were observed with the tagged marlin. SM87-5 was also joined by one other marlin at 0800 hrs the morning after tagging. While such gatherings were observed only during these early morning "sleeping" episodes, or afternoon breezing activity, commercial swordfish spotter pilots have reported that large groups of striped marlin are often seen just below the surface during mid-day, as well.

Environmental Responses

Horizontal displacement. The horizontal movements of striped marlin in this study fall into two groups. There were those that left the area following tagging (Fig. 1), and others that remained in the same general locality where they were first captured (Fig. 2). Five of the eight fished tracked for 20 hours or longer left the area, swimming on a heading ranging from southeast to southwest. The other three marlin followed paths which reversed course or even crossed over a previous track. We did not find, within our study period, that season played any role in predicting whether a fish would leave the area, although the general movement of all fish in a southward direction suggests that migration may play a role.

Relatively large distances were covered, in all cases, considering the time intervals, ranging from 16 nm to 57 nm. The average speed for all tracked marlin was 1.24 kts and the individual average ranged between 0.75 and 1.54 kts. This compares favorably with the top speed, 1.07 kts, reported by Squire (1987b) for striped marlin tagged with conventional tags off southern California, and recovered between 0 and 60 days later. The eight marlin tracked over 20 hours spent an average of 28% of track time at a speed of less than 1 kt and 17% of their time over 2 kts. None was tracked at greater than 3 kts for more than one hour. The highest speeds were generally recorded between sunrise and noon just before sunset. None had speeds greater than 2 kts during the dark. The hours from midnight to dawn were usually the hours of least activity (Fig. 4).

Marlin SM87-8 was the least active (released

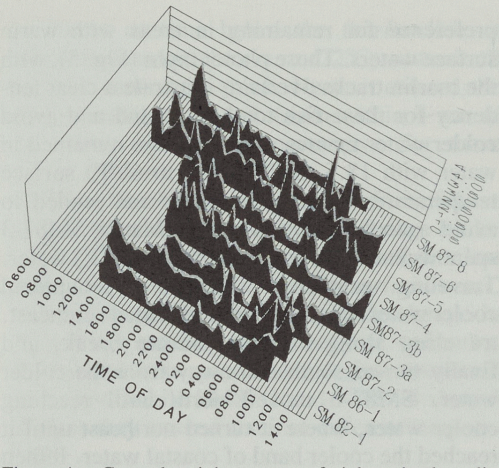

Figure 4. General activity pattern of eight striped marlin tracked for greater than 20 hours. The track of SM87-3 has been split into two 24-hour sections.

in fair condition) and spent nearly half of the tracking time at less than 1 kt and only 6% at greater than 2 kts. By contrast, marlin SM87-5, released in good condition, spent 40% of its time swimming in excess of 2 kts.

Depth preferences. Striped marlin off southern California are surface fishes, i.e., they spend all of their time in the upper, light-penetrating zone. This observation applies despite the fact that they are normally found only in the deep clear offshore waters, where the depth ranges between 400 and 2,000 m (1,300 and 12,000 ft). The greatest depth recorded by a marlin in our study was 93 m (305 ft). This was a short duration dive by SM87-3 and occurred just after sunset on the first tracking day. The second deepest dive was to 90 m (295 ft) by SM87-4. Like SM87-3, this dive occurred just after sunset and lasted only a few minutes.

Few marlin in our study descended to such depths. Marlins SM87-2, SM87-6, SM87-8 spent their entire tracking period in less than 40 m (131 ft). Four marlin (SM86-1, SM87-2, SM87-3 and SM87-5) spent their nighttime hours at significantly ($a = .01$, Kolmogorov-Smirnov) greater depths than their daytime hours. These fish modified their depths just after sunset. All four descended to depths approximately two to two-and-one half times their daytime depths. Marlin SM87-3 and SM87-5 returned to within 10 m of the surface at sunrise, but SM87-2 returned to near the surface at 0100 hrs and maintained that depth throughout the remainder of the tracking period. Marlin SM87-5 exhibited a pattern of extended deep dives during the hours of darkness that was not observed in the others. One particular dive to 70 m (230 ft) lasted 2.5 hours.

This pattern of descending to somewhat deeper depths during the nighttime hours has not been reported from other tracking studies and seems contrary to studies involving swordfish *(Xiphias gladius)* (Carey and Robison 1981), yellowfin tuna *(Thunnus albacares)* (Yonemori 1982), and skipjack tuna *(Katsuwonus pelamis)* (Yuen 1970). In these studies, the fish spent greater portions of time at depth during the day than at night.

Temperature preferences. Striped marlin are predominantly surface swimming fish and treat the thermocline break as a hindrance to vertical movements. Three of our marlin (SM82-1, SM87-6, and SM87-8) spent only 2.9% to 6% of their time below the thermocline. Others (SM87-3 and SM87-5) showed less reluctance to enter the cooler waters below the thermocline and spent from 25.3% to 76.7% of their time below the mixed layer. Dives from the mixed layer to below the steepest portion of the thermocline's temperature gradient were typically of short duration and quite abrupt. The coldest temperature reached was recorded by SM87-3 (also SM87-5) at 10°C (50%), although the time it spent in this 10°C water was less than 3 minutes. This fish spent about half of its 48-hour track in the mixed layer and half below it in water from 14 to 19°C (57 to 66°F). Of the daytime hours, 88% of the time was spent in the mixed layer, whereas only 9% of the nighttime was spent above the thermocline. Marlin SM87-4 spent more time below the mixed layer (76.6%) than any of the others. This was a particularly warm and sunny period and surface temperatures reached 22°C with a shallow 13 m thermocline. A total of 42.1% of the tracking period was spent at 16 to 19°C (61 to 66°F). Marlin SM87-5 spent 54% of its tracking time below the mixed layer. Four hours of this time was spent at temperatures between 10 and 12°C (50 to 54°F) indicating that striped marlin are capable of tolerating cold temperatures for extended periods.

There is, as discussed earlier, a difference between observed depth at night and that of the daytime. These marlin spent daylight hours at and near the surface with only short and infrequent excursions into and below the thermocline. During nighttime hours a greater amount of time was spent in and below the steepest part

of the thermocline. Soon after sunset these fish descended to the thermocline and began making more numerous excursions between the surface and 50 to 70 m. They spent from 50% to 100% of the daytime in the mixed layer, compared to only 13% to 66% time at night. Two marlin, SM87-6 and SM87-8, spent 97% of the time in the mixed layer with no statistical difference between day and night. Temperature data for SM82-1 were insufficient for inclusion.

Sea-surface temperature. Satellite imagery of sea-surface temperatures was available for six of the marlin tracks. These photographs provide evidence of a strong surface temperature influence on horizontal movements of the fish. Just as the fish in this study showed a reluctance to spend much time in the colder water below the thermocline, they demonstrated an even greater preference for remaining in areas with warm surface waters. These photographs (Fig. 5), with the marlin tracks overlaid, illustrate a clear tendency for these fish to skirt around and avoid colder water masses. These marlin remained in water with 18.5 to 20°C (65 to 68°F) surface temperatures most of the time and tended to avoid a cooler body of water. Marlin SM87-3 spent its entire 48-hour track in the 20°C) water. Traveling northeast, SM87-5 encountered cooler water near the coast and turned southeast, traveling along the temperature break, and finally turned south and away from the colder water. SM87-6 moved north until reaching cooler water, where it turned northeast until it reached the cooler band of coastal water. It then turned south and then west to remain in the warm water. Although marlin SM87-4 spent

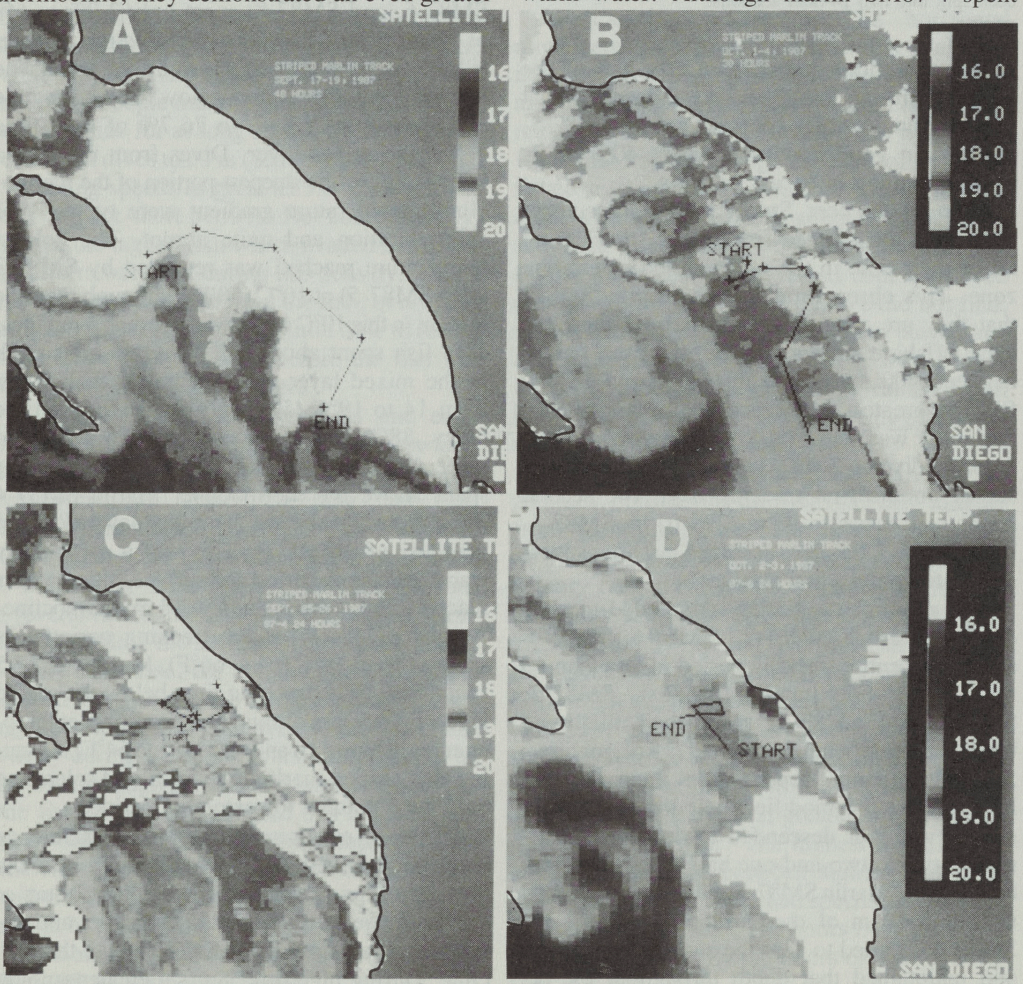

Figure 5. Satellite photographs of sea-surface temperatures with marlin track overlays provide good illustration of striped marlin presence in specific temperature zones.

76.7% of its time below the thermocline, it appeared to avoid the warm (22°C) water until near the end of the track. Here, it entered the warm coastal water and swam within 4 nm of the shore, an unusual occurrence for these largely offshore fish.

It is worthwhile mentioning that four of these marlin were lost soon after entering colder bodies of water, and that one (SM87-4) was lost shortly after entering a warmer surface water. None of these fish made a notable change in depth when entering a new body of water, but all changed their speed. Four slightly increased their speed while SM87-2 and SM87-4 slowed down as they entered water of different temperatures.

The photographs, taken from NOAA satellites on the occasion of each tracking cruise, were not available to us until after the actual cruise date. Thus, after reviewing these images, it is now apparent that several fish may have been lost as a result of sudden changes in course after encountering water masses of differing temperatures. The fish may have reversed direction in these cases, whereas we had assumed that the fading signal was due to the marlin outswimming the tracking vessel. In such a case, we may have increased our speed in the wrong direction.

Tagging Efficacy

We found the striped marlin to be a sturdy fish, tolerant of a great deal of handling. Eight of the twelve striped marlin were judged to be in good to excellent condition after they had been tagged and released. Three were listed as fair due to exhaustion. Although not injured, one (SM87-8) had everted its stomach in an attempt to regurgitate the baitfish and hook. It then re-swallowed it's stomach during capture and before tagging. This behavior is an apparently common method by which striped marlin attempt to expel undesired food items. This marlin was tracked for 24 hours, although it was the least active of the eight fish tracked.

During our cruises, we observed only two fish which died as a result of handling during capture. One of these was "tail-wrapped" and towed backwards for nearly an hour before being brought alongside. The other appeared to be in good condition when it was brought to the boat, but a failed attempt to plant a tag resulted in a 5-minute delay during which the fish was held by its bill against the fishing vessel's swim step. While struggling to free itself, it flailed against the swim step repeatedly, finally resulting in its death. Other fish, notably SM87-1, were held by their bills for 20 minutes before our arrival. Marlin SM87-1 appeared to be completely exhausted but not injured. It was subsequently tagged and tracked for 3.5 hours before an equipment failure resulted in our losing the fish.

Tagging-Induced Trauma

For a period of up to 2 hours following tagging and release, most fish displayed rapid changes in both heading and depth. Seven of the marlin descended to a deeper than normal depth and exhibited a heightened activity level immediately after release. Overall speed of travel varied between 2 and 3.5 kts and depths varied between 13 and 33 m (43 and 108 ft). These episodes lasted from 30 minutes to 2 hours, after which these marlin normally returned to near-surface waters. They then settled into swimming patterns which remained more consistent and generally more subdued for the remainder of the tracks. Three marlin did not exhibit a post-tagging pattern and stayed at 5 m or less for over an hour after release. Two moved moved away at 1 and 2 kts while the third (SM87-7) remained at the tagging site for about 2 hours.

We conclude that this initial burst of activity is a result of trauma induced during capture and tagging, and that the subsidence of this behavior, along with subsequent observations of feeding, sleeping, gathering into groups and "breezing," are good indications that this trauma is quickly overcome.

Summary

During September, 1982, a striped marlin was tagged with a sonic transmitter and tracked by National Marine Fisheries Service (NMFS) biologists, in waters off southern California. This event was the first time this species had ever been tracked. In 1986 and 1987, 11 more striped marlin were tagged with sonic transmitters, also off southern California. This renewed effort was conducted as a joint program of the National Marine Fisheries Service and the California Department of Fish and Game. Eight marlin were successfully followed for periods ranging from 20 to 48 hours and covered 254 nautical miles.

No single repetitive behavior was found to be characteristic of all the marlin tracked during this study, although a few behaviors were common to several fish. The behaviors were classified

into three broad categories including occasional behaviors, periodic behaviors, and those influenced by environmental parameters.

Two patterns of horizontal movement emerged from these tracks. Five of the eight moved predominantly in one direction after tagging, usually south. The other 3 marlin remained in the vicinity where they were first captured. Distances traveled ranged from 22 to 57 nautical miles at an average speed of 1.18 kts.

The greatest activity was observed during the late afternoons, when some of the marlin swam rapidly down-wind and down-swell in a behavior known to fishermen as "tailing" or "breezing". General activity of all fish slowed during the night. Several fish exhibited behavior which might be characterized as "sleeping", the fish remaining motionless, just below the surface, for 1 to 4 hours. This behavior was observed only during the night and early morning hours. Vertical movements during day and night hours showed some consistency among all marlin tracked. These striped marlin showed a preference for warm surface water and remained within the mixed layer more than 85% of the time. Four fish spent their nighttime hours at somewhat greater depths than during the daytime.

Vertical movement tended to be exaggerated and erratic for up to 2 hours after tagging. Beyond this time, the fish assumed a behavioral pattern which remained consistent throughout the duration of the track. We believe that this pattern indicates that the trauma induced by capture and tagging is short lived and tracks of as little as 24 hours should faithfully reflect "normal" marlin behavior.

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*use of trade names does not indicate endorsement by the NMFS or CDFG.

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Parasites Of The Pacific Sailfish *(Istiophorus Platypterus)*: A Preliminary Investigation Of Their Usefulness In Stock Discrimination

Peter Speare

The sailfish *[Istiophorus platypterus* (Shaw and Nodder)], has a worldwide circum-tropical distribution and represents an important component of both commercial and recreational fisheries. It is one of the most sought-after game fishes along the northeastern seaboard of Australia. The fishing seasons are largely restricted to the summer months (December-March) in the south and to the winter months (June-September) in the north.

Tag returns from the New South Wales Gamefish Tagging Program show that sailfish are seldom recaptured away from the point of tagging (Pepperell unpubl. data). While this information indicates strong site attachment, there is no evidence supporting the existence of independent stocks associated with each fishing ground. The whereabouts of fish outside the respective fishing seasons are not known. Artificial tagging (Cooperative Gamefish Tagging Programme), as presently carried out, is unable to determine the integrity of sailfish stocks along the northeast coast of Australia.

Parasites are well recognized as valuable tools for the delineation of intraspecific fish populations (MacKenzie 1983, 1986). They have also been useful in elucidating seasonal migrations and recruitment of juveniles to adult feeding and spawning grounds (Margolis 1965, McGladdery and Burt 1985). Research in this area has focused on discriminating stocks of commercially important fish species. Only two studies (Maksimov 1970, Iles 1971) have commented on the distribution of parasites on swordfish *(Xiphias gladius)*. Helminth parasites of swordfish in the northwest Atlantic have been evaluated as biological tags (Hogans et al 1983) but the authors were unable to find evidence of discrete stocks between sampling areas.

At least 26 species of parasites have been reported from sailfish (Silas 1967, Silas and Ummerkutty 1967, Yamaguti 1970, Love and Moser 1983). Information is available on populations and movements of other marine fishes based on the distribution and abundance of some of these parasites (Dubina 1985, Lester et al 1985). It is expected that much can be learnt about sailfish stocks and migrations from a study of their parasites.

In this paper, the distribution of sailfish parasites between two fishing grounds are described. Emphasis is placed on identifying those parasites which are most likely to assist in stock discrimination. Data are presented on several of these parasites.

Materials and Methods

Twenty-one sailfish were obtained from amongst those weighed during tournaments, club competitions, and charter operations in 1987/1988 at Cape Bowling Green (CBG) and Cape Moreton (CM) (Fig. 1). Weight (kg) and body length [tip of mandible to caudal fork (Rivas 1956) in cm] were recorded for each fish examined. Sex and spawning condition (Merrett 1970) were verified through histological examination of gonad sections.

With a few exceptions, all external, visceral and gill metazoan parasites were removed or dissected out and counted. Parasites from the

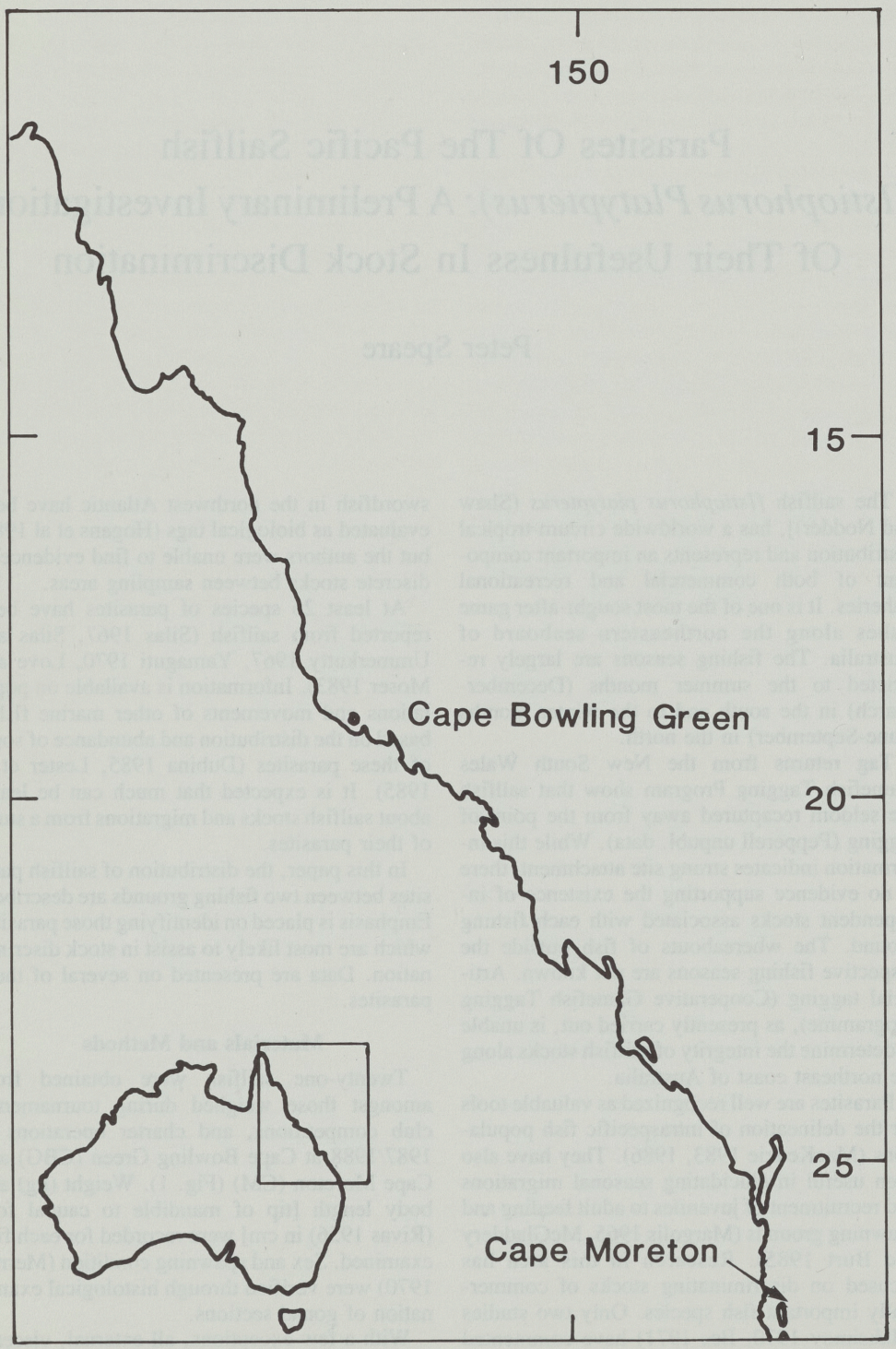

Figure 1. Locations of the two fishing grounds — Cape Bowling Green and Cape Moreton — on the northeast coast of Australia sampled for sailfish *(Istiophorus platypterus)*.

lumen of the stomach were identified but not included in counts due to the common sailfish behaviour of everting the stomach during capture. Intestinal contents remain to be sorted and infrequently recorded parasites await identification.

Representative parasites were fixed in AFA (50 parts 95% ethanol: 6 parts conc formalin: 4 parts glacial acetic acid) or BNF (10% neutrally buffered formalin). Trypanorhynch plerocerci were first placed in tap water until the proboscis extended. All other material was placed in BNF for later sorting. Encapsulated didymozoids were usually paired and each capsule was counted as one parasite.

The distributions of 10 parasites were compared using the mean intensity (mean number of individuals per fish) and prevalence (percent of individuals in which infections occurred) of infection for CBG and CM fish. Analysis of variance was used to compare the intensities of infection. The relationship between body length (BL) and parasite burden was investigated for selected parasites.

Results

Host Statistics

Sailfish weighed between 4.1 kg (BL of 102 cm) and 53.7 kg (BL of 237 cm) (Table 1). There was no significant difference between the average weight of fish from CBG (30.4 kg) and those from CM (29.2 kg) ($P = 0.05$), although the CBG sample contained 2 small females and the heaviest fish. Only 3 males were examined and none of the females were in spawning condition as described by Merrett (1970). Eight of the fish were recaptures and only one of these (87-566) had moved any measurable distance (156 km S).

Parasite Distribution

Six of the 10 species of parasite reported here have not been previously identified from sailfish (Table 2). Six parasites had significantly different mean intensities of infection between CBG and CM. There were corresponding differences in the prevalences of five of these parasites. Two parasites were more abundant and prevalent on fish from CBG and four were more

Table 1. Details of individual sailfish (Istiophorus platypterus), examined at Cape Bowling Green and Cape Moreton.

Postmortem number	Location[1]	Date	Weight (kg)	Body Length[2] (cm)	Sex
87-400	CBG	07/12/87	32.0	199	M
87-445	CBG	07/31/87	29.4	188	F
87-T1S	CBG	09/09/87	7.1	128	F
87-T2S[3]	CBG	09/09/87	43.5	217	F
87-T3S[3]	CBG	09/10/87	37.5	204	F
87-T4S	CBG	09/11/87	36.0	201	F
87-T5S[3]	CBG	09/11/87	29.5	194	F
87-T6S[3]	CBG	09/22/87	36.5	207	F
87-566[3]	CBG	10/01/87	25.6	174	M
87-670	CBG	11/21/87	4.1	102	F
87-T7S	CBG	10/06/87	53.7	237	F
88-258[3]	CM	01/23/88	24.5	185	F
88-259	CM	02/06/88	25.0	197	F
88-260	CM	02/12/88	20.0	175	M
88-261	CM	02/19/88	27.6	190	F
88-262[3]	CM	02/19/88	26.0	192	F
88-263	CM	02/19/88	30.5	200	F
88-264[3]	CM	02/19/88	27.0	197	F
88-265	CM	02/19/88	33.5	204	F
88-266	CM	03/13/88	32.0	197	F
88-267	CM	03/14/88	46.0	227	F

1. CBG — Cape Bowling Green; CM — Cape Moreton.
2. Tip of mandible to caudal fork; after Rivas (1956).
3. Recaptued fish.

Table 2. Mean parasite numbers and prevalence of parasites on sailfish (Istiophorus platypterus), from Cape Bowling Green and Cape Moreton.

Parasite	Mean Intensity		Prevalence	
	CBG	CM	sig[2] CBG	CM
Floriceps minacanthus[1]	11.3(3.53)[4]	1.1(0.98)	* 82	20
Pennella instructa	1.8(1.09)[4]	6.1(1.21)[4]	* 27	100
Lepeophtheirus eminens[1]	17.6(4.04)	158.3(43.12)	** 100	100
Gloiopotes longicaudatus	12.9(3.98)[3]	13.2(3.76)	n.s. 82	90
Neodidymozoon macrostoma[1]	1.1(0.48)	5.9(1.93)[4]	* 55	80
Nematobothrium sp. A[1]	0(0.00)	1.6(0.57)	** 0	50
Nematobothrium sp. B[1]	0.5(0.39)	1.7(0.51)[4]	n.s. 18	80
Metadidymozoon branchiale	20.7(6.69)	204.9(117.72)	n.s. 100	100
Cardicola sp.[1]	13.7(4.37)	0.3(0.28)	** 90	10
Tristomella pricei	5.2(2.44)	9.8(3.89)	n.s. 45	80

1. New host record.
2. Results of ANOVA; n.s. – not significant ($P>0.05$); * – $P<0.05$; ** – $P<0.01$
3. Mean (+/ – standard error).
4. Counts include dead parasites.

abundant and prevalent at CM.

Floriceps minacanthus Campbell and Beveridge 1987, (Cestoda:Trypanorhyncha) was common amongst fish from CBG but infrequently recorded from CM. The plerocercus of this trypanorhynch was dissected from the intestine, stomach mucosa, pyloric caecae, and infrequently from the peritoneum and mesentaries. Intensities for *F. minacanthus* were not correlated with sailfish body length ($r = -0.07$) although the smallest infected fish had the fewest plerocerci. Mortality was also recorded in *F. minacanthus* amongst fish from CBG. The incidence of these dead parasites was independent of the size of the fish and the level of infection.

Three species of copepod were identified from sailfish and the distributions of two of these varied significantly between fishing grounds. *Pennella instructa* Wilson 1917 (Copepoda: Pennellidae) was infrequently recorded from CBG but was present on all fish from CM. This endoparasitic copepod's preferred sites of attachment included dorso-lateral below the first dorsal fin and lateral to the first anal fin. All counts of *P. instructa* from CBG were of degenerate cephalothoraces compared with 16 percent from CM fish. All remnants could be detected only with thorough dissection of subdermal muscle. Localised proliferation of fibrous tissue was associated with the remains of this parasite.

Lepeophtheirus eminens Wilson 1944 (Copepoda;Caligidae) was found on all fish but the mean intensity of infection was ten times greater at CM. *L. eminens* was unevenly distributed on the gill filaments, being predominant on the anterio-ventral 6th and 7th hemibranchs. Ease of dislodgement was tested by washing the gills in seawater, fresh water, and 10% ethanol. These treatments did not result in substantial dislodgement of copepods.

Gloiopotes longicaudatus (Marukawa 1925) (Copepoda:Euryphoridae) was equally abundant and prevalent amongst fish at both locations. It was mobile over much of the body surface and would readily detach.

Four species of didymozoid (Digenea: Didymozoidae) were identified on sailfish — three from CBG and a further species from CM. Three of these didymozoids were encapsulated in host tissue. Two left recognizable remnants on death.

Neodidymozoon macrostoma Yamaguti 1970 was more abundant and prevalent amongst fish from CM. Preferred sites included the first dorsal and first anal fins, pelvic groove, posterior margin of the cleithrum and overlying the lateral red muscle mass. Capsules containing eggs and degenerate worms were dissected from three fish at CM. There was a weak correlation ($r = 0.42$; $P>0.05$) between body length and the numbers of *N. macrostoma*.

Nematobothrium sp. A was found free in the body cavity of five fish from CM but did not occur at CBG. This parasite was most closely associated with the liver and pyloric caecae.

Intensities of infection with *Nematobothrium* sp. B were not significantly different between sites. Difficulty was experienced in dissecting out this worm. It occurred subcutaneously and

was impossible to count due to it's close association with these tissues and fragility. Occurrence was scored as one worm per site of infection from examination of gill covers, fine membranes, and the connective tissue lateral to the first dorsal and first anal fins.

Metadidymozoon branchiale Yamaguti 1970 was recorded from all fish examined. It was found in large numbers between the gill filaments of several fish from CM. This parasite was secured to the filaments by host tissue. There was no significant difference between the distributions of this didymozoid at either locality.

Cardicola sp. (Digenea:Sanguinicolidae) was abundant in fish from CBG and infrequently recorded at CM. This parasite was found in the heart, ventral aorta, and branchial arteries of 90% of fish from CBG, whereas only three specimens were recorded from one fish at CM (88-267).

Tristomella pricei (Hidalgo 1959) (Monogenea: Capsalidae) numbers were not significantly different between the two samples of sailfish. They were unevenly distributed amongst fish from both localities but were more prevalent at CM. Preferred sites included the buccal cavity, lower jaw, operculi, and caudal peduncle. Pathology associated with *T. pricei* infections included abrasion of dermal tissue, especially about the mandible and branchial arches. Damage did not appear to extend beyond these superficial wounds.

Discussion

For a parasite to be a useful marker in fish population studies it needs to be relatively long lived, the life span approaching that of the host or at least covering the time scale of the investigation (MacKenzie 1983). Further criteria include ease of detection, including identification of remnants, attachment to the host so that dislodging is unlikely, and it must be non-pathogenic. By necessity, the parasites must have different levels of infection between study areas before much can be said about stock integrity. Six of the parasites recorded on sailfish in this study had significantly different intensities of infection at CBG and CM.

Trypanorhynch plerocerci have been used successfully in several biological tag studies (Sindermann 1961, Lubieniecki 1977, Lester et al 1985). MacKenzie (1983) considered these parasites as possibly the best biological markers for populations of marine teleosts. Low infection levels have, however, been implicated in host mortality for other fish species (Adjei et al 1986), while relatively high levels of *F. minacanthus* infections do no apparent harm to sailfish off eastern Australia. Sindermann (1961) suggested that trypanorhynch plerocerci live longer than 1 year in herring (Table 3). Infrequently recorded mortality of *F. minacanthus* plerocerci, unrelated to the size of the fish or the level of the infection, suggests a relatively long life span for this parasite. Thus, *F.*

Table 3. Probable life spans of parasites related to those found in sailfish (Istiophorus platypterus).

Parasite	Site	Host	Life Span	Reference
Copepoda				
Clavella uncinata	skin	Odontogadus merlangus	months	Shotter (1971)
Lerneocera branchialis	skin	Gadus spp.	< 1 yr	Templeman and Fleming (1963)
L. obtusa	skin	Melanogrammus aeglefinus	1.5 yrs	Kabata (1958)
Didymozoid Digenea				
Nematobothrium texomensis	ovary	Ictiobus bubalus	> 8ms	Self et al (1963)
Neometadidymozoon helicis	buccal cavity	Platycephalus fuscus	1 yr	Lester (1980)
Nematobothrium spinneri (eggs)	muscle	Acanthocybium solandri	> host	Lester (1980)
Larval Cestoda				
Trypanorhynch sp.	mesentary	Clupea hargengus	> 1 yr	Sindermann (1961)

minacanthus may prove to be the best natural tag for east coast sailfish stocks.

It has been determined that cephalothoraces of *Pennella instructa* can be detected externally for up to several months following death (Glazebrook pers. comm.). Cephalothoraces of a related species *Sphyrion lumpi* (Sphyriidae), in the flesh of redfish *(Sebastes marinus)*, represented 40% of parasites detected by Templeman and Squires (1960), who considered these remnants to be of earlier generations that remained in the flesh for several years. Thus, *P. instructa* with a probable life span of <1 year (Table 3), through the accumulation of detectable remnants, may be considered as surviving several years in sailfish. While the potential for pathogenicity has been reported for related species (Kabata 1981), the sites of attachment of *P. instructa* in sailfish are not likely to affect host fitness; therefore, this parasite may also be a useful tag.

Possible loss of *L. eminens* during sampling was tested and it appears that they will not readily leave the host. This indicates that they may not freely exchange hosts and will remain with the fish for several months (Kabata 1981) (Table 3). Amongst billfish at CBG and CM, sailfish are their preferred host (Speare unpubl. data). Although the life span of this copepod is presumed to be relatively short, it could be used to study seasonal migrations of adult fish where the time scale of investigation is correspondingly small (MacKenzie 1986).

Didymozoid digeneans may have a three- or four-host life cycle so that the distributions of intermediate hosts have a major influence over the level of infection encountered in the definitive host. Didymozoid larvae are common amongst intertidal fishes which act as second intermediate or paratenic (transport) hosts in Moreton Bay (Koie and Lester 1985). Speare (unpubl. data) has found metacercariae in scad *(Decapterus* sp.) at Cape Bowling Green. These are an important baitfish species at both locations (Williams pers. comm.; Speare pers. obs.) and sailfish are, therefore, most likely infected seasonally on the fishing grounds. Seasonal occurrence of infection has been reported elsewhere in didymozoids (Lester 1980) and it would be useful in the context of this study to monitor the incidence of metacercariae in baitfish on the fishing grounds.

Loss of encapsulated didymozoids, especially those associated with the gills or gonads, has been reported prior to host spawning (Self et al 1963). Lester et al (1985) considered didymozoids as semi-permanent parasites but he also indicated that encapsulated species may remain recognizable in host tissues for the life of the fish. *M. branchiale* may be readily lost prior to spawning. Similarly for *Nematobothrium* sp. B. if its life cycle is similar to *N. texomensis* (Self et al 1963). Remnants of *N. macrostoma* and *Nematobothrium* sp. B may remain with the host for at least several years. The time of sampling relative to spawning in sailfish may have a direct influence on the observed distributions of the two former species. Didymozoids are predominant in pelagic fish and they have characteristics which enhance their value as biological tags for sailfish.

Cardicola spp. appear to be highly specific in requirements for the intermediate host (Roberts 1978) so that the distribution of this host will directly determine the area in which the definitive host becomes infected. Pathogenicity as reported in trout (Bauer et al 1973) may not be relevant to sailfish because infestations, as recorded, were relatively low (Williams 1967). There is no information on the life span of these parasites and the low prevalence of infection of sailfish from CM may be the result of sampling following seasonal evacuation by miracidia. Temporal aspects of infection and the distribution of the molluscan intermediate host need to be investigated before the value of *Cardicola* sp. as a biological tag can be assessed.

While the intensities of infection of *T. pricei* at CBG and CM were not statistically different, the mean intensity and prevalence of this parasite at CM were twice that recorded at CBG. Related monogenetic trematodes, *Tristoma* spp., have been suggested as suitable tag parasites for swordfish *(Xiphias gladius)* (Iles 1971). Monogeneans have direct life cycles so that the distributions of intermediate hosts do not have to be considered. It is not known how long they live. They have been recorded as highly pathogenic in hatcheries, but there is no indication that pathology, as recorded in this study, could lead to mortality of the host.

The insignificant difference in the distribution of *G. longicaudatus* between sailfish from CBG and CM, its mobility and potential for exchanging hosts (Kabata 1981) indicate that it is unlikely to be a good biological marker for sailfish stocks. It probably also has a short life span, which means that short-term sampling at different latitudes and seasons on the east coast are not directly comparable.

A major constraint on the interpretation of

these results is an understanding of the dynamics of the parasitic infections, especially with respect to the identity and seasonal availability, at each locality, of intermediate hosts. There is no opportunity for simultaneously obtaining samples from sailfish at these two localities, but further investigation of parasite life histories should indicate potential natural tags that provide information on sailfish stock integrity along the east Australian coast. Artificial tagging has not yet provided this needed information. Data presented here show that five parasites satisfy requirements for good tags and these will be the focus of future work.

Summary

A preliminary survey of parasites from the Pacific sailfish *(Istiophorus platypterus),* occurring in coastal waters northeast of Australia, was conducted over the 1987-1988 billfish season. Ten fish were sampled from the game-fishing grounds off Cape Bowling Green and 11 from waters off Cape Moreton through cooperation with normal gamefishing activities in these waters. The distributions of ten parasites on sailfish revealed significant differences in the levels of infection between fishing grounds for six parasites that are potentially useful in stock discrimination. A digenean infecting the heart, ventral aorta, and branchial arteries, *Cardicola* sp., was prevalent amongst fish from the Cape Bowling Green area but almost absent from fish taken off Cape Moreton. A didymozoid digenean, *Nematobothrium* sp. A, was recorded only from the body cavity of fish taken off Cape Moreton. *Neodidymozoon macrostoma* was more abundant and prevalent at Cape Moreton. Two copepods, *Lepeophtheirus eminens* and *Pennella instructa,* were found in larger numbers and more widely distributed amongst fish at Cape Moreton. A trypanorhynch, *Floriceps minacanthus,* was also more abundant and prevalent at Cape Bowling Green.

A discussion of those factors that are relevant to considerations of each parasite as a useful biological tag for sailfish stocks indicated that *F. minacanthus* has the greatest potential. *N. macrostoma* and *P. instructa* probably have short life spans but detectable remnants accumulate in the host tissues, thereby increasing their effective life spans and value as natural markers. Possible loss of *N.* sp. A infections prior to sailfish spawning, and seasonal evacuation of *C.* sp. miracidia, need to be assessed before between-site differences in the distributions of these parasites can be more completely interpreted. *L. eminens* probably remains with the one host but, as it is short lived, identification of any seasonal variations in the levels of infection relative to the times of sampling will improve its value as a biological marker for sailfish stocks.

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P. Speare is presently undertaking post-graduate study at James Cook University in Townsville, Queensland, Australia. His thesis includes an evaluation of the parasites of black marlin as natural tags for the migratory habits of this species. Previous related research includes a study of an epidemic disease in red and gray kangaroos and parasite-related pathology in kangaroos and wallabies. He has also spent several years with the Australian Institute of Marine Science, at Townsville, Queensland, studying the crown-of-thorns starfish epidemics on the Great Barrier Reef.

Further Acoustic Telemetry Observations of Swordfish

Francis G. Carey

A previous publication on the activities of swordfish *(Xiphias gladius)* described a number of features which seemed worth further study (Carey and Robinson 1981). These activities included a daily cycle of vertical movements in which the swordfish were on the surface at night but went to depths as great as 600 meters during the day. The fish experienced temperature changes as great as 19°C in these vertical movements. From the "U"-shaped pattern of the depth changes it seemed that the fish might be following an isolume. Some of the swordfish (numbers 2 & 3) had daily cycles which took them to the bottom on an inshore bank during the day and out over deep water on the surface at night.

Five of the early experiments were done in the eastern tropical Pacific Ocean near the tip of Baja California. A well developed oxygen-minimum layer (Wyrtki 1966) occurs in this region, and the swordfish encountered oxygen concentrations at their daytime depths that were only 10% of air saturation. These fish returned to the surface periodically during the daytime, a behavior which makes swordfish vulnerable to a harpoon fishery in some locations. It seemed that such "basking" might allow them to recover from stress experiences at depth while foraging in low-oxygen water in the eastern Pacific, or in low temperatures in the Atlantic Ocean near Georges Bank.

In the course of those experiments, it was found that swordfish and other billfishes have an unusual thermogenic organ in their head, the brain heater (Carey 1981, Block 1986). The function of this organ seemed closely related to the large temperature changes the fish experienced on passing through the thermocline.

Acoustic telemetry studies with swordfish have continued, but it is much easier to plan experiments with pelagic animals than it is to get the actual data. Funding for such work is difficult to obtain. The experiments require extraordinary luck for catching the fish in good condition and necessitate a great deal of time and effort. Progress has been slow, and the experiments have usually been flawed by some circumstance or other. In general, the results have been similar to those reported earlier (Carey and Robison 1981). The additional experiments and the opportunity to observe the fish in new situations helps to understand the behavior of these fish. There is also some new information on the body temperatures of these fish and on the possibility of behavioral thermoregulation.

Methods

The telemetry system used for swordfish numbers 8 through 11 was similar to that described earlier *(op. cit.)*. The depth and temperature data were broadcast in a pulse-rate code. When only depth and body temperature transmitters were deployed on the fish, water temperature was inferred from isotherm-depth plots constructed from XBT casts made every four hours. A description of the mutliplex transmitters and computer-based data acquisition system used for swordfish 12 is available from the author. Swordfish 11 was tracked with a directional hydrophone mounted on the keel, the others were tracked with towed directional hydrophones. A plot of LORAN positions, determined when the tracking vessel was close to the fish, was used to approximate the course of the swordfish. The echosounder used in some experiments was a 50 kHz Japan Radio Corp. Model 516 with a 10 kW, 8° beam transducer towed over the side in a streamline towbody. The echogram was

displayed on color video and on a 19-inch EDO-Western Corp. dry paper recorder. Weights of the swordfish were estimates made by the fishermen (in pounds; converted to kg).

Results and Discussion

Five more swordfish have been followed. Numbered to continue the sequence in the earlier paper (Carey and Robinson 1981), these are:

8. 7-8 Nov. 1978. New York Bight
9. 11-17 Nov. 1978. New York Bight
10. 26-29 March 1981. Straits of Florida
11. 30 Aug.-1 Sept. 1982. Georges Bank
12. 10-14 July 1985. Georges Bank

Swordfish 8 and 9

Swordfish 8 and swordfish 9 were caught on longline by Jimmy Ruhle on the Dorana R, out of Wanchese, North Carolina. The fishing gear was set and hauled at night, being left in the water only a few hours to improve our chances of getting fish in good condition. The fish were brought aboard using a noose around the tail. Thermistors were installed in the cranial cavity in a position that was near, but not in, the brain. For this purpose, a hole was made in the top of the head by twisting a no. 30 drill bit through the bone. The hole was located by external features on the head and was approximately 2 cm (0.75″) lateral to the dorsal midline and on a line connecting the posterior margins of the eyes. A 2.5 mm (0.1″) dia. catheter containing a thermistor was pushed vertically down through the hole until it was felt to make contact with the bottom of the cranial cavity, just lateral to, but not in, the brain. The catheter was clamped on the bony surface of the head with a 5/8″ (1.6 cm) No. 8 sheet metal screw and the transmitter itself fastened to the muscle just behind the head with a small dart. A pressure transmitter was attached at the base of the dorsal fin and the fish returned to the water. We used the Polish vessel, Wieczno, of Morski Instytut Rybaki, Gdynia, for tracking the fish.

Swordfish 8 was an approximately 40 kg (90 lb) fish caught near Norfolk Canyon (37°15′N, 74°30′W). It was motionless when released, and sank away from the surface, but it recovered activity within a few minutes and began to swim away. The fish followed a consistent course, but remained at one depth level near the upper surface of the thermocline. This swordfish did not dive during daylight. The brain was warm however, with temperature elevations in excess of 10°C (18°F), the highest temperature elevations we have yet measured in a swordfish head (Fig. 1).

An interesting feature of this experiment was its termination after 27 hours. This is the only fish of any species that died while being followed. There was a sharp decrease in cranial temperature and depth increased at a rate of about 15 m (50 ft) per min. The depth change was too slow for a free-falling transmitter, indicating that the device was still attached to the fish, but the cranial thermistor showed a rapid temperature change as if it had pulled out of the head. The fish may have died as a result of its traumatic experience during capture and installation of the transmitter, but the disruption of the thermistor raises the possibility that it was hit by a shark (Jolley and Irby 1979).

Swordfish 9 was an approximately 100 kg (220 lb) fish caught south of Veach Canyon (40°N, 69°30′W). It was fitted with temperature and depth transmitters in the same fashion as swordfish 8. This was a lively fish that thrashed about and, in the struggle to get it aboard, one of the crew was severely slashed just below an eye. This incident convinced me that the operation was more dangerous than it was worth and we have not tried to bring a live swordfish aboard since that time.

Swordfish 9 was in better condition than 8 and swam away strongly when released. During the first day (11 Nov) it descended an hour before sunrise and reached a depth of 500 m (260 fath) by 0900 hrs (Fig. 2). At this point it had entered 6°C (43°F) water, the lowest water temperature we have recorded for any swordfish. The fish returned to shallow depths at 1400 hrs, some 2.5 hrs before sunset, coming near the surface during full daylight rather than an hour after sunset as we would normally expect. This was the only prolonged dive it made. Because of a storm system, which made it impossible to obtain another fish, we stayed with swordfish 9 from 11 to 17 Nov., but it did not again go below the thermocline for a significant amount of time. Nevertheless, the dive during the first day made this a valuable experiment, for the fish experienced a 10°C (18°F) decrease in water temperature for a period of some 8 hours. While in cold water the cranial temperature decreased only 5°C (9°F) and stabilized at a new equilibrium temperature within 4 hours (Fig. 3).

Because of the manipulations, the behaviors of swordfish 8 and 9 were probably aberrant,

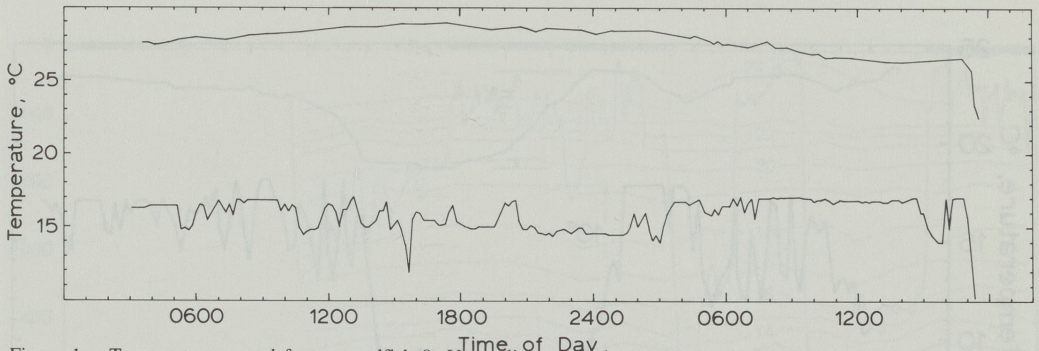

Figure 1. Temperature record from swordfish 8. Upper line, cranial temperature; lower line, water temperature. This swordfish remained in the mixed layer and did not go into cold water below the thermocline. The brain temperature elevation recorded here is the highest yet measured in swordfish.

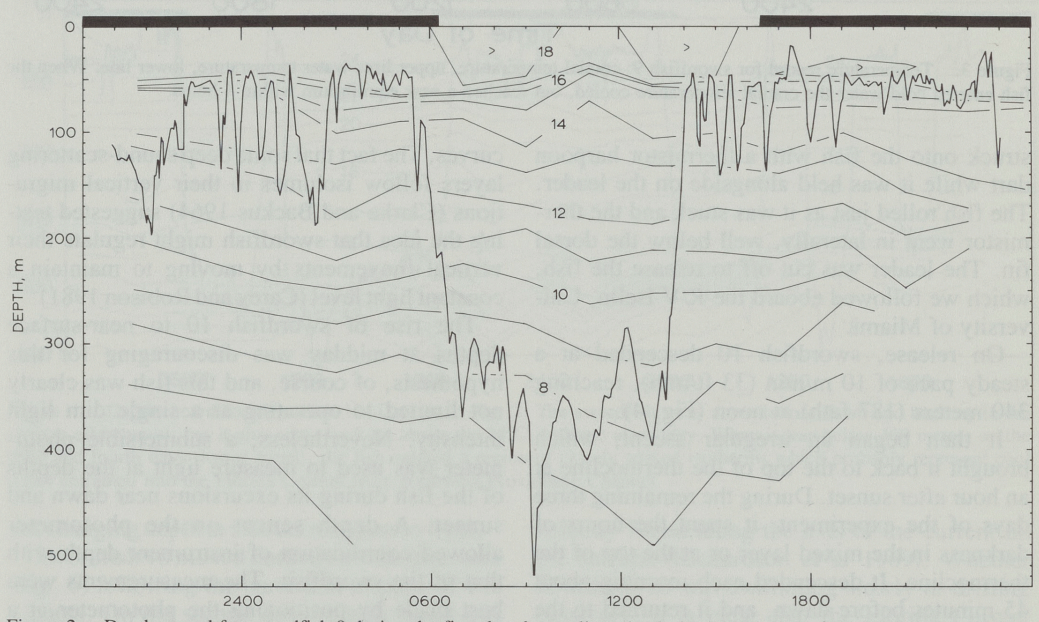

Figure 2. Depth record for swordfish 9 during the first day: heavy line, depth; horizontal lines, °C isotherms; black bars, night. The fish was in warm water near the thermocline during the night, but descended into cold water at first light. The water temperature dropped 10°C and the fish remained in cold water for 8 hours.

but they were still able to follow consistent courses. Swordfish 8 moved south, swimming strongly at first but slowing toward the end. Swordfish 9 remained in an area just east of Veach Canyon for the first two days, then moved off toward the south. Inspection of satellite sea-surface thermal images for 10 Nov. 1978 showed that there were no strong eddy systems in the area of either experiment. The fish were swimming on coherent courses and were not just drifting with currents.

Swordfish 10, 26 to 29 March, 1981, Straits of Florida

Swordfish 10 was caught on standard Florida longline gear by Larry Thompson on Sea Lion IV at 25°52′N, 79°31′W in the Straits of Florida. It was estimated to weigh about 70 lb (32 kg). The condition of the fish caused concern, as there was some bleeding from the mouth or gills, but it was the first live swordfish in four days of waiting so we used it. Depth and muscle temperature transmitters were tied in tandem and

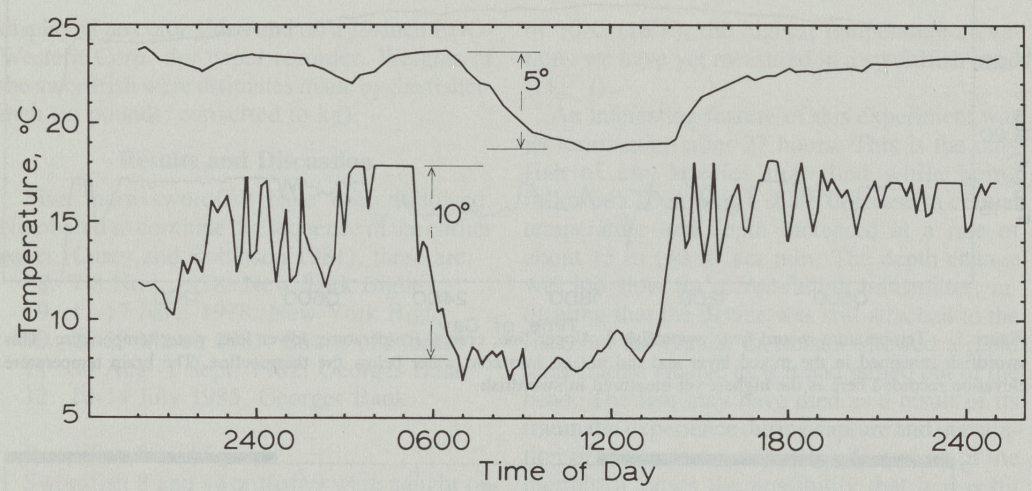

Figure 3. Temperature record for swordfish 9: cranial temperature, upper line; water temperature, lower line. When the fish entered cold water the cranial temperature cooled, but reached a new equilibrium within 4 hours.

struck onto the fish with a thermistor harpoon dart while it was held alongside on the leader. The fish rolled just as it was stuck and the thermistor went in laterally, well below the dorsal fin. The leader was cut off to release the fish, which we followed aboard the R/V Iselin, University of Miami.

On release, swordfish 10 descended at a steady pace of 10 m/min (33 ft/min), reaching 340 meters (187 fath) at noon (Fig. 4).

It then began an irregular ascent, which brought it back to the top of the thermocline at an hour after sunset. During the remaining three days of the experiment, it spent the hours of darkness in the mixed layer or at the top of the thermocline. It descended each morning about 45 minutes before dawn, and it returned to the near surface waters shortly after sunset. During the day, it reached depths of 340, 595, 525, and 485 m (186, 325, 286, 265 fath). The great difference between this experiment and fish such as swordfish 7 (Fig. 5) is that swordfish 10 did not stay down for the entire daylight period. Each day, after several hours at depth, it rose through the thermocline into the mixed layer, where it remained for 1 to 3 hours before descending again (Fig. 4). When swordfish 10 was near the surface, it seemed to favor the 24°C (75°F) isotherm. The coldest temperature reached at depth was 7°C (12.6°F) during the dive at 1300 on the last day (29 March).

It had been noted earlier that the depth movements of swordfish may follow a "U"-shaped pattern (Fig. 5) similar to that of isolume depth curves. The fact that some deep sound-scattering layers follow isolumes in their vertical migrations (Clarke and Backus 1964) suggested testing the idea that swordfish might regulate their vertical movements by moving to maintain a constant light level (Carey and Robison 1981).

The rise of swordfish 10 to near-surface depths at midday was discouraging for this hypothesis, of course, and this fish was clearly not limited to operating at a single dim light intensity. Nevertheless, a submersible photometer was used to measure light at the depths of the fish during its excursions near dawn and sunset. A depth sensor on the photometer allowed coordination of instrument depth with that of the swordfish. The measurements were best made by positioning the photometer at a level where the fish might be expected a short time later and making light readings when the fish traversed that depth. The instrument was not calibrated to any absolute scale, but the detector was a photodiode (United Detector Technology Inc. PIN 10D/SB) with an essentially linear response. Extinction coefficient alpha, calculated as 0.027 from photometer readings between 300 and 400 m (164 and 218 fath), is a reasonable result for clear Florida Current water (Clarke and Backus 1964) and gives confidence that the instrument was indeed linear at low light levels. Despite problems in coordinating the telemetry and light meter measurements, the vertical movements of the fish appeared more rapid than the rate of change in isolume depth, and the swordfish was probably

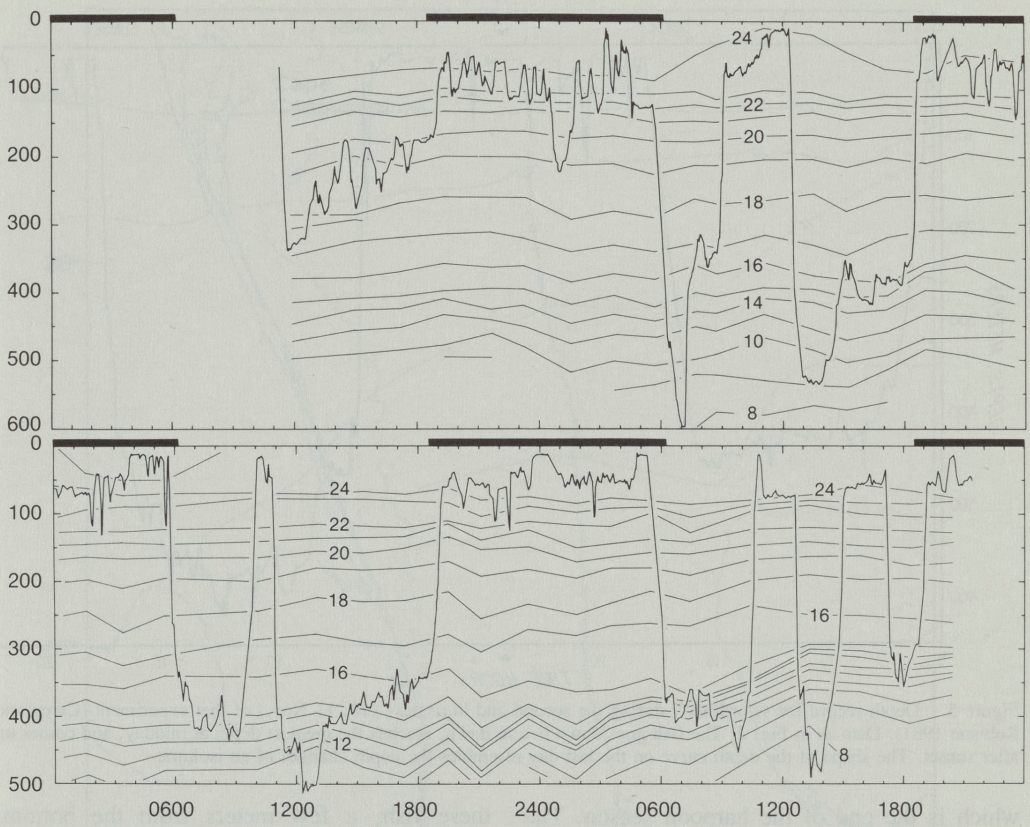

Figure 4. Depth record for swordfish 10. Data as in Fig. 2. The swordfish went down before dawn and back up to the surface after sunset, but it also came back up above the 24°C isotherm at midday. When it was below 300 meters on the third and fourth days (lower panel), the fish entered a region of closely spaced isotherms which probably represent cool water entrained into the Florida Current from northwest Providence Channel.

not changing depth in a direct response to light.

Swordfish 10 moved north on a smooth course (Fig. 6) following the current at a speed of 1 to 3 knots. On the second day, current speed was estimated from the drift of longline gear set by two nearby fishing vessels as 1 and 1.7 knots to the north. On the third day, drift of the tracking vessel during a 3-hour period (engines stopped, breeze less than 5 knots) was 2 knots toward the north. The similarity of fish and current speed make it appear that the swordfish was drifting more than swimming during this time. The increased speed of the fish on the third and fourth days (Fig. 6) corresponded to the faster current. On several occasions, it was necessary to steam against the current to stay near the fish, probably because most of the movement of the fish was due to the current, which is slower at depth than on the surface. At the 300 to 400 m (164 to 218 fath) daytime depth of the swordfish, the current is approximately half the maximum velocity found along the axis of the current on the surface (Richardson et al 1969). Whether swordfish 10 was swimming slowly or drifting passively, it is clear that the Florida Current dominated its movements.

Swordfish 11, 29-31 August 1982

Depth and muscle temperature transmitters were harpooned into swordfish 11 by William Gell of the fishing vessel Gale out of New Bedford. The thermistor harpoon was implanted about 40 cm behind the dorsal fin. This was a 140 kg (308 lb) fish struck while it was on the surface at 42°N, 66°W on the Northeast Peak of Georges Bank (Fig. 7). The fish, which seemed relatively undisturbed by the dart, was back near the surface within 10 minutes after being struck. The fish was followed on the NOAA-NMFS trawler, Gloria Michelle, out of Narraganset.

This experiment was done at the end of August,

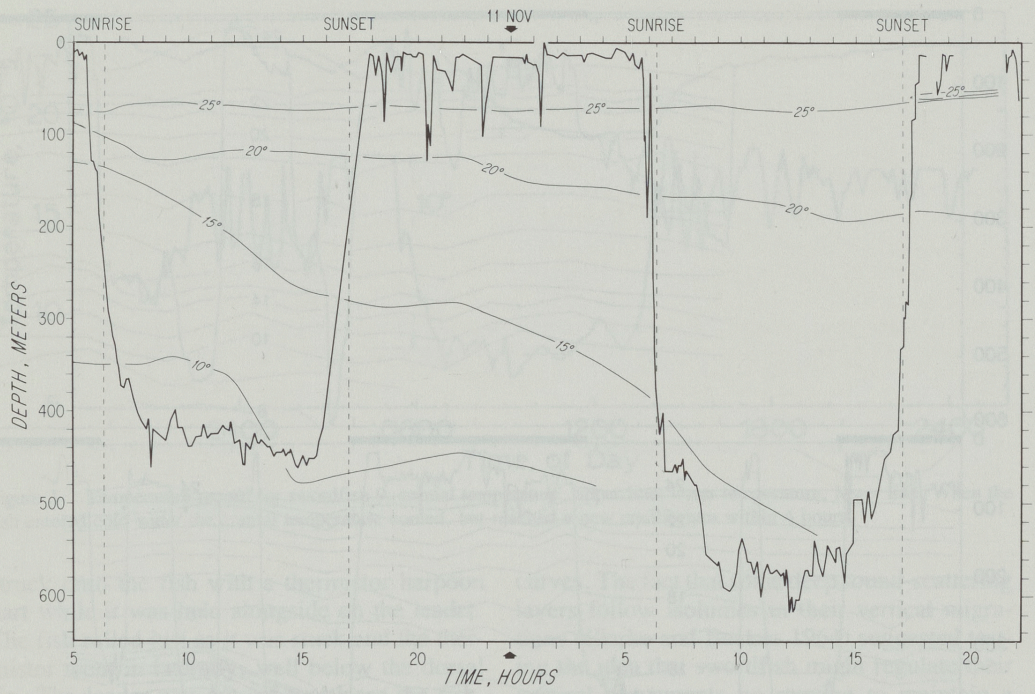

Figure 5. Depth record for swordfish 7 during the second and third days (10, 11 Nov.) of that experiment (Carey and Robison 1981). Data as in Fig. 2. The fish goes down before dawn, reaches the greatest depth at midday, and comes up after sunset. The shape of the depth curve on the last day resembles the depth changes of an isolume.

which is the end of the harpoon season. The fish left the area where it was struck, moving out Northeast Channel and along the southeast edge of the bank (Fig. 7). It remained near the surface that afternoon and throughout the night (Fig. 8), swimming 5 miles or more out from the edge of the bank (the 100-fathom bottom contour). After sunrise, it turned in toward the bank again, but stayed near the surface. At 1000 hrs it descended to 100 m (55 fath) and remained at that depth until over the 100-fathom (183 m) bottom contour, whereupon it dropped to the bottom. It appears that the fish could sense when it was at the proper location to descend.

Echograms made during this experiment allowed visualization of the relationship of the fish to the bottom (Figs. 9A and 9B). The swordfish spent the day swimming along the bottom at depths somewhat greater than 100 fathoms (183 m), moving on a SE course just below the edge of the shelf break. Despite the abundance of echo returns in mid water, the swordfish was associated with the bottom, where there were echo returns from schools of demersal fish, probably hake *(Merluccius* spp.). The swordfish was swimming at the depth of these fish, a few meters from the bottom, perhaps feeding on them (Scott and Tibbo 1968). Figure 10 sometimes shows the fish to be below the bottom, 10 m (33 ft) down in the mud, or well up above the bottom. This anomaly is due to the ship and echo sounder being up slope or down slope from the swordfish and recording a bottom shallower or deeper than the true bottom depth at the fish. At 1510 hrs on 30 August, the swordfish was caught in the beam of the echo sounder and was marked on the echogram at the same depth as indicated by telemetry.

Swordfish 11 continued on its SW course after reaching the point where the bottom deepens as Corsair Canyon cuts into the shelf (Fig. 7). The swordfish was out over the canyon at 1800 hrs when it suddenly breached the surface about 8 times just in front of the ship. It remained near the surface after sunset and gradually moved offshore. By dawn the next day it was some 10 miles out from the 100-fathom (183 m) bottom contour, at which point it turned inshore again. Swordfish 11 was abandoned at 0900 hrs when we ran out of ship time.

A most interesting echogram was obtained on 31 August, the final day. A heavy band of sound-

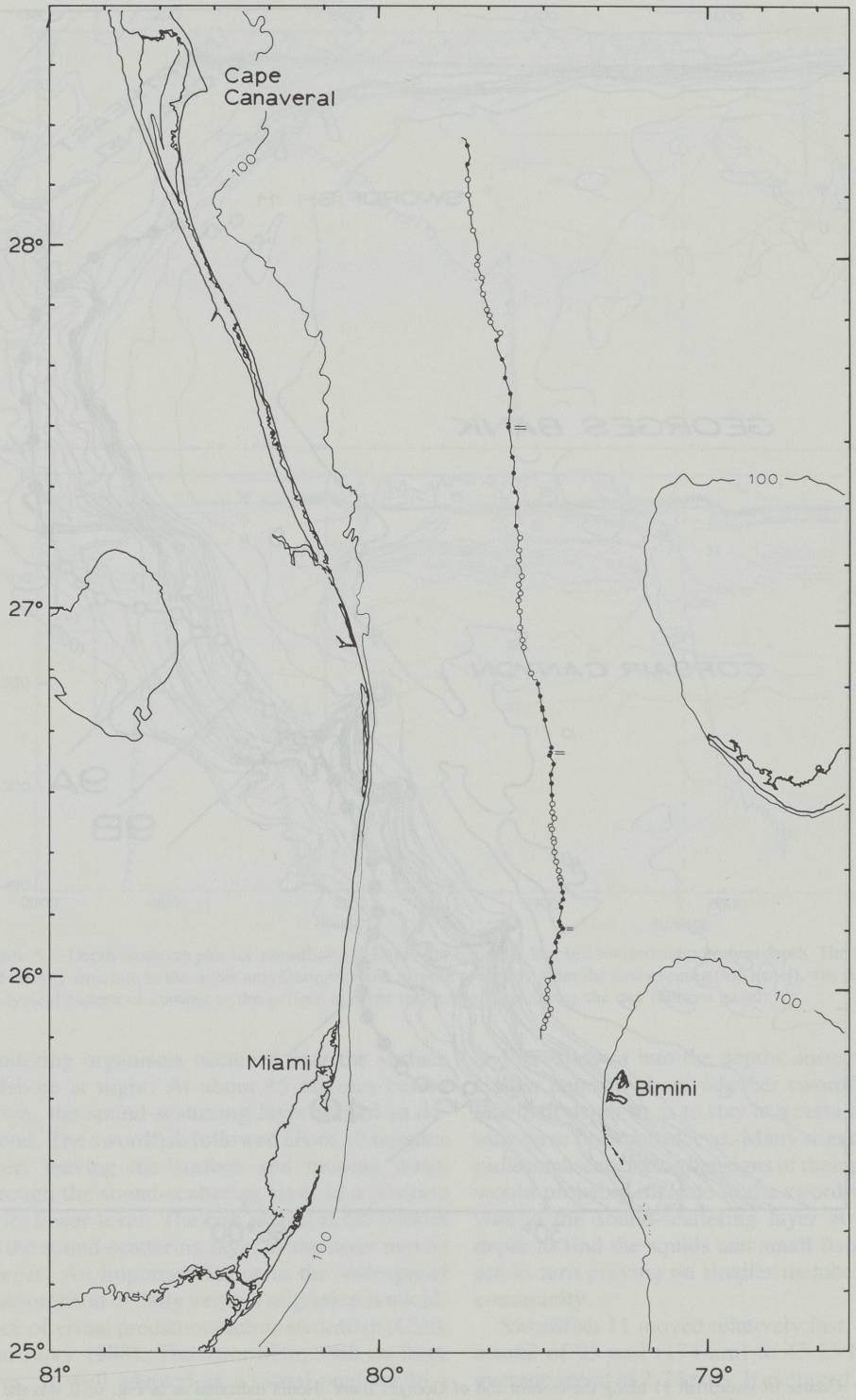

Figure 6. Course of swordfish 10. One-hour intervals indicated by open circles (day) and closed circles (night). Double tics indicate midnight. This fish drifted north along the axis of the Florida Current at about the same speed as the current.

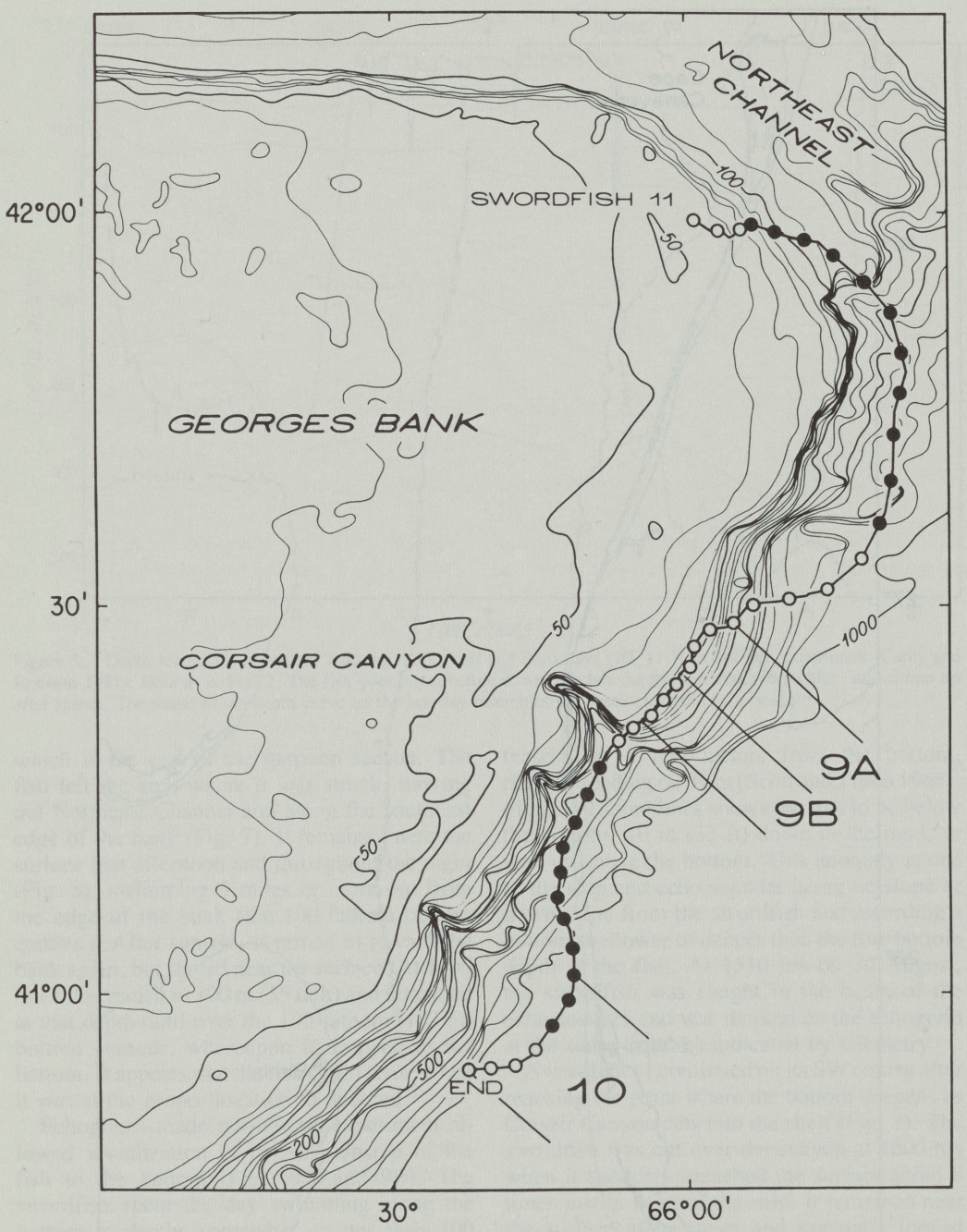

Figure 7. Course of swordfish 11 along the eastern end of Georges Bank. Hours indicated as in Fig. 6. It was the end of the harpoon season and the fish was probably leaving the area. It moved offshore over deep water at night and back to the bank in the day. Locations of Figure 9 and Figure 10 are indicated.

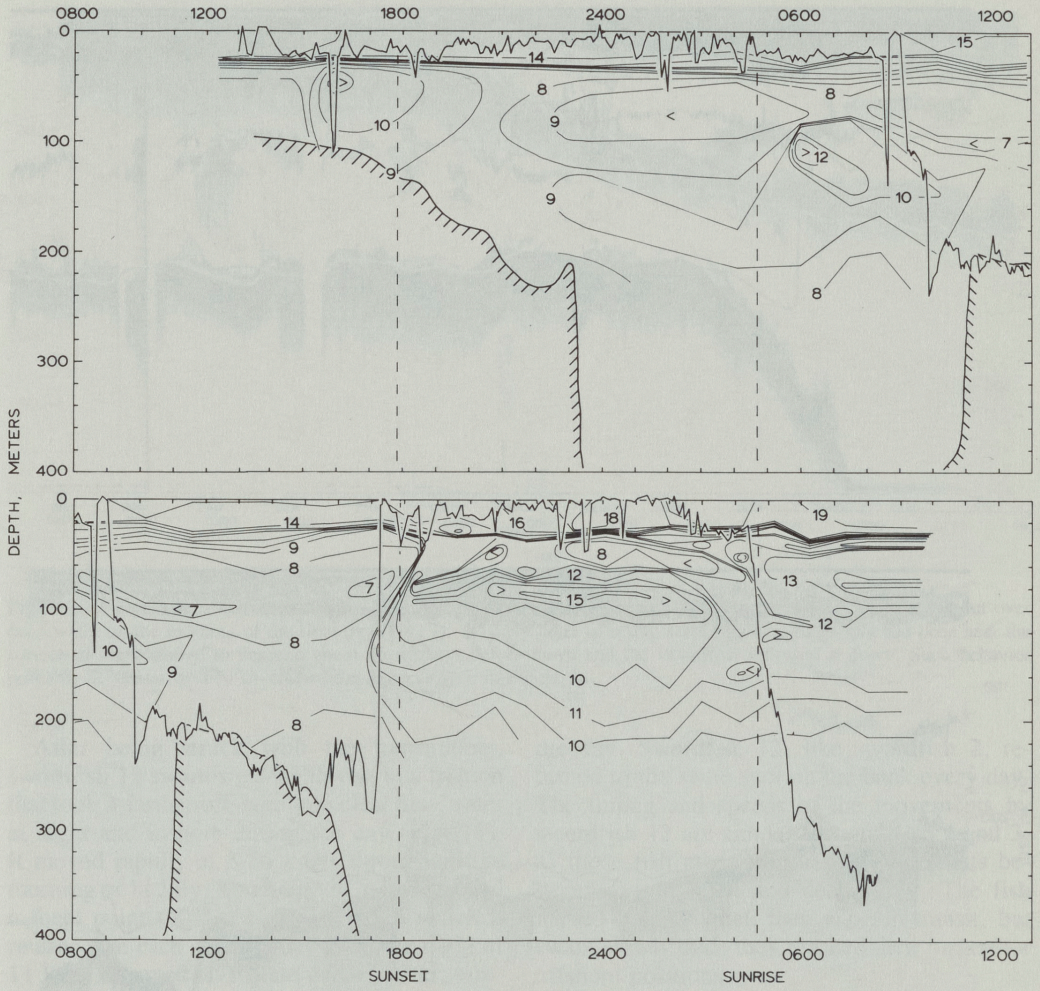

Figure 8. Depth-isotherm plot for swordfish 11. Data as in Figure 2. hatched line indicates bottom depth. The temperature and salinity structure in the water near Georges Bank is quite complex. After the first evening (top panel), this fish followed the typical pattern of coming to the surface at night and going deep during the day (bottom panel).

scattering organisms occurred near the surface offshore at night. At about 45 minutes before dawn, the sound-scattering layer started to descend. The swordfish followed about 10 minutes later, leaving the surface and moving down through the sound-scattering layer to a position at its lower level. The fish stayed at the bottom of the sound-scattering layer as the layer moved deeper. An important factor in the widespread phenomenon of daily vertical migration is avoidance of visual predators such as swordfish (Clark and Levy 1988). The swordfish, with its large eyes, is well adapted as a visual predator in a dimly lit environment, and is able to pursue its prey effectively while on the surface at night and to follow it into the depths during the day. Earlier concern about whether swordfish regulate their depth so as to stay in a certain isolume may have been misplaced. Many organisms, by bioluminescence or other signs of their presence, would probably indicate to the swordfish that it was in the sound-scattering layer at the right depth to find the squids and small fishes which are in turn preying on smaller members of that community.

Swordfish 11 moved relatively fast, covering a total of 95 nmi (174 km) in 43.25 hours, an average speed of 2.2 knots. It averaged 3.1 knots during a period of rapid movement between 2100 hrs on 29 August, when it swam out the

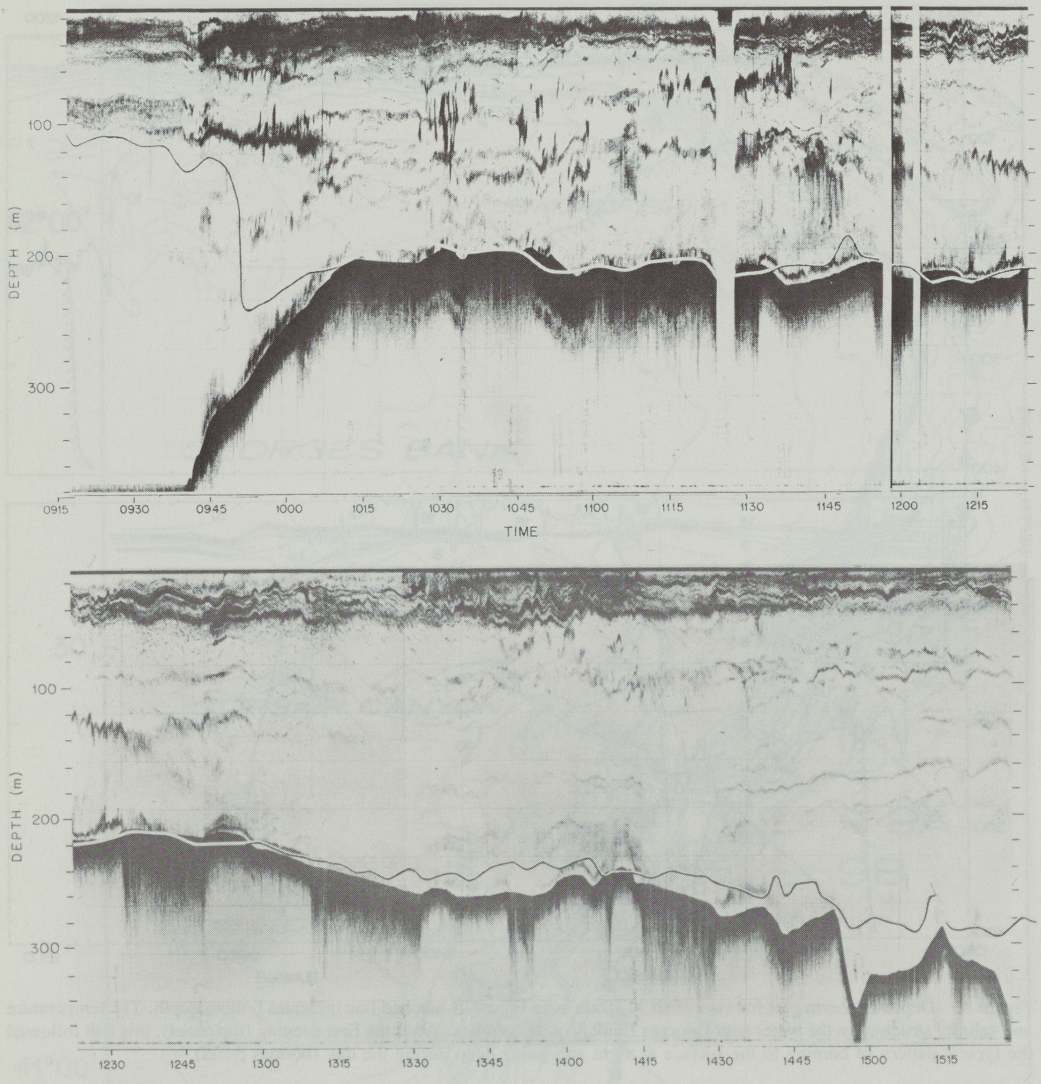

Figure 9 A and B. This is a composite figure showing the depth of swordfish 11 by acoustic telemetry superimposed on a 50 KHz echogram. The fish approached Georges Bank from seaward on the morning of the second day (Fig. 7). When over the bank it dropped down and spent the day swimming along the bottom. Although there are many echo returns in mid water the swordfish swam among schools of demersal fish near the bottom. At 1500 hours (lower panel, B), we located the swordfish in the beam of the echosounder and got a strong echo return from the fish.

Northeast Channel, and 0900 hrs on 30 August, when it returned to the 100-fathom curve (Fig. 7). When offshore on 31 August, it moved at a speed of 2 knots.

Swordfish 12, 10-14 July 1985

Swordfish 12 was a 150 kg (330 lb) fish which was found on the 50-fathom (92 m) curve on the southeastern edge of Georges Bank, between Corsair and Nygren Canyons (41°N, 66°32′W). A coccolithophore bloom had turned the water in this region a milky pastel lime-green, and the swordfish stood out in high contrast when near the surface. A multiplex transmitter was harpooned into the free-swimming fish, again by William Gell of the Fishing Vessel Gale, and it was followed with the R/V Cape Henlopen, out of Lewes, Delawre.

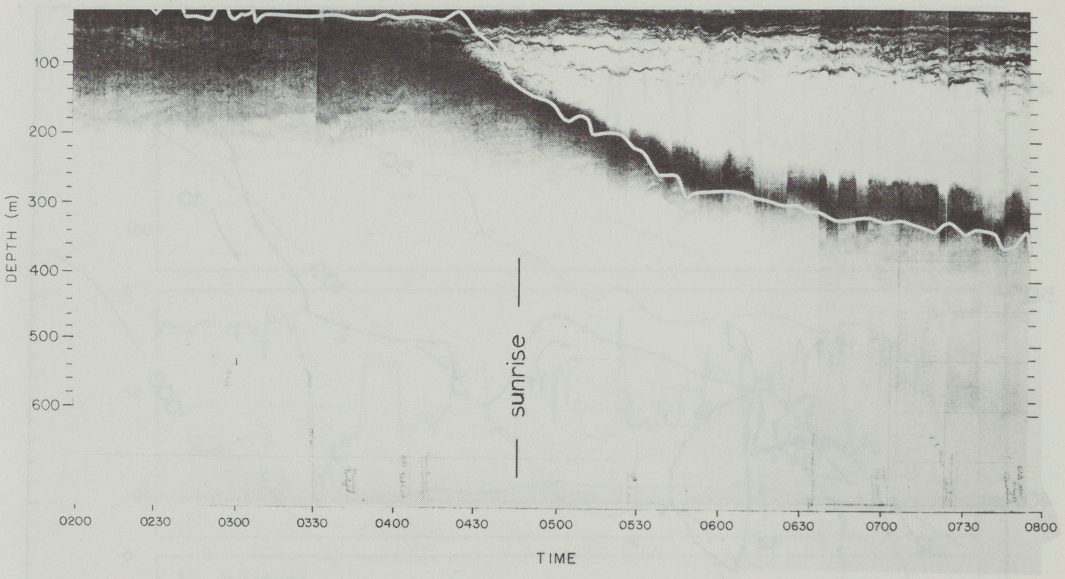

Figure 10. Depth record for swordfish 11 superimposed on 50 Khz echogram, as in Figure 9. The fish was out over deep water on the morning of the final day (Fig. 7). A heavy layer of sound-scattering organisms that had been near the surface at night started to descend about 45 minutes before dawn and the swordfish followed it down. Such behavior probably accounts for the "U"-shaped depth curve seen in Figure 5.

After being struck with the transmitters, swordfish 12 swam west-southwest in a fashion that took it farther offshore into clear blue water at night and inshore during the day (Fig. 11). It moved rapidly at 3.56 knots throughout the morning of 11 July. By afternoon, it had reached a focal point (40°43′N, 67°10′W) to which it returned on each of three days. On the night of 11 July, it moved off toward deeper water, turning back several hours before dawn and moving toward its focal position at a speed of 2.0 knots. On 12 July, it remained at the focus both day and night but, on the night of the 13 July, it again moved offshore. It reached the 100-fathom curve that night and moved slowly, at 1.32 knots, while over deep water. At 0300 hrs, it turned back inshore at a speed of 2.85 knots.

There is a similarity between the movements of swordfish 11 and 12 and those of swordfish 2 and 3 near Gorda Bank, Baja California, Mexico. At night, these swordfish (11 and 12) came to the surface and moved out over deep water. At dawn they headed back to the bank and spent the day on the bottom. Swordfish 11 was en route somewhere, rather than just moving back and forth, but the pattern was similar to what we had seen in Mexican waters: offshore on the surface at night, inshore and deep during the day. Swordfish 12, like swordfish 2, returned to the same spot on the bank every day. The timing and speeds of the movements by swordfish 12 are similar to swordfish 2 and 3, as those fish made their daily movements between Gorda Bank and deep water. The fish moved rapidly when they were in transit, but swam slowly once they reached their inshore or offshore positions.

The water temperature structure was exceedingly complex and would make the depth isotherm plot in Figure 8 seem simple. We failed to take a sufficient number of XBTs to define it properly. The fish moved between pastel green water on the bank in the day and bright blue water offshore at night. The blue water had a simple thermal structure with more or less monotonically descending temperature with depth. The pastel green water had multiple cold inversions between depths of about 20 and 60 meters. Temperatures were 16°C to 17°C (61°F to 63°F) on the surface, dropping as low as 8°C (46°F) in the cold layer, then back up to 14°C (57°F) below the cold layer. When swordfish 12 was inshore during the day, it associated with the cold inversion, usually swimming just below it, or in its upper margin. The echo sounder showed many reflective layers associated with the com-

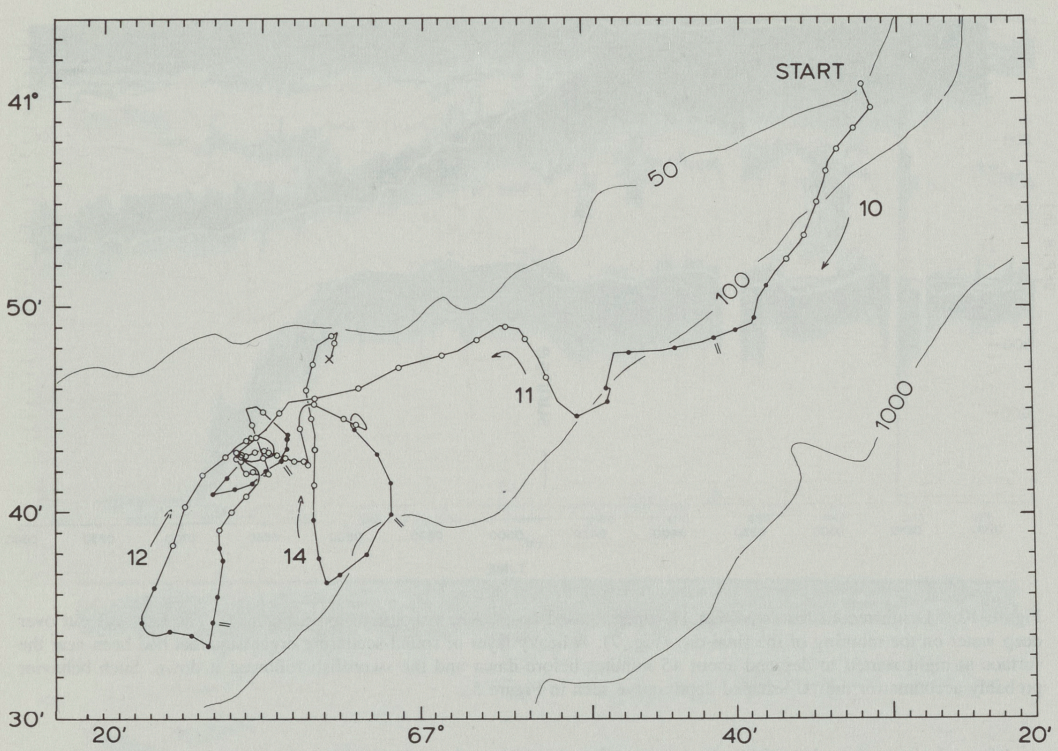

Figure 11. Course of swordfish 12 on the southeast corner of Georges Bank. Hours as in Figure 6, bottom contours in fathoms. Numerals near track are dates (during July 1986) and arrows indicate direction of movement. This fish moved offshore at night and came back onto the bank during the day. It seemed to find a focal point at 40°43′N, 67°10′W, moving off toward deeper water at night and returning to this place in the day. On 13 July it spent a 24-hour period within this 2-km area. The "X" at the end of the track is where the fish was harpooned and recovered.

plex cold inversion layer, and schools of fish frequently appeared to occur in the cold water, but the 14°C (57°F) water below the inversion was usually free of echo returns. The swordfish rarely went far into the 14°C bottom layer, even when the sounder occasionally showed schools of fish there. It was clearly not hunting for demersal fishes on the bottom.

Swordfish 12 was generally on or near the surface at night but, at about an hour before dawn, it would make a rapid descent which took it to the greatest depth reached that day (Fig. 12). It then slowly rose back to lesser depths. This "morning dive" was a prominent feature in depth records from swordfish off Baja California (Carey and Robison 1981). For the Pacific fish, we suggested that the dive was the beginning of the normal descent to greater depths at dawn, but which was cut short by the layer of low-oxygen water in that region (Wyrtki 1966). There was no such low-oxygen barrier for swordfish 12 on Georges Bank; it may simply have been retreating from an area unsuitable for foraging.

At 1220 on 14 July, when it came to the surface, the swordfish was harpooned to recover the fish, inspect the location of the thermistor dart, and look at the stomach contents. It contained 8 butterfish *(Peprilus triacanthus)* and two ruffs *(Centrolophus medusophagus,* both midwater species. This swordfish was not hunting demersal fish such as hake, but was feeding in mid water at the upper and lower margins of the cold inversion layer.

Body Temperature of Swordfish

Muscle temperature and water temperature were telemetered from swordfish 10, 11, and 12. Muscle temperature was only about 1°C (1.8°F) warmer than the water after the fish had been on the surface for several hours at night (Figs. 13, 14, and 15). This is quite different from the large temperature elevations found in the brains and eyes of swordfish (Figs. 1 and 3).

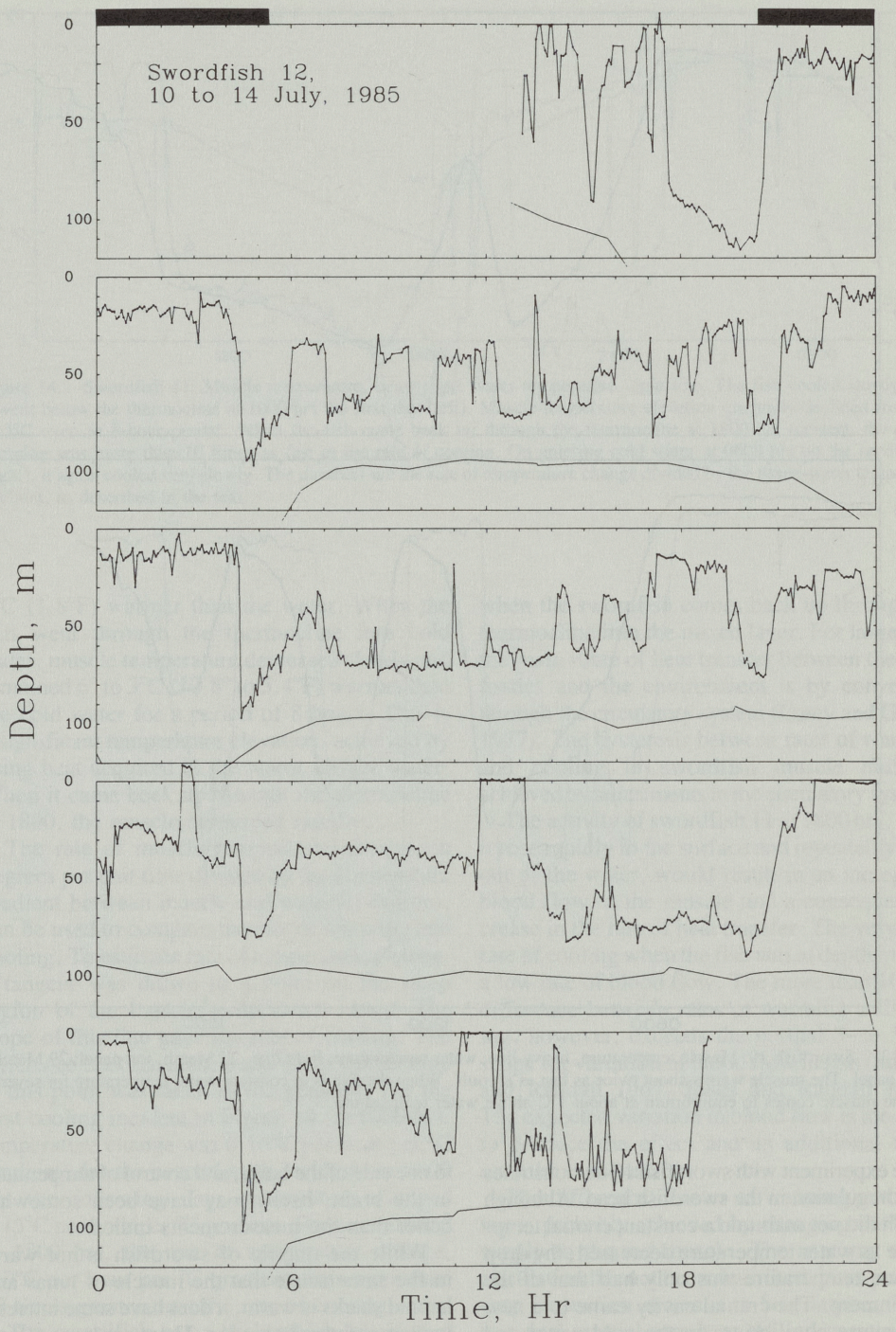

Figure 12. Depth for swordfish 12 (upper line) and bottom depth (lower line) for first day (top panel) continuously through fifth day (bottom panel). This fish was usually on the surface when over deep water at night (black bars on top panel) but in mid water when on the bank during the daytime. It spent much time in mid water, either above or below a cold inversion layer centered at about 50 m. It was harpooned at 1220 on the final day and recovered at 1900.

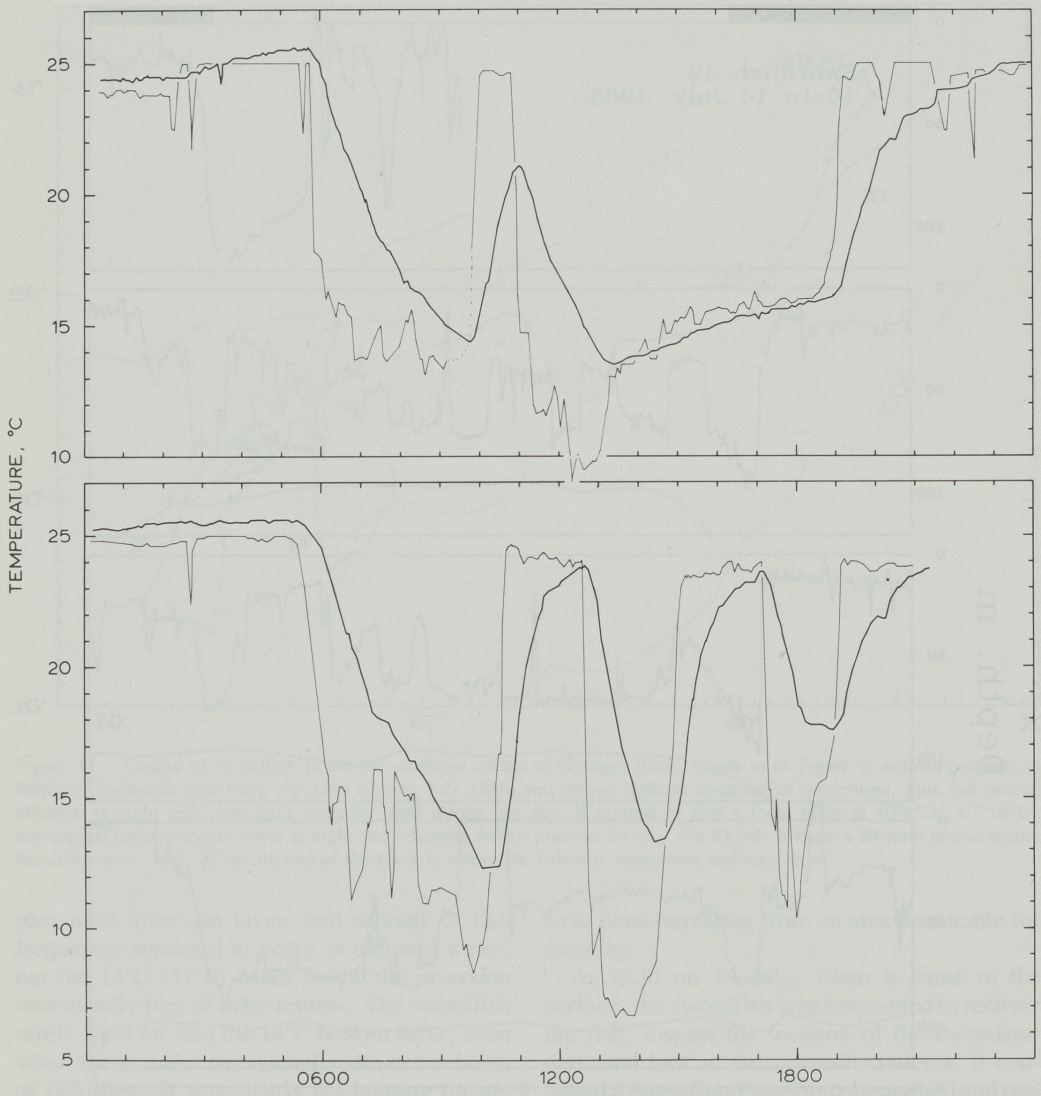

Figure 13. Swordfish 10: Muscle temperature, heavy line; water temperature, light line. 27 March, top panel; 29 March, bottom panel. The muscle warms about twice as fast as it cools. When the fish is at constant water temperature for several hours the muscle comes to equilibrium at about 1°C above water temperature.

The experiment with swordfish 10 demonstrates thermoregulation in the swordfish head. Although the fish did not maintain a constant cranial temperature as water temperature decreased, the drop in tissue temperature was only half that of the environment. The cranial cavity came to a new temperature equilibrium in the cold water and maintained a larger temperature elevation than when near the surface. This implies active physiological thermoregulation. Presumably, the point of measurement was actually in the fat to one side of the brain, and control of temperature in the brain, itself, may have been somewhat better than the measurements indicate.

While the muscle of swordfish is not warm in the same sense that the muscle of tunas and lamnid sharks is warm, it does have some interesting temperature behavior. There are large differences between rates of warming and cooling in the muscle. The best example of this is for swordfish 11 (Fig. 14). While on the surface at night the muscle came to a temperature about

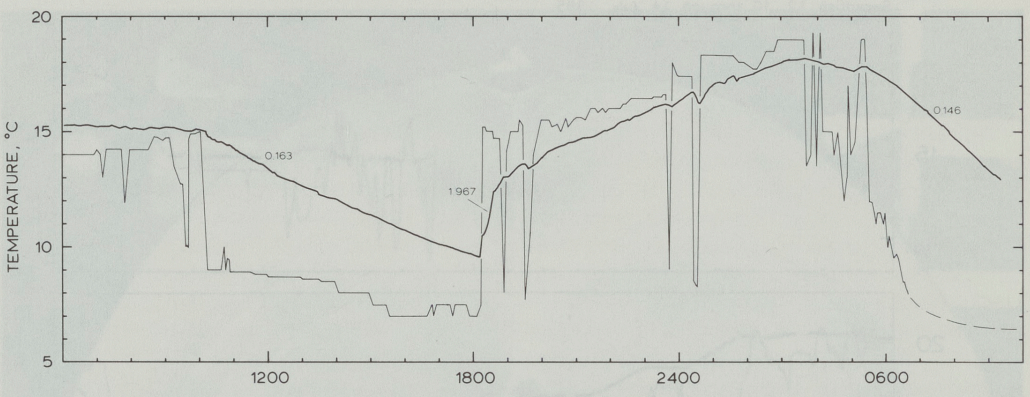

Figure 14. Swordfish 11: Muscle temperature, heavy line; water temperature, light line. The fish cooled slowly when it went below the thermocline at 1000 hrs the first day (left). Muscle temperature elevation gradually declined from 6°C to 3°C over an 8-hour period. When the fish came back up through the thermocline at 1800 hrs (center), the rate of warming was more than 10 times as fast as the rate of cooling. On entering cold water at 0600 hrs on the second day (right), it again cooled very slowly. The numbers are the rate of temperature change divided by the tissue-water temperature gradient, as described in the text.

1°C (1.8°F) warmer than the water. When the fish went through the thermocline into cold water, muscle temperature decreased slowly and remained 6° to 3°C (10.8° to 5.4°F) warmer than the cold water for a period of 8 hours. This is a significant temperature elevation, achieved by using heat acquired in the warm surface water. When it came back up through the thermocline at 1800, the muscle rewarmed rapidly.

The rate of muscle temperature change, in degrees per unit time divided by the temperature gradient between muscle and water in degrees, can be used to compare the rate of warming and cooling. To estimate rate of temperature change, a tangent was drawn to a point on the steep region of the muscle temperature curve. The slope of this line gave the rate of cooling. The difference between muscle and water temperature at this point was taken as the gradient. For the first cooling incident in Figure 14, at 1000 hrs, temperature change was 0.16°C per hour per °C gradient; for the second such incident, at 0600 hrs the following day, temperature changed 0.15°C per hour per °C gradient. For the warming at 1800 hrs, the rate of temperature change, 2.0°C per hour per °C gradient, was more than 10 times greater than the rate of cooling.

The swordfish has a trick which lets it cool slowly when it enters cold water. It can thus use heat acquired on the surface to stay significantly warmer than the water for many hours while at depth. The muscle rewarms rapidly when the swordfish comes back up through the thermocline into the mixed layer. For large fish, the main route of heat transfer between the deep tissues and the environment is by convection through the circulatory system (Carey and Gibson 1987). The hysteresis between rates of warming and cooling in swordfish muscle must be achieved by adjustments in the circulatory system.

The activity of swordfish 11 at 1800 hrs, when it rose rapidly to the surface and repeatedly leapt out of the water, would result in an increase in blood flow to the muscle and a consequent increase in the rate of heat transfer. The very slow rate of cooling when the fish was at depth implies a low rate of blood flow. The more than 10-fold difference between rates of warming and cooling, however, exceeds the normal 3- to 5-fold scope for variation of blood flow in fish (Stevens and Randall 1967, Jones and Randall 1978). The expected variation in blood flow is too small to produce the effect and an additional factor must be involved.

The difference in rates of warming and cooling is probably achieved by changing the blood supply to the red muscle. The anatomy of the circulation has not been described, but a preliminary inspection shows it to be complex. There is a dual arterial supply to the red muscle. One route is from the centrally located aorta and post cardinal vein through bands of parallel arteries and veins which could act as a heat exchanger. This is a simple rete, with only one to six layers

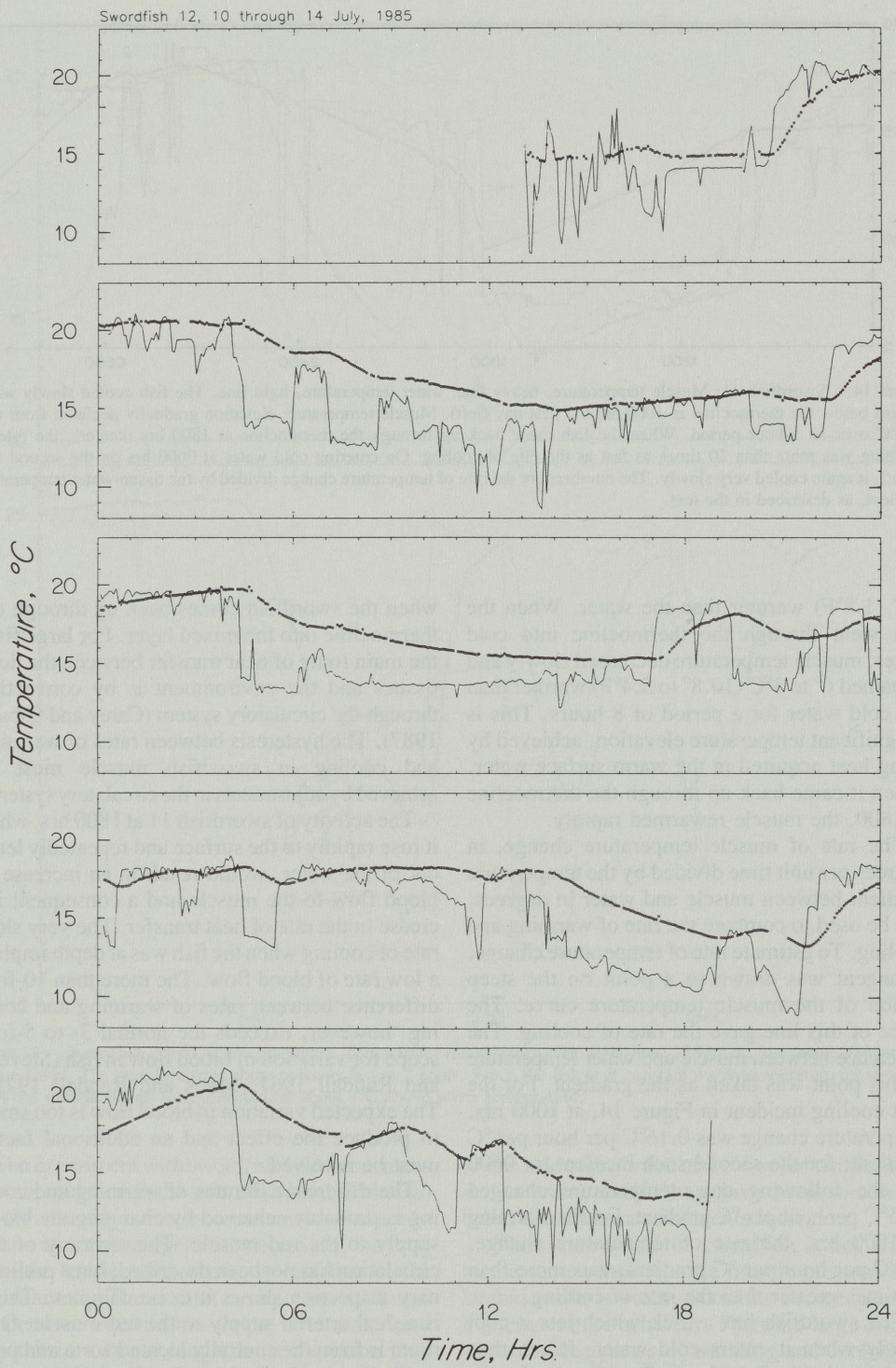

Figure 15. Swordfish 12: Muscle temperature, heavy broken line: water temperature, light line. First day (top panel) continuously through fifth day (bottom panel); in this experiment the rate of muscle warming is about 4 times the rate of cooling.

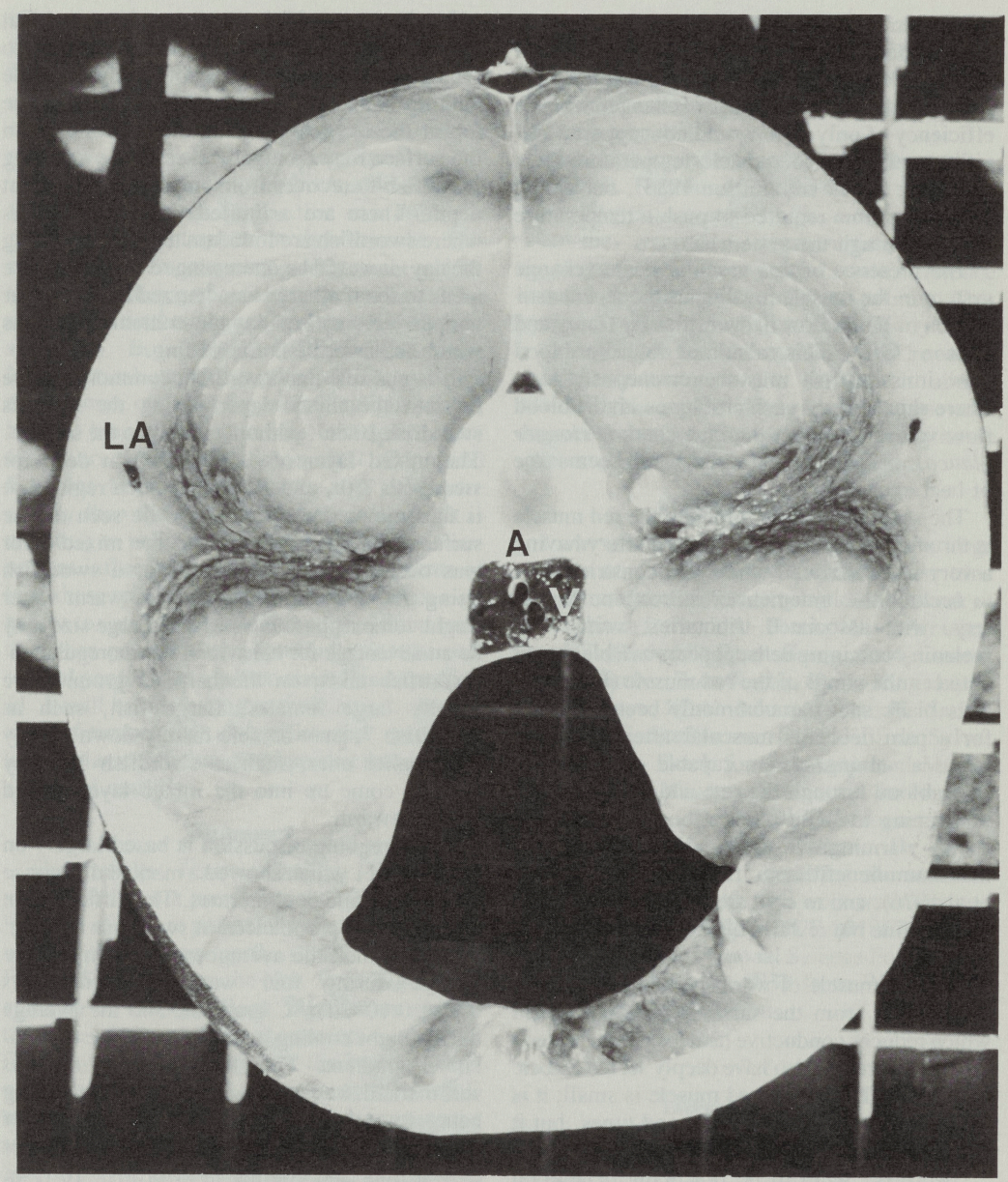

Figure 16. Cross-section of swordfish taken near the posterior end of the body cavity. The red muscle is located well in from the surface. It has two arterial blood supplies: one through a rete from the dorsal aorta (not visible in this photo) and the second through a black pigmented artery with an extraordinarily thick, muscular wall. The thick-walled artery can be seen lateral to the wings of the red muscle which are accentuated in this photo by use of a green filter. A, aorta; V, postcardinal vein; LA, thick-walled lateral artery.

of vessels. While it cannot be as efficient as the much more elaborate retia in tunas and lamnid sharks, it could still have a strong effect on the rate of heat ransfer. A heat exchanger with an efficiency of only 50% would not support a significant elevation of muscle temperature (less than 1°C; Carey and Gibson 1983), but would double the time required to push a temperature change through the system.

The presence of this vascular heat exchange system in the muscle invalidates the recent estimation of blood flow in swordfish by Carey and Gibson (1987). This calculated value for blood flow in swordfish must be erroneously low. There should be no such problem with the blood flow values given for the blue shark *(Prionace glauca),* because the blue shark still seems free of heat exchangers.

The second supply of blood to the red muscle is through a large laterally located artery having a very muscular wall which can constrict so as to occlude the lumen. In cross section, this artery, with associated tributaries, veins, and melanin-containing cells, appears as a black spot between the wings of the red muscle (Fig. 16.). This black spot has commonly been mistaken for a parasite. This muscular artery probably forms a valving system capable of closing to force blood through the rete and slow cooling, or opening to shunt blood around the rete and speed warming. It allows the fish to gain maximum benefit from its thermal inertia (Neil et al 1976), and to cool slowly when below the thermocline but rewarm quickly on return to the surface.

The red muscle of warm-bodied fishes is set deep, away from the surface, an arrangement which reduces conductive heat loss. It is interesting that swordfish also have deeply set red muscle (Fig. 16). The bulk of red muscle is small; it is not as red as in lamnid sharks and tunas, but it is located well away from the surface.

Swordfish seem to be practicing behavioral thermoregulation. Their red swimming muscles are arranged to acquire heat rapidly when on the surface and to retain this heat at depth. Swordfish thus use heat from the warm surface waters to maintain an elevated muscle temperature for many hours when in cold water at depth. It is likely that this adaptation is what brings swordfish to the surface during the day in some regions. They may be coming up to rewarm after a period of hunting below the thermocline. It was proposed earlier (Carey and Robison 1981) that swordfish in the eastern tropical Pacific come to the surface during the day to recover from an oxygen debt acquired while hunting in the poorly oxygenated water at the top of the oxygen-minimum layer. Basking on the surface may be a general response allowing swordfish to recover from stress experienced at depth. There are a limited number of places where swordfish are found on the surface during the day. It would be interesting to compare these areas to see if all are characterized by low water temperatures or low oxygen contents at depths where the swordfish are feeding.

It is possible that swordfish commonly move up into the mixed layer during the day, as swordfish 10 did, without coming to the surface. The mixed layer was 50 to 100 m deep for swordfish 7, 9, and 10 and, in such regions, it is uncommon for swordfish to be seen on the surface. On the banks, where the mixed layer was only 10 or so meters deep, a swordfish rising above the thermocline into warm water might come right to the surface. Large size may be an advantage for behavioral thermoregulation. Swordfish taken on the harpoon grounds are usually large females. Large fish, such as swordfish 7, may be able to stay down all day but smaller ones, such as swordfish 10, may need to come up into the mixed layer at mid day to rewarm.

The foregoing discussion is based largely on swordfish 11 which showed a marked difference in warming and cooling rates. The difference in rates was less pronounced in swordfish 12 (Fig. 15), for which the average rate of temperature change during four warming events was 0.99 ± 0.10°C/Hr/°C gradient, and the average during eight cooling events was 0.24 ± 0.04°C/Hr/°C gradient. This difference in rates is still marked, however, with the rate of warming being four times more rapid than the rate of cooling. There was even less difference in rates of warming and cooling in swordfish 10 (Fig. 13), for which the rate of warming — 1.19 ± 0.33 (6 events), was twice the rate of cooling — 0.69 ± 0.4 (7 events).

The large variation among these experiments, is disappointing, but is probably largely due to differences in location of the muscle temperature thermistor. Proximity to the red muscle should be an important factor. The thermistor in swordfish 11 was probably in or near the red muscle. The thermistor dart was found in recovered swordfish 12 among the neural spines

of the vertebrae, just posterior to the level of the first dorsal fin, a region of white muscle. The location of the thermistor in swordfish 10 was uncertian, but it was well anterior, in a region where there is little red muscle, and it may have been near the body cavity.

Despite the variability in the muscle temperature results, it does appear that swordfish can manipulate heat transfer in their muscle. This allows them to accumulate surface heat and retain it when they go below the thermocline. Blue sharks also do this, though less successfully than swordfish. Both sharks and swordfish make large vertical excursions. Swordfish stay down a long time, often for the entire daylight period, but the blue sharks swim up and down every few hours (Carey and Gibson 1987, Carey and Scharold 1989b). Blue sharks also cool more rapidly than the swordfish when at depth. It is tempting to believe that temperature has an important influence on the vertical movements of both these species. Swordfish have become ever harder to catch in the western north Atlantic and there has not been no opportunity for the past several years to get another result like swordfish 11. It will be interesting in the future to observe rates of temperature change in other species of large pelagic fish that swim up and down, especially the marlins.

Summary

The results from following five more swordfish since a previous account (Carey and Robison 1981) are presented here. All swordfish were in the western north Atlantic, one in the Florida Straits, two in the New York Bight area, and two on Georges Bank. Results are similar to those of the earlier experiments in that the fish may spend the day near the bottom when near a bank, but move off shore on the surface at night. In the open ocean, they swim near the surface at night and deep during the day. Swordfish on banks may come to the surface periodically during the day, perhaps to recover from stress experienced at depth. In the eastern tropical Pacific Ocean, this stress would be from low oxygen concentrations; in the Atlantic Ocean, the stress factor may be low temperature.

In experiments where cranial temperatures were measured, one swordfish was able to maintain a temperature elevation of 12°C (22°F). A second swordfish showed an ability to regulate cranial temperature. When it moved from 17°C (63°F) surface water to 8°C (46°F) deep water, cranial temperature changed from only 24°C (75°F) to 19°C (66°F). The 5°C (9°F) cranial temperature change in response to a 10°C (19°F) environmental change is a clear demonstration of thermoregulation.

Muscle temperature was recorded from three swordfish. The muscle cooled slowly when they went into cold water, but re-warmed rapidly when they returned to warm surface water. In the best example, there was a 12-fold difference between the rates of warming and cooling. This hysteresis allows the fish to cool slowly when it goes below the thermocline, but re-warm rapidly on return to the surface. It allows swordfish to keep their body temperature several degrees above water temperature for many hours when swimming below the thermocline.

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Physiology and Ecology of Brain and Eye Heaters in Billfishes

Barbara A. Block

Tunas and related fishes (Scombridae) have aroused the interest of physiologists for decades because of their unusual ability to regulate muscle temperatures above the ambient water temperatures. On the contrary, billfishes, which are abundant in both tropical and temperate seas, have received little physiological study despite the fact that they lead nomadic lifestyles similar to those of scombrids. Representative species such as the blue marlin *(Makaira nigricans)* migrate great distances across the oceans in search of prey.

Most fish are not capable of regulating their body temperatures above that of the ambient water temperature due to the significant heat loss associated with extracting oxygen from water. The large surface areas and thin membranes of fish gills facilitate heat as well as gas transfer between blood and water (Carey 1971). Billfishes have generally been classified as ectothermic or cold-blooded fish. This view of the group, which includes several of the largest teleost fish in the oceans, stems from the limited physiological studies on billfishes. A new picture of their thermal biology is emerging and it is now apparent that all billfishes have the capacity to warm their brains, and that some species such as the swordfish are also capable of behaviorally regulating their muscle temperature (Carey 1982, Block 1987a).

Tunas and mackerel sharks (Lamnidae) are well known for their ability to maintain elevated muscle, viscera, and brain temperatures (Carey and Teal 1966, Linthicum and Carey 1972, Carey et al 1985, Block and Carey 1985, Wolf et al 1988). Tuna muscles have high capacities for aerobic metabolism (and thus heat generation) and elaborate countercurrent heat exchangers to retain the heat generated in these muscles (Carey 1971, Gordon 1968, Guppy et al 1979). Most importantly, the internally located large aerobic muscle mass of tunas provides a metabolic heat source as these fast-swimming fish are always in motion. The ability to maintain a constant as well as elevated body temperature and, in particular, the warming of the locomotory muscles, is a strategy that allows the tunas to maintain an optimum performance at all ambient water temperatures although at high metabolic cost (Brill 1979, Gooding et al 1979, Graham and Laurs 1982).

Temperature exerts a major influence on the rates of biological and chemical reactions (i.e., metabolic reactions often decrease 2- to 3-fold with a 10°C decrease in temperature). Temperature fluctuations, such as those encountered during passes through the thermocline, have a significant effect on the physiological function of muscle (Rome et al 1984). Tunas and mackerel sharks diminish the effects of rapid temperature changes on muscle function by warming the swimming muscles, and gain some advantage in terms of power output by operating their muscles at the elevated temperatures (Johnston and Brill 1984, Rome et al 1984).

Despite the obvious advantage of being warm bodied, and the remarkable convergence in physiological mechanisms for attaining endothermy among the scombrid fish and mackerel sharks, the billfishes are utilizing a unique physiological strategy to achieve a limited degree of thermal independence. Recent studies on the physiology and biomechanics of swordfish *(Xiphias gladius)* and blue marlin indicate

that billfishes have several specializations which increase their performance and mobility in the oceans (Carey 1982, Johnston and Salamonski 1984, Block 1986a, Suarez et al 1986, Dobson et al 1987, Hebrank et al 1990). The focus of this paper will be on *one* of the extraordinary physiological specializations of these fish that enable them to remain apex predators in the oceans without having to employ the energetically costly strategy of endothermy.

Billfishes, such as the blue marlin and black marlin, *(M. indica),* lead a lifestyle that is in many respects similar to that of the scombrids upon which they often feed (Brock 1984, Baker 1966), yet do not support the large volume of red muscle that provides the tunas with their superior locomotor performance and apparent independence from water temperature. Unlike their tuna and lamnid shark counterparts, the billfishes maintain only a limited region of endothermy that involves keeping the brain and eye warm (Carey 1982, Block 1986a). Results from telemetry experiments with free-swimming swordfish, reported elsewhere in this volume by Carey, and in earlier studies (Carey 1982), provide direct evidence that swordfish are capable of regulating their brain temperatures. This ability is especially important for protecting the central nervous system of swordfish from the rapid temperature changes experienced during excursions through the thermocline (Carey and Robinson 1981).

Cross-sections through the body musculature of billfishes demonstrate why these fish are not able to elevate their body temperature in the same manner as do the tunas and mackerel sharks. A blue marlin has considerably less red aerobic muscle fibers, and thus a lack of an internal heat source, than a yellowfin tuna *(Thunnus albacares)* of similar body size (Dobson et al 1987, Johnston and Salamonski 1984). The warm tunas have as much as 12% of their muscle mass associated with the red aerobic swimming muscle (Graham and Laurs 1982). How important is having red muscle for both endurance and heat production purposes? The red muscles of fish that power sustained swimming muscles have some of the highest mitochondrial volumes and myoglobin contents in the animal kingdom (See Table 12 for mitochondrial volumes; myoglobin in yellowfin tuna red muscles is 10-fold higher than in terrestrial bird and mammal red muscles; Block and Wittenberg unpublished data). Thus, when red muscle is contracting, substantial amounts of heat are generated due to the inefficiency of conversion of oxidative energy into mechanical work. It is the presence of the prominent aerobic muscle mass along the midline that enables tunas and lamnid sharks to obtain the benefits of endothermy. Biochemical studies indicate that marlin muscle tissue has the same aerobic capacity as tuna muscle (Suarez et al 1986). The presence of a smaller amount of red muscle diffusely distributed in the body musculature, however, indicates that billfishes cannot employ the same thermal strategy as the scombrids and lamnid sharks.

Physiological studies of the contractile properties (force production, power output) of billfish muscles suggest that contractile performance is relatively temperature independent between 15°C and 25°C (Johnston and Salamonski 1984). Results from the cited study demonstrated that marlin red muscle has a Q_{10} of 1.1, which is low compared to tuna red muscle having a Q_{10} of 3. Thus, the presence of heater organs warming the brains and eyes, combined with muscles that generate force in a constant fashion over the range of temperatures encountered in their daily movements, indicates that the marlins *(Makaira* spp), and perhaps all billfishes, have a limited degree of thermal independence from water temperature.

Table 1. Mitochondrial volumes of aerobic cells.

Cell	Mitochondrial Volume as % of Cell Volume	Reference
Pigeon Pectoralis	29	James and Meek 1979
Brook Trout Red Muscle	31	Johnston and Moon 1981
Finch Cardiac Muscle	34	Bossen et al 1978
Mackerel Red Muscle	36	Bone 1978
Insect Flight Muscle	44	Elder 1975
Anchovy Red Muscle	45	Johnston and Moon 1981
Billfish Heater Cells	63	Block 1986b

The Heater Organ of Billfishes

What truly makes billfishes unique, in terms of their thermal strategy, among not only the teleost fish but within the entire animal kingdom, is the presence of a mass of heat producing (thermogenic) tissue in the head which warms the brain and eyes (Carey 1982, Block 1986a, 1986b, 1987a). The specialized thermogenic organ acts as a furnace and keeps the brain and eye temperatures significantly above that of the ambient water temperature (Carey 1982, Carey this volume). The heater organ supplies both the brain and eye with warm blood (Block 1986a), and provides all of the billfishes with the physiological capability of regulating their brain and eye temperatures.

The remarkable telemetry experiments with free-swimming swordfish, reported elsewhere in this volume by Carey, in which a thermistor probe was placed inside the cranial cavity, indicate that swordfish are able to maintain a relatively high and constant brain temperature during periods when water temperature is fluctuating (see Figure 1 in paper by Carey in this volume). The results from this experiment and others (Carey 1982) demonstrate unequivocally that swordfish are actually regulating their brain temperatures: generating more heat from the thermogenic organ when deep in cool waters and turning down this furnace (and heat production) at the surface. The ability to maintain a constant temperature in the cranial region, while ambient temperature is changing, implies that the heater organ is regulated by a temperature dependent neural or hormonal control. No similar attempts have been made to monitor temperature in the brains of free-swimming istiophorids, but surface measurements taken on sport-fishing boats, immediately after a fish was captured, demonstrate elevations in temperature above that of the surrounding water (Fig. 1). Given that the telemetry records from swordfish indicate that the temperature in the cranial cavity approaches ambient when the fish returns to surface waters after a deep dive, it is clear that there is diminished heat generation at the surface. It appears likely that the very low elevations in temperature seen in the measurements from the istiophorid heater organ are due to the fact that the temperature recordings are being taken in warm surface waters (26°C).

In all billfishes, the superior rectus muscle, one of four rectus muscles located posteriorly to the eyes and close to the brain, is modified into a novel type of muscle tissue that generates heat (Fig. 2). A portion of this eye muscle contains normal muscle fibers, but the rest of the muscle is composed of a muscle cell type that is structurally and functionally specialized for generating heat (Block 1987a, Block and Franzini-Armstrong 1988). The orbital regions surrounding the eye muscles and associated heater organs are exceptionally well packed with a fatty adipose tissue that most likely functions as an insulator but may also be the source of fuel for the heater.

Associated with the presence of a heater organ in the head of a billfish is a highly unusual blood supply to the brain and eyes (Carey 1982, Block 1986a). The entire carotid circulation supplying both the brain and eyes is diverted through the modified eye muscles on both sides of the head. This allows for warming of the blood after it passes from the gills. Most of the blood that courses through the heater organ passes to the back of the retina providing a convective supply of warm blood to the eye. To keep the heat being produced in this tissue from being dissipated at the gills, a large vascular countercurrent heat exchanger is situated at the base of the heater organ.

The morphology of the heater organ among the different species of billfishes is similar. Once removed from a billfish, it is difficult to distinguish between the eye muscle and the heater tissue except for variations in size of the tissues involved (Block 1986a). Thus, the presence of heater organs in the heads of billfishes, results in a set of unique internal features in the crania of Xiphiidae and Istiophoridae which provides a suite of characters that supports monophyletic classification of these two families of fish (Table 2). The major difference between the heater organs of the Istiophoridae and Xiphiidae is the large size of the heaters in *Xiphias* (heater organs are 2.5-fold larger in mass than in a blue marlin of similar size), coupled with the loss of the basisphenoid bone beneath the brain. The loss of this bone, noted by several researchers (Gregory and Conrad 1937, Carey 1982), facilitates conductive heat transfer between the heater organ and the brain in *Xiphias*. The large size of the brain and eye heater in swordfish is most likely associated with a greater capacity for heat generation and an increased ability to warm the brain and eyes over larger thermal gradients.

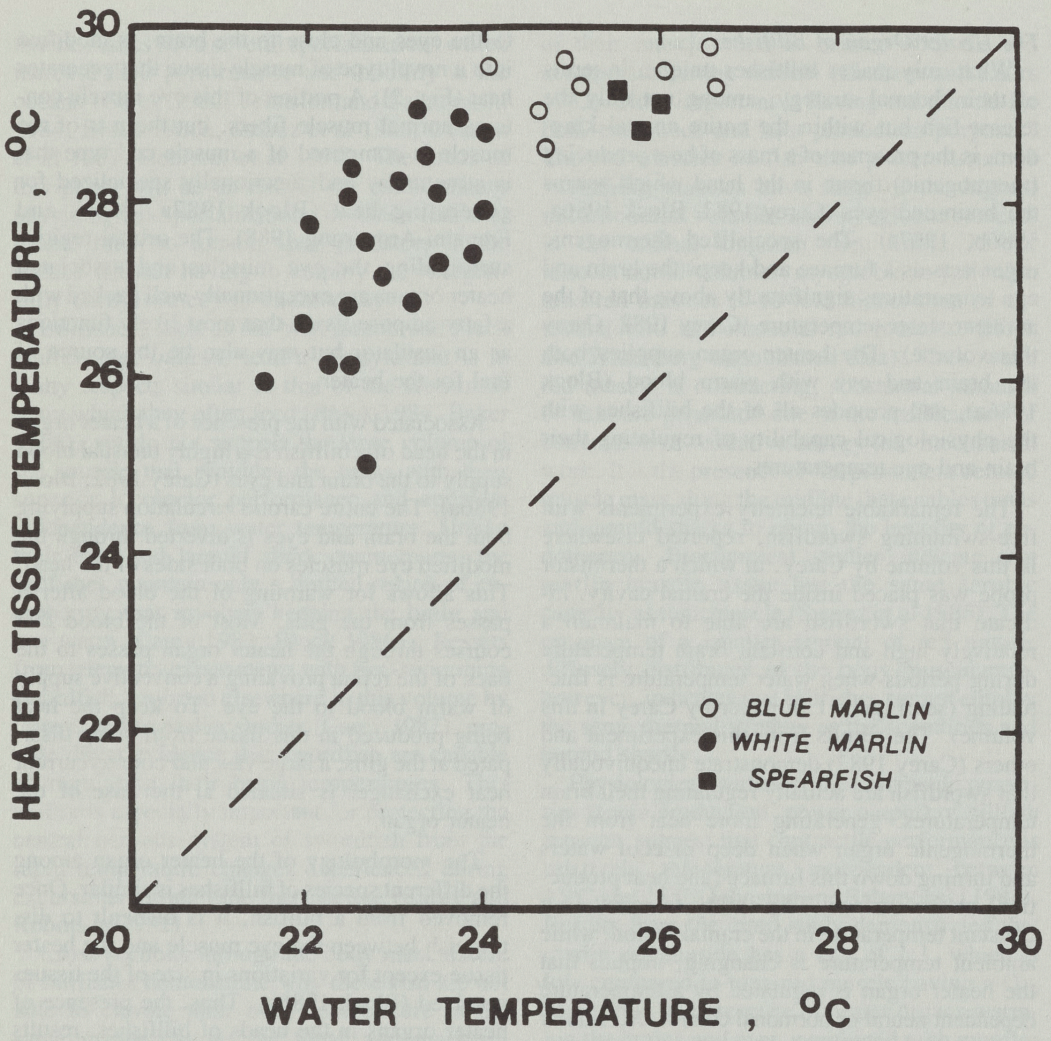

Figure 1. The relationship between surface water temperature and heater tissue temperature in blue marlin *(M. nigricans)*, white marlin *(T. albidus)*, and shortbill spearfish *(T. angustirostris)*. The measurements are taken one to three minutes after landing billfishes captured on hook and line. Blue marlin and spearfish measurements were from the Kona coast of Hawaii in August and the North Carolina coast in June and September. White marlin measurements were obtained in September off the North Carolina coast.

The major outlet for warm blood leaving the heater organ is to the eye (Block 1986a). This circumstance indicates that the organ most likely has a major function as an eye heater. Visual responses in many vertebrates, including fish, have been shown to be temperature sensitive, and warming of the retina in the billfishes is most likely a mechanism for improving the visual response time to a stimulus (Ali 1975). Because the warm supply of blood from the heater is presumably low in oxygen (after passage through the heater organ, an oxygen consuming tissue), an additional supply of well-oxygenated blood to the eye is required. The oxygenated blood supply to the retina in billfishes, particularly the blue marlin, is by way of an exceptionally large choroid rete mirabila (Fig. 3). This structure is found in most teleost fish and functions as an oxygen delivery system for the retina (Wittenberg and Wittenberg 1974). Why the istiophorids have such a large choroid is not entirely clear but is an indication, along with the presence of the heater organ, that they are active visual predators.

The heat generating muscles have been studied in detail in the marlins, sailfish, and

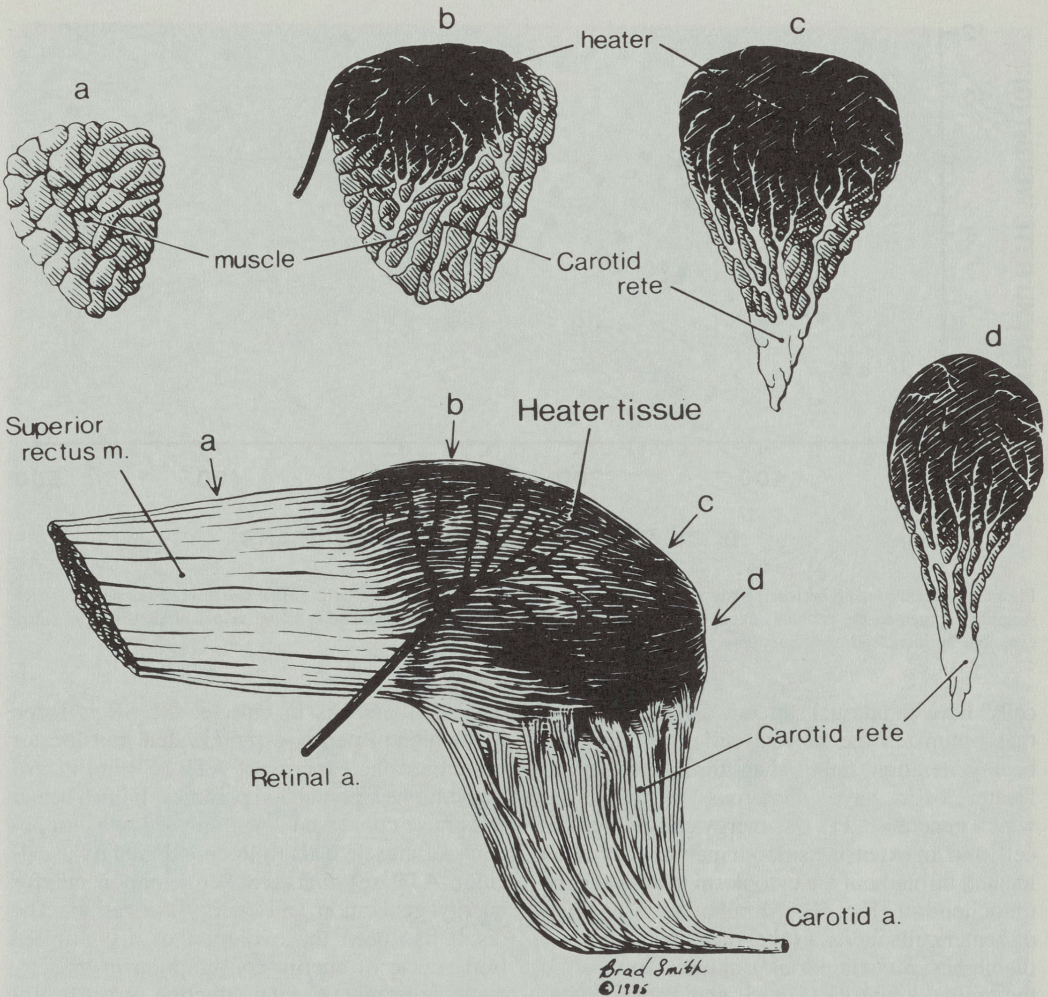

Figure 2. Diagram of the superior rectus eye muscle and heater organ of an istiophorid billfish. Cross-sections a-d reveal the transition from muscle to heater which occurs in this muscle. Blood supplied to heater is in the form of a counter-current heat exchanger at the base of the heater and blood leaving the heater courses to the eye via the retinal-heater artery (from Block 1986a).

spearfish due to the accessibility of these fish close to a laboratory such as that of the Pacific Gamefish Research Foundation in Kona, Hawaii. Here, where fresh samples can be obtained within 30 minutes of capture, biochemical and structural work has yielded results concerning how this unusual muscle tissue generates heat (Block 1986b, 1987a; Block and Franzini-Armstrong 1988). In the istiophorids, the muscles are composed of modified muscle cells that are structurally distinct from all other types of muscle in the animal kingdom. The billfish "heater

Table 2. Characters associated with the presence of a heater organ in Istiophoridae and Xiphiidae.

1. Superior rectus muscle modified into a heat generating tissue.
2. Heater cells have mitochondria and muscle cell internal membranes but lack organized contractile filaments.
3. Carotid arteries course through superior rectus muscle.
4. Presence of a carotid rete mirabilia.
5. Eye receives blood from retinal-heater artery as well as from a well developed choroid circulation.
6. Presence of foramen in sclerotic bone for passage of retinal-heater artery to the eye.

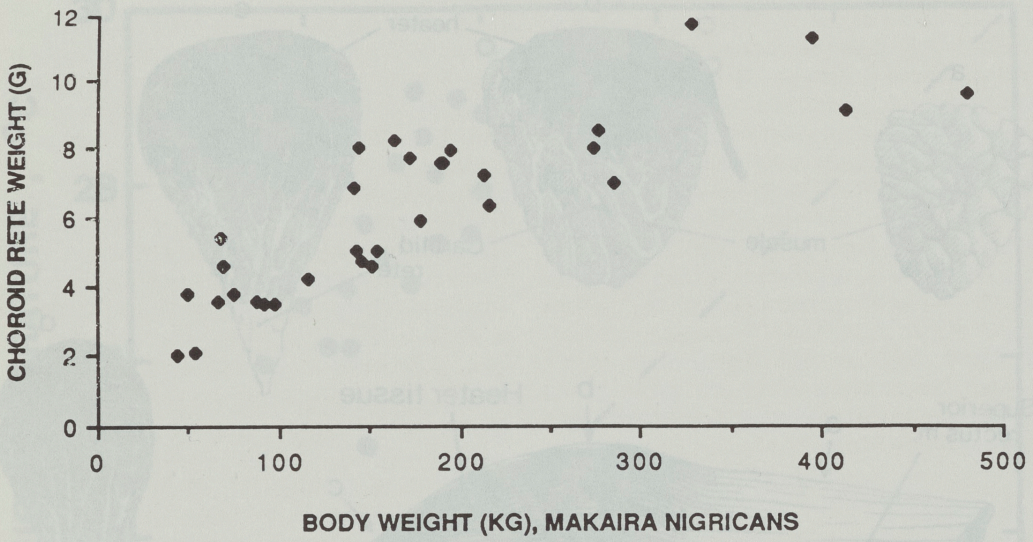

Figure 3. Relationship between body size and choroid rete weight in the blue marlin *(M. nigricans)*. The choroid which supplies oxygen to the retina is exceptionally large in this species of billfish. These active visual predators have warm eyes and an increased oxygen supply to the retina.

cells" have an unusual structure and biochemistry that optimizes the muscle cell machinery for heat generation rather than force production. Heater cells have numerous mitochondria, which generate ATP, the energy currency of the cell, and an extensive smooth membrane system located throughout the cytoplasm in between the mitochondria (Fig. 4). Morphometric analysis of heater cells indicates that they appear to have the highest mitochondrial packing of any cell in the animal kingdom (Fig. 5, and Table 1). Recent results have also shown that this tissue has a high myoglobin content of 400 umoles/kg wet weight (Wittenberg and Block unpublished observations). Carey (1982) has also demonstrated a high cytochrome C content in the swordfish heater organ. All of these results indicate that the heater organ has an extraordinary oxidative capacity. This capacity is evident in the telemetry results mentioned above, given that heat production from 200 to 300 grams of heater tissue is sufficient to keep the swordfish brain warm during long periods at great depths.

The extensive membrane system of the heater cell (see Fig. 4) houses the actual "furnace" of the heater cell. Biochemical and structural results indicate that most of the internal network can be identified as sarcoplasmic reticulum (SR), the internal membrane system that is responsible for storage of calcium in normal muscle fibers. As in muscle, the SR is laden with calcium pump, a protein that translocates calcium at the expense of ATP (CP in Fig. 6). Thus, for heat production purposes, billfish heater cells have conserved and amplified two components of muscle cells (mitochondria and the calcium ATPase) that are key components for energy generation and energy utilization. The result has been the evolution of a controlled futile cycle of energy consumption in muscle, that results only in heat production and no useful work.

In normal muscle cells, it is the release and reuptake of calcium from the sarcoplasmic reticulum (SR) that initiates and controls muscle contraction and relaxation. The loss of the contractile proteins, coupled with the retention of the membranes that regulate the cycling of calcium in heater cells, has resulted in an altogether new functional relationship between the components of the modified muscle cell. In heater cells, release of calcium from the SR initiates thermogenesis by stimulating the splitting of ATP by the calcium pump. The release of free energy that results from ATP hydrolysis is not translated into any mechanical work and is thus liberated as heat. The heater cell will generate heat as long as calcium is present. The numerous mitochondria, capillary supply, and rich myoglobin content indicate that heat generation

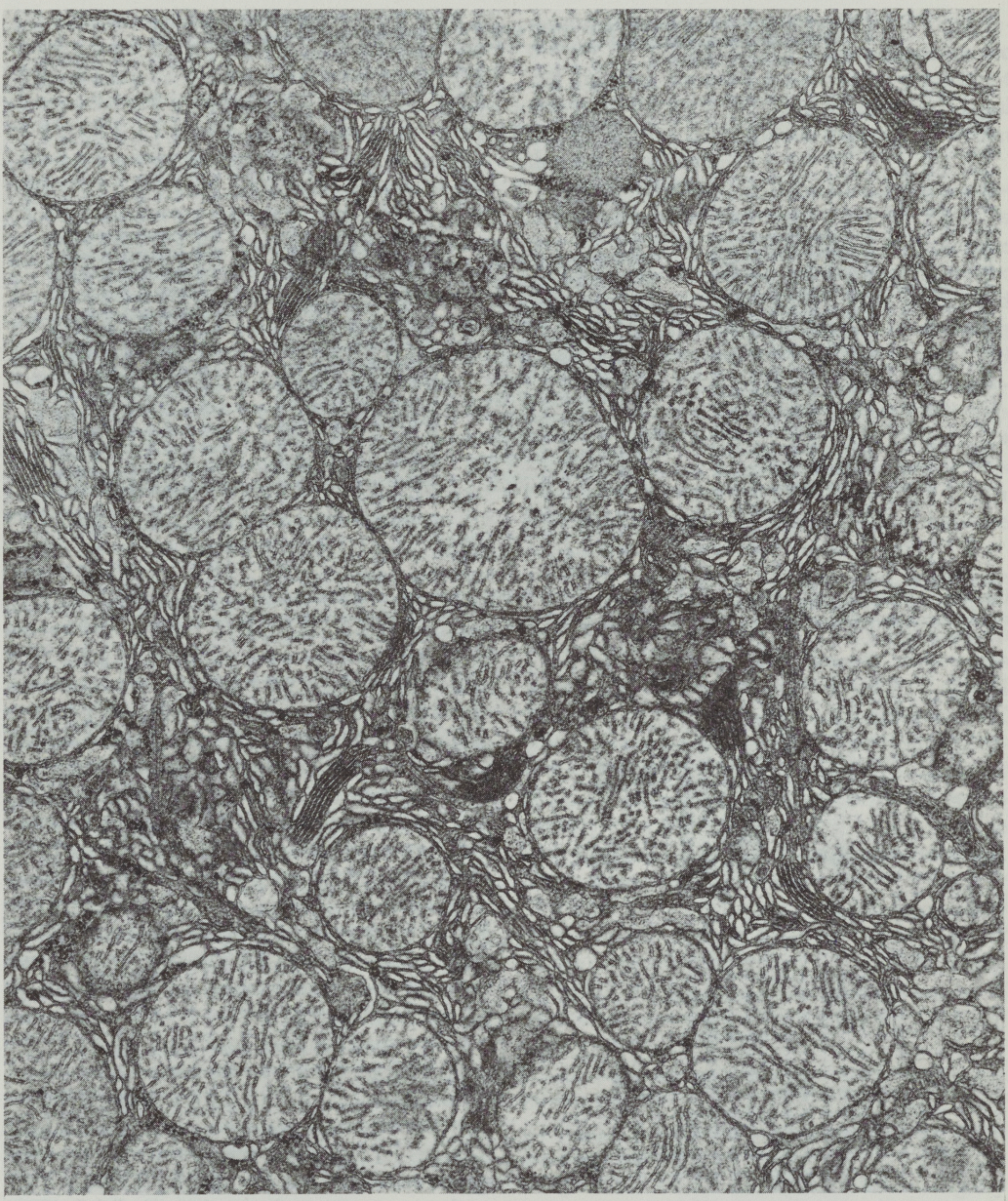

Figure 4. Electron micrograph of a heater cell revealing the major components, mitochondria and smooth membranes, found in these unusual muscle cells. Organized contractile proteins are not present in heater cells.

could continue for long periods of time. One analogy for comparison of this decoupling of the muscle cell is to imagine what would happen if the axle from a car was removed but the engine and the rest of the car remained intact. When the motor was running only heat would result instead of transmission of energy generated by the engine into movement.

In normal muscle, the signal that triggers calcium release from the SR is thought to be transmitted via depolarization of the transverse tubule system of the muscle cell. This latter event is precisely regulated by the firing of the nerve supplying the muscle. A remarkable transverse tubule system is also present in heater cells, implying that there is motor nerve control of the

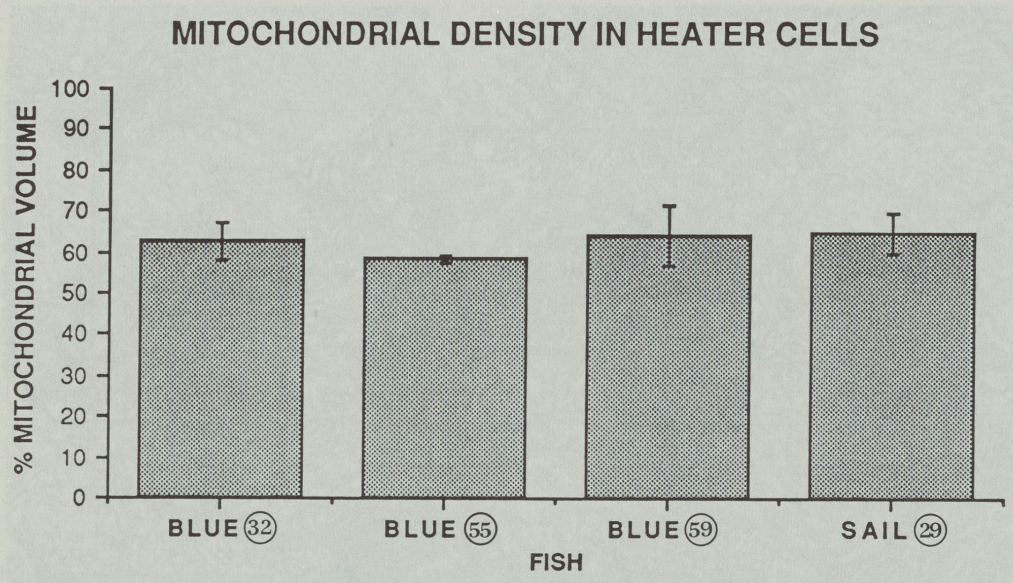

Figure 5. Morphometric analysis of mitochondrial density in heater cells from blue marlin and sailfish. Each histogram represents point-counting results from 50 micrographs. The size of the billfish is indicated in kg in the data-label.

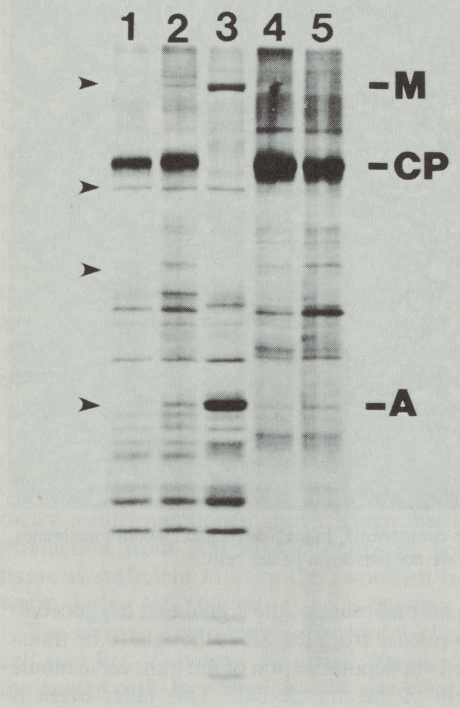

Figure 6. SDS-PAGE gel of sarcoplasmic reticulum membranes from muscle (lanes 1-3) and heater tissue (lanes 4 and 5). Heater has a high quantity of the calcium pump protein (CP) and virtually no contractile proteins (myosin and actin).

heat generating cycle (Block and Franzini-Armstrong 1988). Recent findings have indicated that the eye muscles associated with heat production are capable of contracting after stimulation of the nerve supplying the muscle, but that the portion of the muscle associated with heat production did not contract. Such experiments indicate that neural control is present in this muscle. The end result in the heater cell is that it is possible that the same nervous signal that triggers the contraction of a normal fish muscle fiber, is controlling heat production in the modified muscle cell.

Given that the heat generating cycle in the heads of these fish appears to be under the control of the normal neuromotor pathway for regulating muscle contraction and relaxation, then a simple pathway for regulating heat production is readily apparent. When a swordfish descends into cooler waters (or perhaps when the fish is visually active), nervous impulses activite the thermogenic muscles in an event which leads to heat production instead of contraction beneath the brain. The end result is more warm blood to the eyes and brain, which should buffer these tissues from changes in temperature.

Ecology of Heater Organs, or Why Have a Brain Warmer?

Many species of mammals, birds, and fish

are able to maintain their brains and eyes at temperatures different from those of their body cores (Baker 1979, Linthicum and Carey 1972, Carey 1982, Block and Carey 1985). The ability to regulate selectively the temperature of the blood perfusing the brain and eyes is of vital importance to many species of terrestrial and aquatic vertebrates. The central nervous system in vertebrates is more sensitive than other tissues to temperature variations, and chilling or heating the brain often has adverse effects that can be lethal (Prosser and Nelson 1981). Rapid temperature changes disrupt fish behavior due primarily to the effects on the central nervous system.

Brain and eye warming is apparent in several groups of large pelagic fish and two different strategies have been identified. The warm fish such as the tunas and mackerel sharks use vascular heat exchangers in the circulation to the brain and eyes (Linthicum and Carey 1972, Block and Carey 1985). The vascular anatomy permits the conservation of heat in the cerebral and ocular tissues. In addition, the sharks are able to tap into the large heat source represented by the red aerobic swimming muscles that comprise a portion of their muscle mass (Wolf et al 1988). As already mentioned, heater organs are present in billfishes because they lack the large red-muscle volume (and, hence, heat source) and appropriate circulation for shunting warm blood to the head that are found in tunas and mackerel sharks. The presence close the brain of large amounts of red aerobic muscle tissue (the six eye muscles provide more than 1 kg of muscle tissue beneath the brain of a large fish or shark) appears to have provided the raw material for natural selection to generate a heater out of muscle in fish (Carey 1982).

Most of the structural and biochemical studies indicate that heater cells are actually muscle cells expressing a program that is phenotypically different from that of a typical muscle fiber (Block 1986b, 1987a; Block and Franzini-Armstrong 1988). Such plasticity in muscle fiber expression is not unprecedented in fish, for electric organs have also developed from muscles in many different fish. Much of the structural evidence gathered on heater tissue in adult and juvenile fishes suggests that there is a transition from muscle into heater tissue during the life cycles of these fish. This event would imply that heater cells begin expressing a normal muscle program and switch to the heater phenotype at a particular stage during development (i.e., when a swordfish begins making diurnal vertical movements). It is possible that muscle fibers in the eye muscles produce heater cells, instead of muscle cells, in response to a hormonal signal to provide for an increased capacity to warm the brain and eyes.

As mentioned above, the major difference between istiophorid and xiphiid heater organs is one of size (Fig. 7). Results obtained thus far indicate that swordfish has the largest heater organ, at least twice the size of the istiophorid having the largest heater — the blue marlin (three swordfish in the 55 to 70 kg range had 2.5 times as much heater tissues as a similarly-sized blue marlin; eye volume in swordfish was up to 3.8-fold higher). Although there is not enough evidence to draw conclusions at this time, the size differences between the heater organs of the various billfishes most likely are related directly to their thermal ecology.

Telemetry results indicate that swordfish spend up to 12 hours on a diurnal cycle in deep (500 to 600 m) cold waters (Carey and Robison 1981 and Carey in this volume). Carey has shown that a swordfish can maintain a cranial temperature of 29°C while swimming in 14°C water. These findings indicate that heat production in the head of a swordfish: (1) proceeds for extended periods of time, and (2) must be extremely efficient at generating heat given the temperature differentials being maintained. Thus, in swordfish, the larger size of the heater organ per kg of body weight, the greater surface area of the carotid heat exchanger (Block 1986a), and the conspicuous loss of the basisphenoid bone are features that would tend to be associated with greater heat production and heat conservation.

Likewise, the smaller size of the heater tissues in many of the istiophorid billfishes most likely correlates with the thermal biology of these fish. Scaling data of body weight vs. heater tissue weight indicates that *Makaira* has a slightly larger amount of heater tissue per kg of body weight than do *Tetrapturus* or *Istiophorus* (Block 1986a). General comparisons can be difficult because of allometric differences among species and the lack of data. It appears likely, however, that species that spend longer periods of time in cooler waters, or those that dive more frequently to greater depths, should have more of the eye muscle converted to heater tissue. This condition clearly occurs in the swordfish, which spends significantly longer periods at

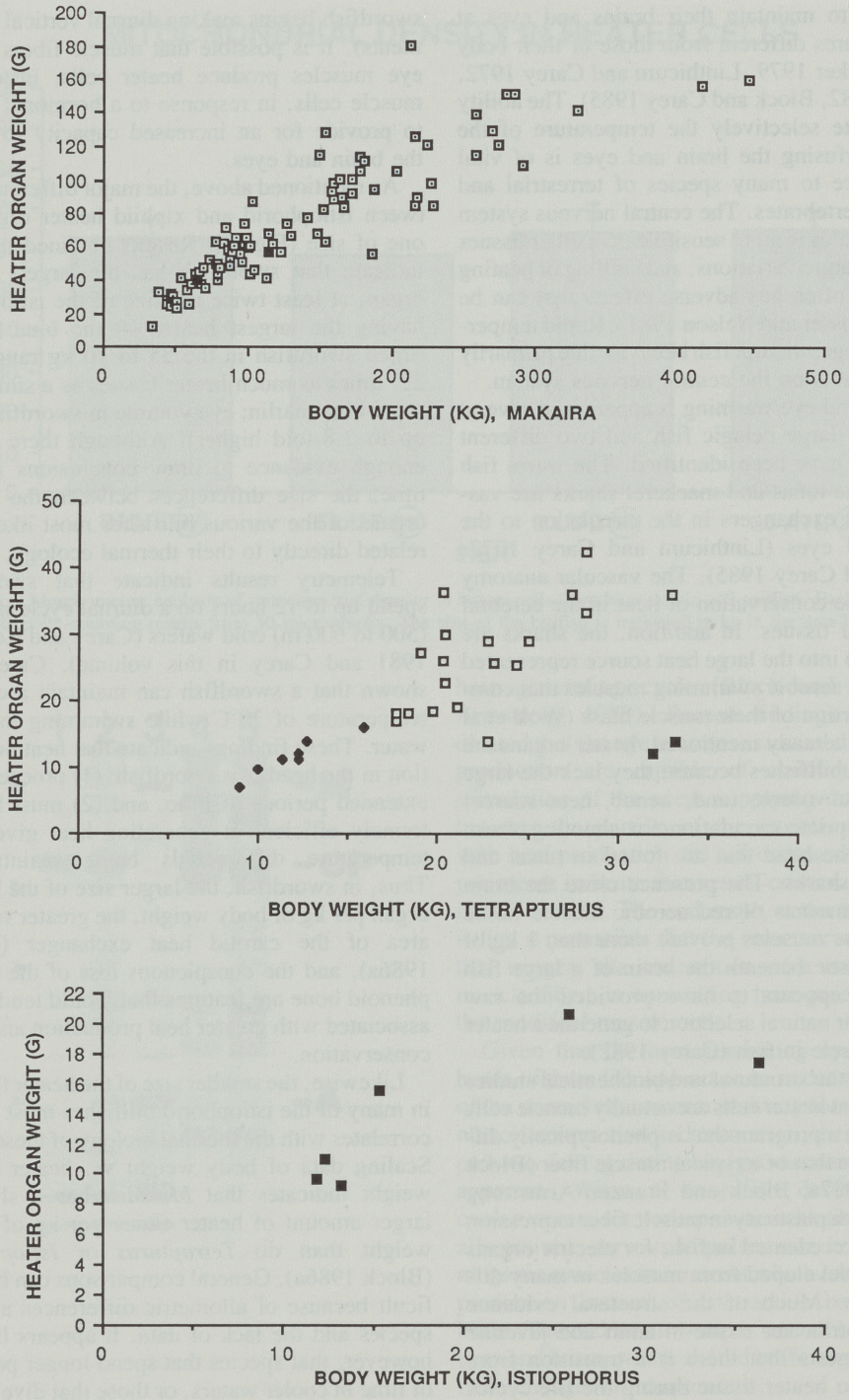

Figure 7. Relationship between body weight and heater tissue weight in several species of billfishes. For *Makaira,* solid black squares represent the black marlin and open squares the blue marlin. For *Tetrapturus,* solid diamonds are shortbill spearfish, open squares are white marlin, and solid squares are striped marlin. *Istiophorus* is represented by both Atlantic and Pacific specimens of *Istiophorus platypterus*. *Xiphias* data are not on this graph, but three specimens examined in the 55 to 70 Kg range had 2.5 times as much heater tissue as *Makaira nigricans*.

greater depths than do the istiophorid billfishes (Fig. 8).

Comparisons of the telemetry depth records from istiophorid billfish such as the blue marlin and white marlin *(Tetrapturus albidus)* demonstrate significant differences in the patterns of vertical movements in these two species. The blue marlin (record shown in Figure 8B) remained in deeper waters for longer periods of time than did the white marlin (8C). The fish moved slowly down in depth after being tagged with the transmitter and spent much of the time between 80 and 95 meters depth. This individual made frequent rapid trips up to the surface, spending little time there and returning rapidly to the depth from which the initial ascent was made. The maximum depth record for this marlin (95 m) is much shallower than for the swordfish shown in Figure 8A (600 m). Yuen et al (1972) tracked three blue marlin off of Kona, Hawaii, and recorded a maximum swimming depth of 185 m. More recently, 400 hours of depth recordings from six blue marlin tracked off Kona showed a maximum swimming depth of 210 m (Block et al 1990). The white marlin, in contrast to the blue marlin, spent the majority of the six-hour tracking period at the surface and made short excursions to 50 and 100 meter depths. Both of these istiophorid billfishes spent significantly less time in deep cooler waters than did the swordfish. In addition, recent telemetry results on a close relative of the white marlin, the striped marlin *(Tetrapturus audax),* indicate that this species also spends a predominant amount of the time in the top of the water column (Holts and Bedford this volume). Thus, from these results, one would predict that *Xiphias* would require the largest heater organ (or, put another way, the most muscle tissue converted to heater tissue), followed by *Makaira,* and then *Tetrapturus.*

Operating a heat-generating cycle is energetically expensive, so the hypothesis that billfishes have precise amounts of muscle tissue allocated as heater tissue, according to their thermal needs, may be correct. Several years ago, a female blue marlin was captured that had a significantly greater amount of heater tissue per Kg body weight than all other blue marlin previously examined. In light of the foregoing discussion, it is possible that this individual fish spent much more time at depth, and a larger proportion of the eye muscle had been converted to heater tissue to account for the increased thermogenesis required for this behavior. Additional telemetry experiments with istiophorids are needed to examine this idea further.

Are Heater Organs Unique to Billfishes?

As discussed, many species of pelagic fish are capable of elevating the temperature of the brain and eyes. Given that many of the top pelagic predators are warming their brains and eyes (Linthicum and Carey 1972, Block and Carey, 1985, Carey 1982, Block 1986b), why are there not more brain and eye heaters in teleost fish? A general survey across many teleost fish has not been done, but most fish have white eye muscles indicative of a glycolytic muscle fiber type. As mentioned, the presence of oxidative red muscle tissue, in a location close to the brain, is the raw material required for the conversion of muscle to heat tissue. Thus, heater organs will most likely be found in fish having robust red oxidative eye muscles.

The Scombridae are the most closely related group of fish to the monophyletic group consisting of the Istiophoridae and Xiphiidae. Most scombrids lack a brain heater tissue that is similar to that of the billfishes. Although tunas have the ability to warm the brain and eyes, this capacity is not related to a specific heat generating tissue (Linthicum and Carey 1972). Surprisingly, a heater tissue modified from an eye muscle has been found beneath the brain in the so-called "butterfly mackerel" *(Gasterochisma melampus)* (Carey 1982). This most unusual and rarest of all scombrids is a large pelagic fish with uncertain relationships to the Scombridae. Collette et al (1983) and Kono (1984) considered *Gasterochisma* to be a primitive evolutionary lineage of the Scombridae, due to several characteristics that align these fish with this group.

Completing *Gasterochisma's* unique position among the Scombridae is the finding that this fish has eye muscles modified into a heater organ (Carey 1982, Block 1986b). Perhaps most interesting is the fact that the heater organ of *Gasterochisma* is derived from the lateral rectus eye muscles rather than the superior rectus as in billfishes. The lateral rectus is associated with the abducens nerve (cranial nerve VI), while the superior rectus is associated with the oculomotor nerve (cranial nerve III). This difference in cranial innervation indicates that the embryonic source of the heater tissue (the preotic myotomes) is distinctly different between *Gasterochisma*

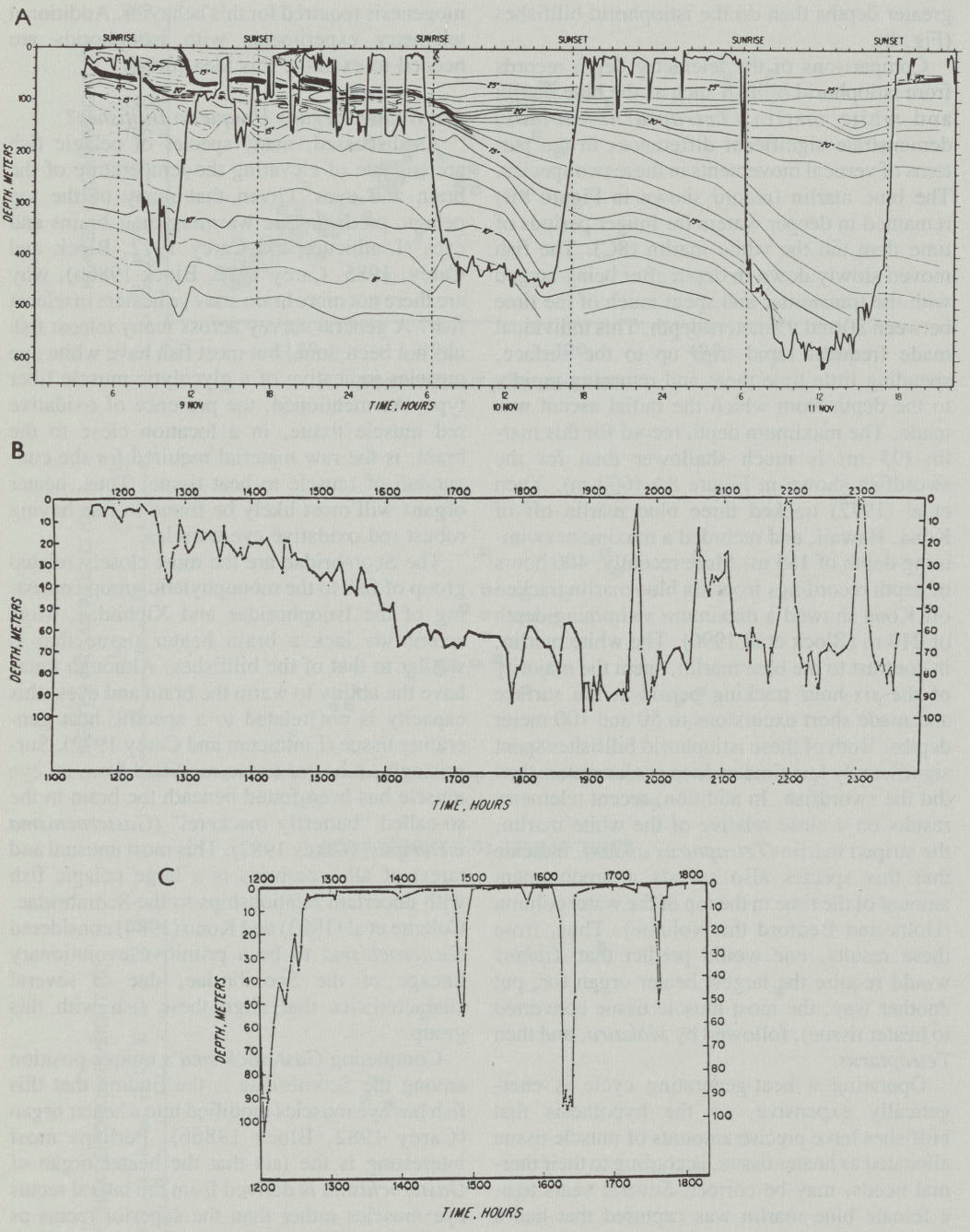

Figure 8. Telemetry depth records comparing the vertical movements of a swordfish (A), a blue marlin (B), and a white marlin (C). The swordfish (A) showed a clear daily pattern of vertical movements, going deep during daylight hours and coming to the surface at night. The swordfish spent up to 12 hours at depth (500 m) in cool (8°C) water. The blue marlin (B), slowly descended to 80 meters and then made regular visits to the surface. The white marlin (C), spent most of the time on the surface but made several dives as far as 100 meters. These three species of billfish have large differences in the size of the heater organ warming the brain, which correlates well with the differences in thermal ecology. The telemetry record from the swordfish is from Carey and Robison (1981). The record shown for the istiophorid billfish are unpublished data from the Tongue of the Ocean, Bahamas, provided by F. G. Carey.

and the billfishes. Thus, the presence of a heater organ in *Gasterochisma* is not indicative of any association with these groups.

The heater tissue associated with the lateral rectus in *Gasterochisma* is structurally similar at the microscopic level to the heater of billfishes (Block unpublished observations). The cells are packed with mitochondria and have remnants of muscle fibers indicating an origin from muscle tissue. The association of the heater tissue with the lateral rectus muscles results in a major position change of the heater tissue, the arrangement of the carotid rete, and the association with both the brain and eyes. The tissue is located more posteriorly in the cranial cavity behind the basisphenoid bone and fills a large cavity created by the prootic bones. The heater tissue associated bilaterally with both eye muscles converges along midline just beneath and posterior to the brain and much further back from the eyes than in billfishes.

Despite the overall similarities in the heater complex, the derivation in *Gasterochisma* of the heater from the lateral rectus eye muscles indicates that the development of this heater organ has occurred independently. Why has such a complex system as the heater organ developed in this fish? Although there is little information, it is clear that *Gasterochisma* is a large active scombrid in very cold waters. The presence of a heater in the butterfly mackerel suggests that brain and eye warming occurs; however, no temperature measurements are available at this time.

Summary

Billfishes employ a novel thermal strategy that provides them with limited degrees of thermal independence. Fish of the genera *Makaira, Tetrapturus, Istiophorus* and *Xiphias* have heater organs modified from extraocular muscles located beneath their brains. The heater is derived from unusual muscle cells that have uncoupled force production from the energy generating organelles. The heater appears to have similar principles of operation in all istiophorid billfish species, and heat production is a result of an ATP-consuming futile cycle regulated by the movements of calcium. The swordfish has the largest heater, which appears to correlate with the ability of these fish to range and physiologically tolerate the largest thermal gradients of all billfishes. The heater allows a billfish such as the swordfish to maintain a relatively constant brain and eye temperature, which protects the nervous system in these fish from the deleterious affects of fluctuating water temperatures.

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Distributional Changes in Billfishes (Istiophoridae) and Sea Surface Temperatures — a Possible Early Warning System to Monitor Global Greenhouse Climate Warming

Donald P. de Sylva

Fishes are intrinsically associated with their physico-chemical environments, especially epipelagic species such as billfishes *sensu stricto* (Istiophoridae) and tunas, which have definite temperature preferences (preferenda) that result in their occurrence within relatively narrow ranges of temperature. This stenothermal quality has engendered the field of "fisheries oceanography," in which pelagic fishes are sought and fished for on the basis of their preferenda.

In this paper, I first document the studies that have related ecological variables — principally temperature — of various species of billfishes to their distributions and migrations. I then propose a method by which scientists and anglers can work together by plotting and analyzing the geographical and seasonal distribution of billfishes in relation to sea surface temperatures (SST) to monitor warming of the global climate resulting from the greenhouse effect.

Temperature Effects on Fishes

Temperature has been viewed "as a subtle, all-pervading, complex environmental factor" (Brett 1970), which affects the behavioral responses of fishes (Bull 1952). An analysis of studies on the effects on fishes of water temperature controlled in the laboratory (de Sylva 1969) indicates that fishes are responsive to changes in water temperature of as little as 0.03°C (see Bull 1952).

It has been known for many years by scientists and commercial fishermen, alike, that fishes are closely tied to physical environmental factors such as temperature, salinity, oxygen, light and currents (Cushing and Walsh 1976), with temperature being one of the chief determinants of distribution and abundance (Dow, 1964). Temperature is generally considered to be such an important abiotic factor determining the occurrence of fishes (Bell and Pruter 1958, Konstantinov and Svetlov 1974) that extensive manuals have been prepared to instruct fishermen how to use thermometers to locate fish schools (Tomczak 1977, Laevastu and Hayes 1981). The field of "fisheries oceanography" has also been used as a basis for fishery management principles (Chapman 1972).

The Development of "Fisheries Oceanography" by Japanese Scientists

Credit should be given to Japanese scientists who, for at least 50 years, have been studying the marine environment to predict the occurrence and abundance of pelagic fishes (Kawana 1934, Uda 1974 and contained references). These studies range from a descriptive nature of the fishing grounds (Ogawa et al 1977) in relation to size of the catch (Morita 1954), to the relationship between salinity and the number of sailfish caught (Kuwahara et al 1982), and the "optimum temperature" for the best catch (Kuraki 1954). Fluctuations in catches have been related to environmental conditions (Nakai et al 1968), while forecasts have been made on the relation between sizes of catches and water temperatures (Matsudaira 1965).

The Japanese have specifically conducted extensive analyses of tuna environments (Enami and Tanoue 1954, Yamanaka 1978; for a review

of pre-World War II Japanese research on tuna ecology, see Shapiro 1950), which has given rise to the sobriquet "tuna oceanography." The Japanese have long considered billfishes to be the same ecologically as tunas, and thus much of their early work on "tuna oceanography" has included billfishes. Subsequent to these Japanese investigations, a number of studies have been carried out, mainly in the Pacific Ocean (Seckel 1972, Radovich 1963, Nakagome 1966, Blackburn 1965) and in the Atlantic Ocean (Squire 1963, Ovchinnikov 1966).

"Billfish Oceanography" — a New Field for Anglers

Not surprisingly, relatively little ecological information is available on billfishes from the Atlantic and Indian oceans, compared to that from the Pacific Ocean. This circumstance arises from the widespread fishing activities by the Japanese in the Pacific Ocean. Yet, since the end of World War II, the ingress of Japanese longline fleets into the Atlantic Ocean has provided scientists with much of what little information scientists have on Atlantic billfishes.

Detailed charts are available, showing the monthly distribution of billfishes in relation to averaged monthly, quasic-synoptic sea-surface temperature (SST) data in the Indian Ocean (Howard and Starck 1975). These data were obtained from commercial and recreational fishermen by Colonel John K. Howard of the University of Miami. Similar data were obtained for the Atlantic Ocean, but the loss of much data in a fire has prevented the publication of results.

More specific synoptic SST data correlated with catches of billfishes by commercial long-liners (mostly) are available for the striped marlin *(Tetrapturus audax)* from the northwestern Pacific Ocean (Uda 1961, Furukawa et al 1958), the northeastern Pacific (Squire 1974, 1985), and the southeastern Pacific (de Sylva 1962). Similar data are available for the black marlin *(Makaira indica)* in the northwestern Pacific (Uda 1952, Morita 1952, Nakagome 1958), the Pacific blue marlin *(Makaira mazara)* in the western Pacific (Nakagome 1965), the Atlantic blue marlin *(Makaira nigricans)* in the western North Atlantic (Squire 1962), the white marlin *(Tetrapturus albidus)* in the western north Atlantic (Gibbs 1957, de Sylva and Davis 1963) and the eastern Atlantic (Ovchinnikov 1966), the Pacific sailfish *(Istiophorus platypterus)* in the western Pacific (Tamari and Tanoue 1955, Koto et al 1959), and the Atlantic sailfish in the eastern Atlantic (Ovchinnikov 1966, Fox 1970).

All of these studies, including early studies by the Japanese, suggest that billfishes clearly respond to SST isothermal changes and find their "optimum temperature" within 0.5°C. Responses of billfishes to SST warming should offer indices of global climate warming and, thus, billfishes should be good early warning systems.

Unfortunately, it is frequently difficult to interpret some of these data, because some reports concern billfishes taken on longlines, which fish at subsurface depths, whereas the usually reported temperatures are SST. Thus, "optimum temperatures" may only be inferred temperatures. In contrast, data from recreational fishermen, who catch billfishes close to the surface (Squire 1974, 1985; de Sylva 1962; de Sylva and Davis 1963), more closely represent the environment in which the billfishes actually live. For this reason, any future catch data from billfish recreational catches should be recorded to reflect any actual SST changes, the data on which can be collected synoptically; consequently, it is believed that the proposed early-warning billfish program offers an exciting, relatively inexpensive method to study global climate change.

El Niño and Changes in Distribution of Marine Animals

It is well known that the short-term El Niño/Southern Oscillation (ENSO) of the Pacific Ocean results in changes in SST (Barber and Chávez 1983), which have broad biological and economic consequences. One such result is the collapse of major fisheries, for example the Peruvian anchovy fishery in the 1970s. The strongest El Niño event of the century, in 1982-1983, resulted in an extensive latitudinal displacement of pelagic fishes, invertebrates, birds, and marine mammals (Squire 1987). Such warm events in Perú and Chile are also correlated with simultaneous changes in pelagic fisheries in South Africa, California, Japan, and northwest Africa (Shannon et al 1986).

Long-term Changes in Global Climate and Fish Distribution

Since the turn of the century, changes in the catch, species composition, and distribution of demersal fish stocks have been documented

widely in the northeastern Atlantic (Holden 1978, Cushing and Dickson 1976). These events are attributable to changes in long-term meteorological and, thus, oceanographic factors, which have resulted in a gradual warming of the North Sea and adjacent waters. Such changes have been associated with range extensions of warm-water marine animals into temperate seas as they gradually warm (Mearns 1988). In the United States, climate change in the eastern Pacific Ocean not attributable to El Niño has been documented by shifts in latitudinal distribution of fishes (Hubbs 1948). A gradual warming of the coastal waters of the northeastern U.S. since the 1900s has been documented by concomitant changes in fish fauna. The changes are usually associated with northerly range extensions of mid-Atlantic or tropical species, rather than as faunal shifts — which may eventually be expected to occur as a result of long-term climate warming (Taylor et al 1957, Edwards 1965). Taylor et al (1957) noted that such range extensions would be indicated by a northward arrival of a species which occurred earlier than usual, or by a departure which occurred later than usual. Such information would be especially useful in the case of billfish catches, and would be relatively easy to document from anglers' records of SST, plus data on time and location of catches.

Global Climate Changes and SST

It is now well documented that man-made emissions from domestic and industrial activities are releasing radiatively active gases into our atmosphere, which result in a global warming of the air, the so-called greenhouse effect (National Research Council 1982; Villach Conference 1986; Jones et al 1986; Hansen and Lebedeff 1988; Hansen et al 1986, 1988). These estimates predict that the average global mean air temperature will rise 1.5°C to 4.5°C by the year 2050 at our present rate of anthropogenic emissions. Such an increase in air temperature will raise SST, which is expected to result in gradual melting of polar icecaps. A rise in air temperature will result in the melting of polar snow and glacial ice; the total effect, associated with the thermal expansion of sea water associated with a rise in air temperature, will be a global sea-level rise. SST are estimated to rise accordingly, with an estimated increase in SST of 3°C for midlatitudes (Rind 1987), regions where billfishes occur. Hence, the pelagic environment of billfishes should be gradually but significantly affected. Global warming and rising SST are expected to result in a poleward expansion of the climatic belts (Hansen et al 1986), which will result in poleward shifts in the distribution of billfishes, nearly all of which are confined to the tropics (›20°C). This means that billfish migrations should occur poleward (i.e., northward in the northern hemisphere) as tropical isotherms shift northward (in the northern hemisphere) earlier than in the past, while their return autumn migrations toward the south should occur later in the year.

There is no clear consensus among scientists on the rate of rise in air temperature or SST, or the rate of rise in sea level. However, all estimates previous to 1988 of rate of sea-level rise should be modified to let us prepare for an earlier, perhaps exponential increase in air temperature (Hansen et al 1988), and thus SST, because most previous estimates have generally included only CO_2 as a radiatively active gas contributing to atmospheric heating. The most recent global climate model estimate (Hansen et al 1988) now includes carbon dioxide, methane, chlorofluorocarbons, nitrogen oxides, and tropospheric aerosols. New estimates suggest that the greenhouse effect will be experienced worldwide at an earlier period; indeed, we may have already begun to experience its effects (Hansen and Lebedeff 1988).

Billfish as Indicators of SST Warming

Global warming is expected to have gradual, subtle effects on the ocean, which include increased SST, a weakening of the strength of surface ocean currents, a change in surface current patterns, a reduction in upwelling, and reduced ocean productivity (Frye 1980, Kawasaki 1985, Sibley and Strickland 1985, Wright et al 1986). It should thus be expected that the higher food chains on which billfishes depend will change accordingly, but the magnitude or direction of change can not be estimated. Since four of the above parameters depend upon SST, we should be able to predict the changes in the other four parameters from measurements in SST. As yet, no detectable changes in SST have been reported in the scientific literature, but this may be because most ocean monitoring of SST is carried out with satellites, and the variance of the satellite readings is presently considerable [RMS deviations vary between 1.67°C and 2.23° (Rasmussen and Williams 1970)]. As improve-

ments in satellite measurements of SST are made, however, we will be able to rely upon more accurate determination of SST to permit us to relate billfishes to isotherm distribution (Svejorsky 1988). In the meantime, SST measurements could be taken by billfish anglers to obtain ground-truth data using calibrated bucket thermometers for SST (Rasmussen and Williams 1979).

Satellites have been used with considerable success to measure SST (Brown and Cheney 1983), Gulf Stream warm core rings (Brown et al 1986), phytoplankton blooms (Brown et al 1985), and currents (Tameishi 1987). Satellites have already been suggested as a method to monitor global climate change in relation to potential changes in world fisheries. In addition, there exist applicable SST data taken from merchant ships and U.S. Coast Guard radiation thermometer flights in coastal waters (Rasmusson and Williams 1979).

A Cooperative Plan Between Scientists and Billfish Anglers

Several international programs are being planned to monitor physical parameters of long-term global climate change. These include the World Ocean Circulation Experiment (WOCE) and the International Geosphere-Biosphere Program (IGBP). The U.S. and international supporters include the National Science Foundation (NSF), the National Research Council (NRC), the U.S. Environmental Protection Agency (EPA), the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), the World Meteorological Organization (WMO), and the United Nations Environmental Programme (UNEP). In 1986, U.S. Senator Albert Gore introduced a bill into the U.S. Congress to provide U.S. support for a decade-long greenhouse effect. In the summer of 1988, 12 additional U.S. senators introduced another bill for similar studies, noting that the work by Hansen et al (1988) suggests that we are likely already feeling the atmospheric unpleasantries of global warming. Yet, despite the interest of the public, the politicians, the atmospheric scientists, and the physical oceanographers, there has apparently been little interest in or input into any of these programs from biologists. Here, then lies a golden opportunity for us.

Billfish angling interests are already well represented by the Pacific Gamefish Research Foundation for the Pacific Ocean and by the International Billfish Foundation in the Atlantic Ocean. Considerable interest has been expressed by scientists at this second billfish symposium in setting up similar organizations for the Indian Ocean. It is here suggested that prior to or at the next billfish symposium, or through mutual and widespread correspondence, a small group of scientists and anglers could form a steering committee to study billfish distribution and isotherm patterns as indicators of global change. This committee, working with university-based scientists, could draft a proposal to be submitted to one or more of these national or international sponsors of global climate research so that action can be taken as soon as funding becomes available. It is strongly recommended that the International Game Fish Association (IGFA) act as the umbrella agency, through which the steering committee would operate, because of its excellent contacts with billfish anglers all over the world. In this way, anglers worldwide would supply information on the dates and locations of their billfish catches, and collect ground-truth SST data (perhaps from bucket thermometers), which could be correlated with ship- and satellite-SST data so that any changes in world-wide SST might be documented.

Summary

Billfishes are closely associated with their physico-chemical environment, especially temperature. A review of the literature reveals that the field of "tuna oceanography" has permitted fisheries scientists to predict when, where, and how large a catch might be. Sufficient studies have already been carried out to enable scientists to delineate the temperature preferences for nearly all of the important species of billfishes. Major but short-term climatic changes such as occur during El Niño events have shown that pelagic fishes respond rather quickly to shifts in patterns of sea surface temperature (SST). It is expected that SST isotherms will move poleward in response to global atmospheric warming from the greenhouse effect as a result of anthropogenic activities. It is believed that billfishes will similarly move poleward to track isotherm movements, and that satellite measurement of SST and the delimitation of poleward-moving isotherms can be associated in time and place, linked to recreational billfish catches. This correlation could serve as a relatively inexpensive

early warning system to detect global climate warming.

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Session 2

Fisheries

Julian Pepperell, Chairman

Aspects of the Biology and Sport Fishery for Billfishes in the S.W. Indian Ocean

Rudy P. van der Elst

The southern tip of Africa represents an important region of interface between two major marine ichthyological divisions: the Atlantic and the Indo-Pacific. It is a region of ichthyological interest and one of considerable species diversity, harbouring some 2,200 varieties of fish representative of 83% of all known marine fish families (Smith and Heemstra 1986). A general characteristic of this ichthyofauna is the high incidence of endemism (about 13%), particularly evident in the demersal species of the porgies or sea breams (Sparidae), galjoens (Coracinidae), and blennies or klipfishes (Clinidae). There is, however, also a large and important component of fish that are transient in nature and often circumglobal in distribution. One such group is the billfishes (Istiophoridae; Xiphiidae), which are particularly well represented with ten of the world's twelve known species found in this region.

Those that have been positively identified from sport fishermen's catches are, in order of abundance: Indo-Pacific sailfish *(Istiophorus platypterus),* black marlin *(Makaira indica),* striped marlin *(Tetrapturus audax),* Indo-Pacific blue marlin (Makaira mazara), shortbill spearfish *(T. angustirostris),* swordfish *(Xiphias gladius),* and longbill spearfish *(T. pfluegeri).* While Atlantic varieties of sailfish *(I. albicans)* and blue marlin *(M. nigricans),* as well as the white marlin *(T. albidus),* have not yet been identified by sport fishermen, their presence is known from commercial and exploratory longlining (Penrith & Cram 1974, Nakamura 1983).

The region sustains some of the largest fisheries in the southern hemisphere, but there has been little targeting for istiophorids. Virtually no commercial billfish harvesting occurs from mainland southern Africa, although foreign longline fleets do harvest moderate catches and this situation is changing. Many of the present fisheries, especially line fisheries, have undergone major changes. Most important has been the depletion of the endemic reef fish resource, in some cases by as much as 90% (van der Elst 1988b). Newly introduced fisheries management in South Africa aims to halt this trend by directing the fishing effort away from these vulnerable reef fishes to the wider ranging pelagic species such as tunas, mackerels, and billfishes. This change, together with a growing acceptance of billfishes as a food source, and an expanding recreational fishery for marlin, can be expected to increase fishing pressure considerably on these fishes.

Little has been published in recent times about billfishes of this region, despite a considerable growth in recreational fishing for marlin and sailfish in the S.W. Indian Ocean. The records of Williams (1970), Merrett (1971), Penrith and Cram (1974) and Nakamura (1983) provide most of the information known about billfishes in this area.

This paper aims to supplement and update this information in the region by providing an overview of the sport fishery for billfishes in the S.W. Indian Ocean, with specific attention to the biology of catches made from South Africa.

Materials and Methods

Due to the fact that billfishes have hitherto represented a very small catch in southern Africa, little research has been directly focused on this group. Consequently, much of the data presented here was collected during the course

of other research projects on line fish of the region. Data has also been obtained from angling clubs and especially from the National Marine Linefish Data Programme, which documents catch statistics of all line fishing in South Africa.

Scientific nomenclature is after Nakamura (1983), although considerable taxonomic confusion remains in the region — especially surrounding the blue marlin. All lengths quoted are from tip of mandible to fork of tail and reproductive stages follow those outlined by Merrett (1971).

Capture of Billfish by Sport Fishermen in the S.W. Indian Ocean

By far the greatest billfish catch around southern Africa is taken by Japanese, Taiwanese, and Korean longliners — most being focused in FAO Fishing Area 51 (FAO 1987). Increasingly, however, other nations are also harvesting billfishes. Only three countries were reported actively involved in catching billfishes during 1970, but 1985 landings reveal catch statistics from at least 11 nations (FAO 1987). This growing demand for billfish can also be detected in the recreational fishery. Increasing numbers of fishing clubs, holiday resorts, and individual sport fishermen have come to recognize the value of the billfish resource. Virtually all of this activity is focused on istiophorids, very few catches of swordfish being reported by anglers. An estimated 99% of billfishes taken by anglers around southern Africa are, in fact, landed within the SW Indian Ocean. Development of a recreational fishery for sailfish and marlin has become particularly important in several areas within this region (Fig. 1).

The Kenyan coast has a long history of excellent marlin and sailfish angling, dating back to the 1950s. Williams (1959, 1970) provided an analysis of this sport fishery, focusing on the capture of sailfish at Malindi (3°S; 40°E) from 1958 to 1968. The fishery has continued to grow since then, and at least nine active clubs now exist at places such as Mombasa, Pemba, and Kilifi. The Kenyan coast is one of the few regions in the W. Indian Ocean where statistics on billfishes are maintained, indicating that an average of 2,100 istiophorids have been landed each year since 1983, with a maximum of 3,245 during the 1987/1988 season (Kenya Association of Sea Angling Clubs 1988). In his analysis on the status of this fishery, Williams (1970) concluded that no declining trends in the abundance of sailfish catches at Malindi were evident up to 1968. He did, however, detect significant changes in the sailfish population structure and warned of possible future negative trends brought on by commercial longlining. Since those 1968 conclusions were made, no data on fishing effort (hence, CPUE) at Malindi have been obtained, although the yearly total catch of sailfish along the Kenyan coast continued to increase, having reached 2,834 during the 1987/1988 season. Analysis of average weights, however, confirm Williams' earlier fears when he reported a significant decline in average size between 1958 and 1968. The average size has continued its decline since then (Table 1 and Fig. 5). It is recognized, of course, that analysis of trends in average size alone are inadequate for stock assessment; nevertheless, it would appear that sailfish populations off Kenya warrant further study.

Table 1. Average weight of sailfish caught by anglers off Kenya.

Season	Sample size	Average weight (kg)	Source
1958-1962	904	30.3	Williams 1970
1966-1968	4,027	27.5	Williams 1970
1983/1984	1,016	26.1	Kenya Associa-
1984/1985	739	28.4	tion of Sea
1985/1986	2,146	25.6	Angling Clubs
1986/1987	2,414	27.2	" "
1987/1988	2,868	26.2	" "

The landings of billfishes off Kenya are predominated by sailfish, which account on average for 83% of the total catch by number. Several other billfish species, which also represent an important resource, also occur in the sport catch. Merrett (1971) reported all five commonest species during a longline survey in the tropical west Indian Ocean, while data from the sport fishing clubs can be used to determine the composition of the four most abundant istiophorids in their catches (Fig. 2).

The lengthy Mozambique coast, lying farther southwest in the Indian Ocean, also represents a region of considerable billfish abundance. While recreational fishing for istiophorids appears to have been seriously curtailed after 1974 due to political implications, earlier development of this fishery was particularly intense around the Bazaruto archipelago (22°S; 35°E) and off Inhaca Island (26°S; 33°E) close to the capital, Maputo. Unfortunately, landings were documented only at Bazaruto, indicating

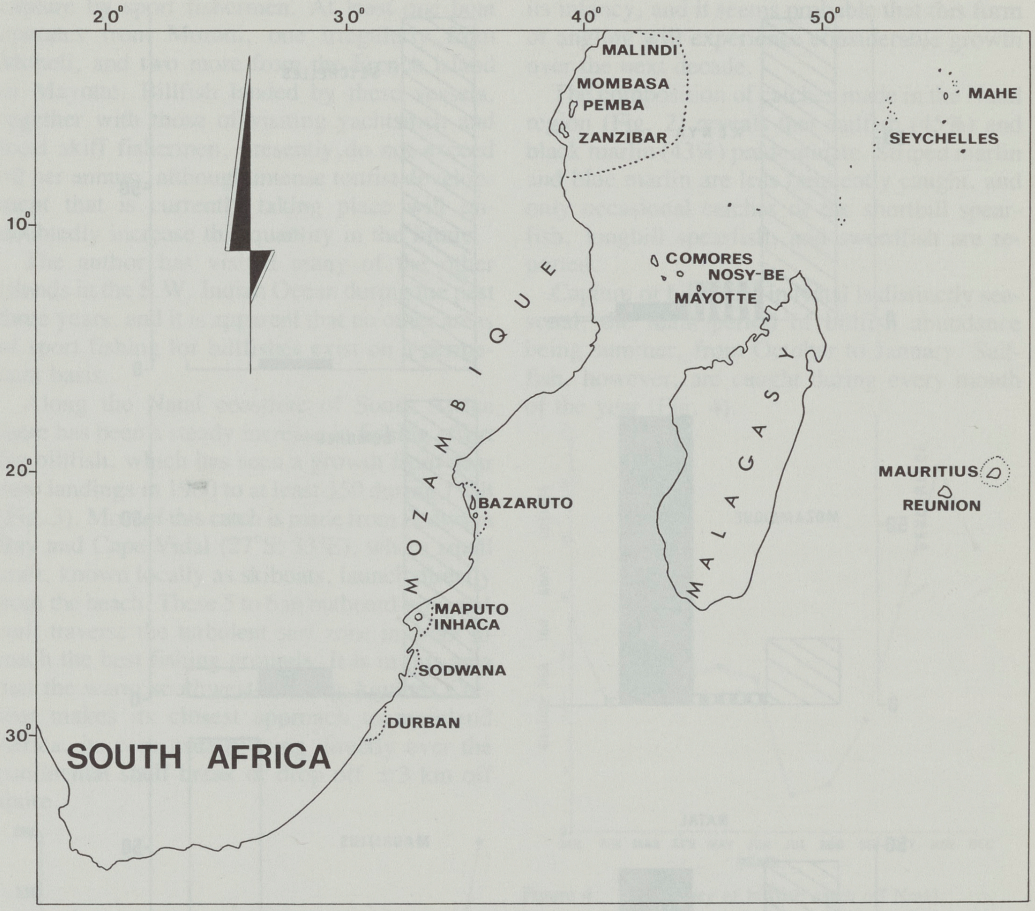

Figure 1. Distribution of regions in the S.W. Indian Ocean where sport fishing for billfishes occurs. Dotted lines represent major billfish fishing areas.

that an average of 110 billfish were caught there per annum between 1960 and 1970. It is estimated, therefore, that the total Mozambique catch made by recreational fishermen could have reached 250 annually. This fishery has been revived since 1987, with moderate numbers of billfishes having been landed by anglers off the Mozambique coast during 1988/1989. The species composition of billfish landings at Bazaruto is strikingly different from that found off Kenya (Fig. 2), with black marlin accounting for 71% of the total catch.

Another important area of billfishing is Mauritius (20°S; 57°E), a mid-ocean volcanic island east of Madagascar. Much of the popularity of this tropical tourist resort stems from angling, especially for marlin, which commenced in about 1962.

Catch statistics on this sport fishery have recently been published for the first time by Cayre & Stequert (1987), documenting the landings from 1976 to 1986. Their records reveal that landings (Fig. 2) are dominated by blue marlin (75%). The total annual sport catch of billfishes made from this island has not yet been accurately reported, but can be estimated from their data to be about 235 fish. As in other regions, there is distinct seasonality, here, in the billfish catch with 90% or more of catches being made between mid-November and the end of March.

Another region where billfishes are known to be plentiful is around the island of Madagascar. Sport fishing for marlin is known to occur there at several localities, the most important being at the resort of Nose Bé off the north of the island. The actual number of boats operating and details of their catch have not been published.

The Republic of Seychelles embraces some

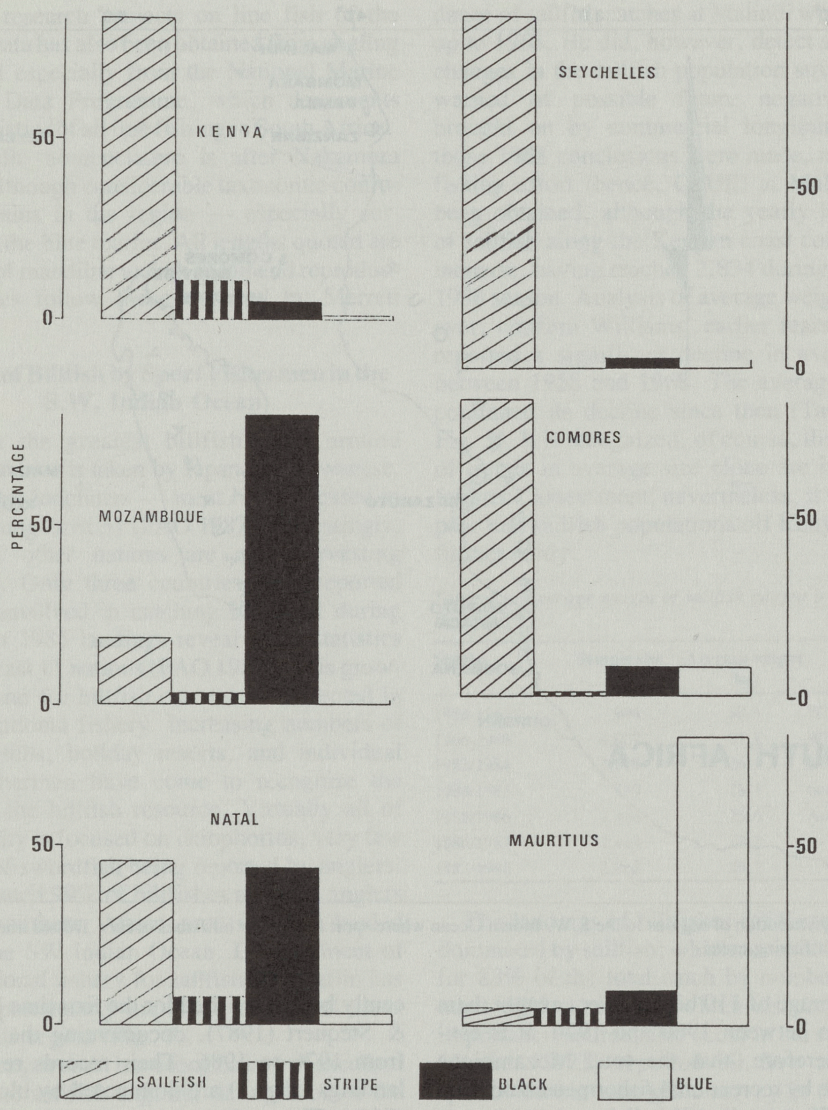

Figure 2. Percentage catch composition of the four main istiophorid species caught by sport fishermen at six localities in the S.W. Indian Ocean.

90 islands covering an enormous area of the tropical Indian Ocean. Several of these islands are important tourist resorts that accommodate sport fishermen, especially Mahé (5°S; 55°E), Praslin, and La Digue. Fishery exploitation in the region is controlled by the Seychelles Fishing Authority which produces comprehensive and regular technical reports, including detailed catch statistics of both commercial and recreational landings (de Moussac 1987a,b). An average of six charter boats were registered in the area during the years 1985 and 1986, reporting an annual catch of 110 billfish or approximately 0.5 fish per outing. In addition, there are known to be a number of visiting yachts that also land billfish in the region. Catches are composed primarily of sailfish (97%), with black marlin being the only other billfish species reportedly caught (Fig. 2). Billfishes are taken throughout the year, sport catches are highest from May to November, with a distinct peak in landings during September and October.

The Comores group of islands (13°S; 44°E) represents another region of potential billfish

capture by sport fishermen. At least one boat operates from Moroni, one irregularly from Moheli, and two more from the French island of Mayotte. Billfish landed by these vessels, together with those of visiting yachtsmen and local skiff fishermen, presently do not exceed 50 per annum, although intense tourist development that is currently taking place will undoubtedly increase this quantity in the future.

The author has visited many of the other islands in the S.W. Indian Ocean during the past three years, and it is apparent that no other areas of sport fishing for billfishes exist on a permanent basis.

Along the Natal coastline of South Africa there has been a steady increase in fishing effort for billfish, which has seen a growth from near zero landings in 1960 to at least 350 during 1988 (Fig. 3). Most of this catch is made from Sodwana Bay and Cape Vidal (27°S; 33°E), where small craft, known locally as skiboats, launch directly from the beach. These 5 to 6 m outboard-powered craft traverse the turbulent surf zone in order to reach the best fishing grounds. It is in this area that the warm southwest-flowing Agulhas Current makes its closest approach to mainland Africa, its core usually lying directly over the continental shelf break or drop off ±3 km off shore.

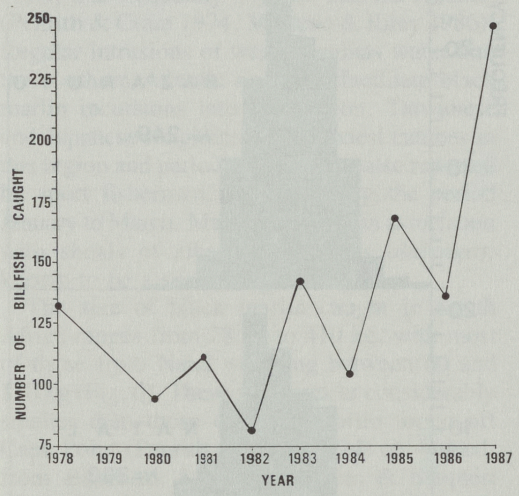

Figure 3. Annual total landings of billfishes made by sport fishermen off the Natal coast.

Increased billfish landings are due to two facts: first, the considerable annual growth in skiboat fishing; second, the increased ability of anglers to successfully land billfishes. Fishing for billfishes off South Africa appears to be in its infancy, and it seems probable that this form of angling will experience considerable growth over the next decade.

The composition of catches made in the Natal region (Fig. 2) reveals that sailfish (45%) and black marlin (43%) predominate. Striped marlin and blue marlin are less frequently caught, and only occasional catches of the shortbill spearfish, longbill spearfish, and swordfish are reported.

Capture of billfishes in Natal is distinctly seasonal, the main period of billfish abundance being summer, from October to January. Sailfish, however, are caught during every month of the year (Fig. 4).

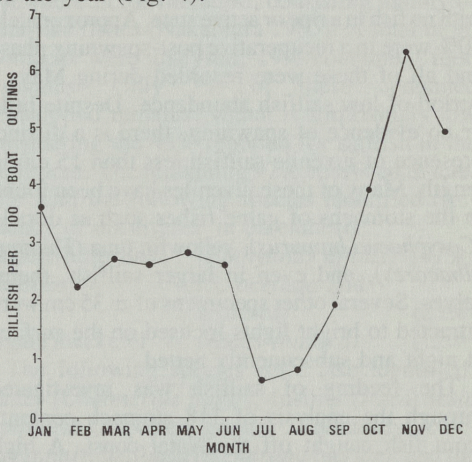

Figure 4. Seasonality of billfish catch off Natal.

The modest number of billfishes caught off the South African coast belies their abundance in the region, as it is only in recent years that anglers have targeted for these game fishes. The rapid annual increase in landings and very low hook-up rates, despite many strikes suggest that future catches will increase substantially.

Sailfish

The sailfish is present throughout the year, although its greatest abundance is attained during summer, mostly from November to February.

The size of the sailfish landed by sport fishermen of Natal ranges from 4 to 90 kg, and generally appears to be a little larger than those from Bazaruto and those reported by Williams (1970) and Merrett (1971) from Kenya (Table 2 and Fig. 5). It is only during the month of December, when most sailfish are caught, that all size classes are represented.

Analysis of the data reveals a markedly

Table 2. Comparative weight statistics (in kg) for sailfish caught at three localities off the East African coast.

Locality	Range	Mean	Median	Sample size
Kenya	10-62	30.1	31	904
Bazaruto	3-64	32.4	33	249
Natal	4-81	33.4	37	333

skewed sex ratio, with females outnumbering males throughout the year, with an overall ratio of males:females = 1:4.3. No significant difference is apparent in size between males and females; in fact, on average, males (mean length = 2,269 mm) are slightly larger than females (mean length = 2,249 mm.)

Reproductive activity was seen to be low, with no fish in a ripe or active state. Approximately 10% were in a recuperative post-spawning phase and all of these were recorded during May, a period of low sailfish abundance. Despite little or no evidence of spawning, there is a distinct presence of juvenile sailfish less than 15 cm in length. Many of these juveniles have been found in the stomachs of game fishes such as dorado *(Coryphaena hippurus),* yellowfin tuna *(Thunnus albacares),* and even in larger sailfish, themselves. Several other specimens of ± 35 cm were attracted to bright lights focused on the surface at night and subsequently netted.

The feeding of sailfish was investigated through the analysis of 118 stomach contents from fish caught off the Natal coast. A high percentage contained identifiable food remains (71%). The remains of teleosts were found in 95% and cephalopods in 43% of the samples. The following main species were identified (frequency of occurrence in parenthesis).

cuttlefish	*(Sepia officianalis)*	(24%)
squid	*(Loligo renaudi)*	*(14%)*
octopus	*(Argonauta argo)*	(5%)
needlefish	*(Strongylura leiura)*	(29%)
sardines	*(Sardinops ocellata)* & *(Eterumeus teres)*	(10%)
scad	*(Decapterus sp.)*	(9%)
sailfish	*(I. platypterus)*	(9%)

In addition there were a variety of other teleosts, including the dorado, the ribbonfish *(Chirocentrus nudus),* the anchovies *(Thryssa vitrirostris* and *Achoviella japonicus),* the soldier *(Priacanthus hamrur),*and several species of the Balistidae.

While the diet of sailfish off Natal comprises a wide range of species, there is a predominance of species normally associated with offshore banks opposite large river mouths. The cuttlefish, needlefishes, sardines, scads, and anchovies all inhabit such areas (van der Elst 1988a) and together represent 76% of the diet by numeric frequency of occurrence. Furthermore, the region from which most sailfish were examined is often under direct influence of water

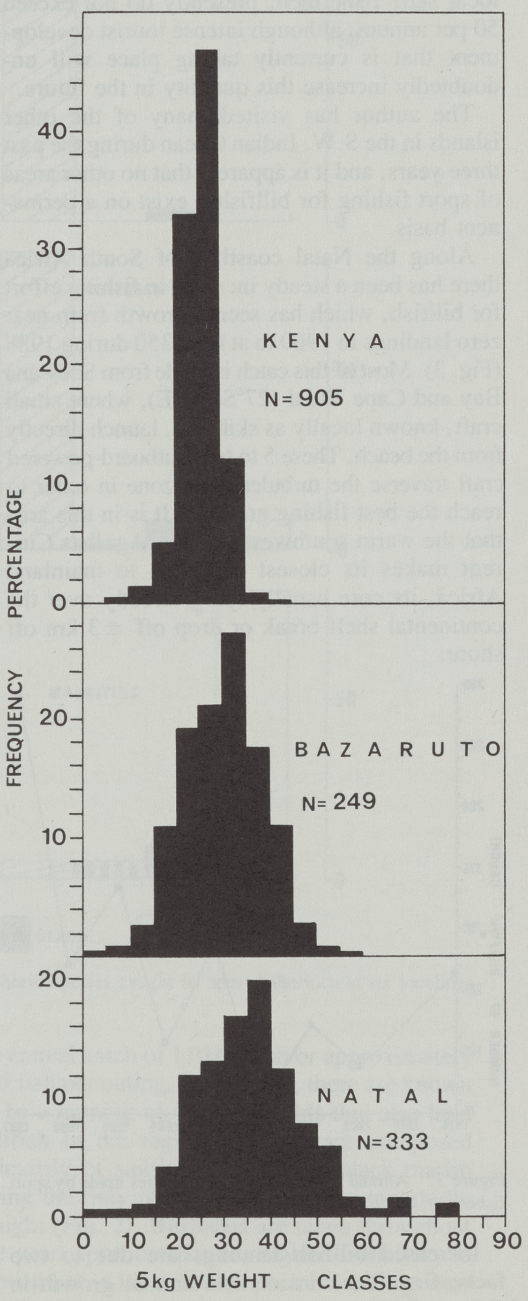

Figure 5. Weight frequency distribution of sailfish caught by sport fishermen at three localities in the S.W. Indian Ocean (Kenya data after Williams 1970).

flowing out of the large St. Lucia Estuary and Mfolozi River, especially during summer months.

Sailfish are known to avoid turbid water due to river flooding, but their frequent capture at the edge of such water suggests that this billfish may well in part be attracted to this region in order to take advantage of the periodic availability of these food sources.

In conclusion, then, sailfish along the Natal coast are most common during summer months, probably as migrants from Mozambique or regions elsewhere in the S.W. Indian Ocean. Females significantly outnumber males but their presence is not related to spawning, despite their average size being well in excess of that at which maturity is attained. It would appear that localized and periodic abundance of food organisms associated with flooding rivers may play a role in attracting sailfish to this region.

Black marlin

The most common marlin species in South African waters is the black marlin, being especially abundant during the summer. Most of them are caught along the coast of northern Natal, but black marlin range widely along the entire South African east coast to reach Cape Point, and frequently beyond, into the Atlantic (Penrith & Cram 1974, Molteno & Riley 1986). Regular intrusions of warm Agulhas water into the southern Atlantic no doubt facilitate black marlin incursions into that region. Taiwanese and Japanese longliners land modest catches in this region and periodic catches are also reported by sport fishermen, mostly during the period January to March. Many are caught in association with shoals of albacore *(Thunnus alalunga)*, known to be a source of their food.

The size of black marlin caught in South Africa ranges from 28 kg to 410 kg, with most of those from Natal weighing between 60 and 110 kg (Fig. 6). These sizes appear considerably smaller than those of black marlin found off Cape Point (Penrith & Cram 1974) or, indeed, from Bazaruto, Mauritius (Cayre & Stequert 1987), and elsewhere in the Indian Ocean (Merrett 1971) (Fig. 6).

About 70% of the black marlin catch off Natal exceeds the size at attainment of sexual maturity, as determined by Merrett (1971), but there is very little evidence of spawning activity in this region. Most fish were in a reproductively inactive state, although about 22% of fish examined were in a recovery/spent phase — all of which were recorded during the months of November and December.

The sex ratio of black marlin examined was seen to be skewed throughout the year with an overall male to female ratio of 1:6.7. This uneven proportion does not appear to be inconsistent with findings elsewhere, which generally confirm a female preponderance in catches (Nakamura 1975).

No juveniles of black marlin have yet been positively identified from the region.

The feeding of black marlin caught off Natal was generally found to be similar to that reported elsewhere in the literature, consisting mainly of tuna-like fishes (Nakamura 1985). A total of 90 stomachs were analysed, 19% containing food remnants. Only 3% of these contained cephalopod remains, which is surprisingly low considering the 43% reported for sailfish in the same area. The remaining 97% consisted of teleosts with the following species identified (frequency of occurrence in parenthesis:

Eastern little tuna	*(Euthynnus affinis)*	*(41%)*
sardines	*(S. ocellata* and *E. teres)*	(23%)
frigate mackerel	*(Auxis thazard)*	(12%)

The following species were also identified: santer *(Cheimerius nufar)*, fusilier *(Paracaesio xanthurus)*, spotted grunter *(Pomadasys commersonni)*, halfbeak *(Hemiramphus far)*, and the yellowtail amberjack *(Seriola lalandi)* (van der Elst & Roxburgh 1981).

This diet is consistent with the behaviour of black marlin in this region. Their distinct avoidance of turbid water, and increased abundance at times when clear water from the Agulhas Current flows close to shore, correlates with the behaviour of the scombroid fishes in the diet.

A further feature that appears to have a significant influence on the abundance and distribution of black marlin off Natal is the presence of submarine canyons. Five such canyons transect the narrow continental shelf of northern Natal, some reaching to a depth of 600 m within 1 km off the beach. The inshore apex and steep edges of these canyons are known to be the best black marlin fishing grounds. It is not possible to derive statistical verification of improved catches based on anglers' catch records, but it is nonetheless noteworthy that more than 75% of all black marlin landed along the Natal coast during 1987 were caught directly over two of these

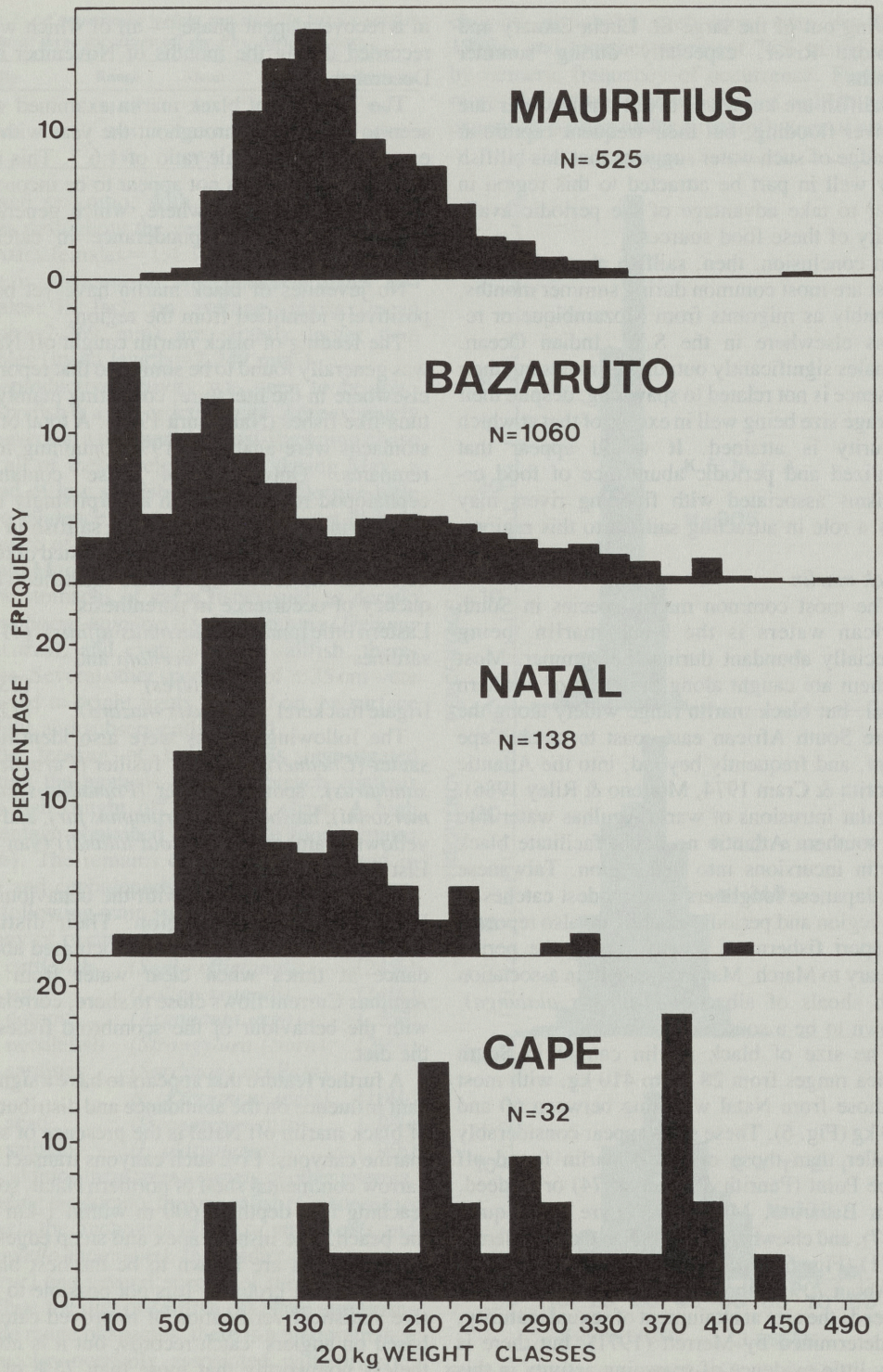

Figure 6. Weight frequency distribution of black marlin caught by sport fishermen at localities in the S.W. Indian Ocean. (Mauritius data after Cayre & Stequert 1987; Cape data after Penrith & Cram 1974.)

canyons. The physical environment of these canyons has not been fully studied, but preliminary investigations with moored thermoprobes and side-scan sonar point to considerable short-term temperature fluctuations and very steeply sloping but stable sides composed in part of sand. This evidence suggests localized upwelling with a strong upward flow of deeper Agulhas water aiding to maintain the profile of the sandy edges (van Heerden, pers. comm.). It is this environment that appears to be favoured by local black marlin.

It can be concluded, therefore, that black marlin are caught along the entire South African East coast, primarily during the summer months. The average size of fish along the Natal coast appears smaller than that recorded off the Cape, indicating that this region may well be important to juvenile and adolescent fish. There is no evidence of reproductive activity in the region, although the presence of post-spawning fish suggests that spawning may well take place off shore or farther north in the region. Food preferences conform to these reported elsewhere and the local distribution of black marlin seems to be strongly influenced by the presence of deep submarine canyons.

Blue marlin

The capture of blue marlin by sport fishermen in South Africa is relatively uncommon and all are landed during the summer, from November to March. There remains considerable confusion about the correct identification of this marlin, many local ichthyologists recognizing only *M. nigricans*. Furthermore, anglers also occasionally confuse this species with the striped marlin. The size distribution of blue marlin landed by anglers (Fig. 7) reveals that most are small fish, though not unlike the sizes reported from the W. Indian Ocean by Merrett (1971). The data suggest a presence of two or three cohorts with midpoints at 85 kg, 155 kg, and 210 kg, although the sample comprises only 66 specimens.

It is known that female blue marlin grow much larger than males (Nakamura 1985), hence it was especially surprising to find that all 33 fish examined were females, despite the presence of smaller size classes in which males would be expected. None of these females showed any evidence of reproductive activity, although most were in excess of the 60 kg reported by Merrett (1971) as size at attainment of sexual maturity.

No larvae or juveniles of blue marlin have been positively identified in the region.

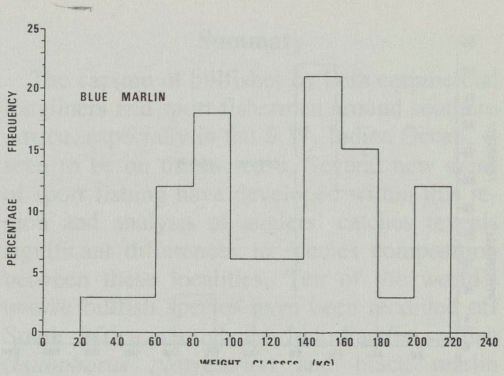

Figure 7. Weight frequency distribution of blue marlin caught by Natal sport fishermen.

A total of 24 (73%) out of the 33 stomachs analysed contained remnants of food. Much of this was unidentifiable teleost remains, but dominant items included the frigate mackerel (21%), skipjack tuna *(Katsuwonus pelamis)* (17%), and also halfbeaks, lizardfish *(Saurus gracilis)*, and squid *(Loligo renaudi)*. This diet is consistent with that reported for blue marlin by other authors (Nakamura 1985) and is indicative of this species' preference for clear water. This preference is borne out by local observations, as it is well known by fishermen that blue marlin are never caught in proximity to river mouths and usually occur only some distance from shore.

Striped Marlin

The striped marlin is of only moderate importance in the sport catches and most are landed during the summer months of November and December. The size distribution of 114 striped marlin caught indicates the presence of two modes, one at 65 kg and another at 125 kg (Fig. 8). The average size appears a little larger than that reported from elsewhere in the W. Indian Ocean (Merrett 1971), with the largest specimen weighing 198 kg. Here, too, males are outnumbered by females, by a ratio of 1:3.3. More than 90% of the catch comprised fish in excess of the size at attainment of maturity (Merrett 1971), yet none in this study revealed any reproductive activity — except for a single female caught during December with spent/recovering ovaries. Feeding was investigated, with 81% of the 31 fish examined having stomach contents. This diet consisted of a variety of organisms, mostly pelagic. Three of the most important were:

sardines *(S. ocellatus & E. teres)* (16%)

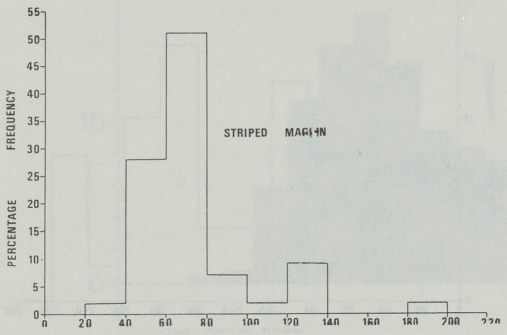

Figure 8. Weight frequency distribution of striped marlin caught by Natal sport fishermen.

squid *(Loligo* sp.) (12%)
Eastern little tuna *(E. affinis)* (12%)

Also present were ribbonfish *(Trichiurus lepturus),* juvenile sailfish, rainbown runner *(Elagatis bipinnulatis),* lizardfish, halfbeaks, and an unidentifid sparid.

Striped marlin are never caught in turbid water and their diet confirms a preference for clear-water species.

Shortbill and Longbill Spearfish

Only three shortbill spearfish were examined, two from northern Natal and one closer to Durban, weighing 12.2 kg, 20 kg, and 23 kg, respectively. All were caught during mid-summer and all were reproductively inactive, being one male and two females. A single 22-kg longbill spearfish was caught during January, 1987, but was gutted before examination.

All the spearfish recorded were hooked by fishermen operating farther off shore than most. Furthermore, there is a considerable inability for correct identification of spearfish and some are known to have been misidentified or simply disposed of without proper recording.

Swordfish

Despite its local presence, sport fishing for swordfish has not developed in South Africa, with only a single fish having been landed — a 93-kg specimen during May, 1986, off Cape Point. Nevertheless, swordfish are undoubtedly available. Japanese longliners are known to take about 2,500 swordfish annually from waters around South Africa. Historically, these catches do not reveal negative trends, although recent data are lacking (Table 3) (Nepgen 1970, Molteno & Riley 1986). Furthermore, South African operators with deep-set longlines and demersal trawls off Cape Point account for up to 28 tonnes (i.e., mt) being landed annually. Off Natal, periodic capture in shark gillnets set to protect bathers, provides further evidence of their presence. Swordfish are known to bask at the surface in several regions of the world, but this behaviour has not yet been reported from Natal. Nevertheless, an occasional beached specimen with propellor lacerations would suggest that this behaviour does occur. The weights of these beached and netted swordfish ranged from 90 kg to 160 kg.

Table 3. Numbers of swordfish caught by Japanese longliners off South Africa.

1964-67 (average)	1975	1976	1977	1978	1979
2,537	2,801	1,785	1,345	3,367	2,467

Discussion and Conclusion

It appears that the seas around southern Africa sustain a considerable diversity but only a moderate abundance of billfishes. Farther eastward into the S.W. Indian Ocean, their abundance is greater, although the species composition of catches varies considerably between different localities. This variation, no doubt, relates to the general habitat preference of individual species. Regions in proximity to oceanic basins support a greater abundance of blue marlin, such as occurs at Mauritius. Conversely, nearshore shelf areas sustain larger populations of sailfish, such as those found off Kenya. Black marlin, too, appear to favour proximity to mainland, hence their abundance in Mozambique and South African catches. It is a little surprising that the Mozambique catch includes so few sailfish, but it seems probable that this situation is partly due to inadequate data.

The presence of billfishes along the east coast of South Africa is seen to be strongly seasonal, with fish presumably migrating polewards during summer. A total of 155 billfish have now been tagged by sport fishermen off the Natal coast, but none have yet been re-caught to confirm such migrations.

Clearly, the east coast of South Africa does not represent a spawning region for any of the species considered, although data on some are inadequate. A noteworthy finding from these preliminary biological investigations has been the skewed sex ratio in favour of females. Assuming the normal overall sex ratio to be 1:1, it remains to be determined where the other male

fish occur. Possibly some of the males are with the larger ripe females on their spawning grounds, competing for valuable reproductive resources. Whatever the reason, the phemonenon of sexual segregation may have a bearing on the management of billfishes in the S.W. Indian Ocean.

Billfishes appear to feed actively in this region, and the persistent presence of the sardine *(Sardinops ocellata)* in the diet of billfishes is of interest. This abundant endemic clupeid undertakes large annual migrations northeastwards along the South Africa coast, reaching northern Natal during early summer. This major ecological event is associated with enormous concentrations of game fishes, cetaceans, and birds, and has already been shown to influence the abundance and life history of many Natal game fishes (van der Elst 1988b). It is also likely to play a role in attracting billfishes to the region.

Future fisheries research in the S.W. Indian Ocean will have to focus on billfish studies and not merely include marlins as a sideline project in other programmes. In particular, the black marlin warrants investigation, emphasized by its relatively limited distribution yet its predominance in South African and Mozambique catches. Its apparent association with submarine canyons, sexual segregation, and as yet undetermined growth rates, are all relevant research topics.

It is also clear that data on billfish catch and effort statistics for the S.W. Indian Ocean are far from perfect, although there has been an improvement since the 1972 billfish symposium, with several important papers published. Most of these reports confirm the relatively underexploited status of Indian Ocean billfishes (Honma & Ueyanagi 1979, Silas 1989); indeed, most of the trends presented in this paper are positive. It is equally apparent, nevertheless, that future demand for billfishes in the S.W. Indian Ocean, both by sport and commercial fishermen, will increase markedly over the next decade. Lack of contact between countries in the region and, especially, inadequate communication among sport fishing organizations, aggravates the paucity of data. It is imperative, therefore, that greater and urgent attention be devoted to this problem in order to obtain better catch statistics, provide improved communication among all parties, and ultimately secure better prospects for billfish exploitation in the region.

Summary

The capture of billfishes by both commercial longliners and sport fishermen around southern Africa, especially in the S.W. Indian Ocean, is seen to be on the increase. Several new areas of sport fishing have developed within this region and analysis of anglers' catches reveals significant differences in species composition between these localities. Ten of the world's twelve billfish species have been recorded off South Africa, though the Indo-Pacific sailfish *(Istiophorus platypterus)* and black marlin *(Makaira indica)* account for 88% of all billfish landings. Most of those caught by sport fishermen come from northern Natal on the east coast, where the abundance of all species increases during summer. Evidence presented indicates that none of the istiophorids are reproductively active in this region, and it is suggested that most immigrate from regions to the north and east. The availability of food and presence of deep submarine canyons is shown to have a probable bearing on local abundance and distribution of billfishes.

The inadequacy of data and catch statistics is seen to be in need of urgent attention.

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A Comparison of Fishing Success and Average Weights of Blue Marlin and White Marlin Landed By the Recreational Fishery in the Western Atlantic Ocean, Gulf of Mexico, and Caribbean Sea, 1972-1986

Eric D. Prince, Angelo R. Bertolino, and Allyn Monty Lopez

Recreational billfishing in the United States can be traced back to the early 1900s. The first billfish taken on recreational fishing gear in the Pacific was a striped marlin *(Tetrapturus audax),* caught in 1903 off Avalon, California (de Sylva 1974). The first billfish caught in the Atlantic on rod and reel was probably a sailfish *(Istiophorous platypterus),* taken off Miami, Florida, around the turn of the century (Beardsley and Conser 1981). Interest and effort in recreational fishing for billfishes on both coasts (as well as world-wide) has expanded substantially since those initial catches, especially following World War II. The world catch of all species of billfishes averaged about 100,000 metric tons per year during the last decade. More than 90% of this total is taken as "incidental catch" by foreign-based tuna longline fisheries (Ueyanagi 1974, Conser 1982). Directed commercial fisheries for billfishes (istiophorids only) are not established in the U.S. and are beyond the scope of this paper.

Most of the recreational fishing effort for billfishes along the U.S. Atlantic coast, Gulf of Mexico, and in the Caribbean Sea is concentrated either around key ports, fishing centers, or at billfish tournaments (Beardsley and Conser 1981). Accordingly, the Oceanic Gamefish Investigation Program (OGFI) was organized at the National Marine Fisheries Service's (NMFS) Miami Laboratory in 1972, to monitor the fishing success and average weights of billfishes landed in the recreational fishery in the Western Atlantic Ocean, Gulf of Mexico, and Caribbean Sea. Beardsley and Conser (1981) presented an analysis of these catch-and-effort data for the period 1971-1978, and evaluated the reliability of sampling techniques, as well as whether these data (i.e., hook-per-unit-effort, HPUE) can indicate changes in relative abundance of billfish populations. This report has been prepared to provide a general overview of the recreational fishery for blue marlin *(Makaira nigricans)* and white marlin *(Tetrapturus albidus)* during the 15-year period, 1972-1986, by determining: (1) trends in mean annual HPUE by area and species; (2) trends in mean weights of marlin landed by species, sex, and area; and (3) the relationship between HPUE and catch-per-unit-effort (CPUE) by area and species.

Methods

Hook-per-unit-effort is our primary index of fishing success and is expressed as the numbers of fish hooked divided by the number of hours spent trolling (using 3 to 4 lines). Beardsley and Conser (1981) discuss the unique characteristics of trolling for billfishes that justified using HPUE as a valid measure of fishing success. They also presented evidence supporting the use of this statistic as an index of relative abundance for the Gulf of Mexico. Catch-per-unit-effort is the number of fish caught divided by the number of hours spent trolling. A caught billfish can be one that is either boated, released, or tagged and released.

Recreational Billfish Survey

To insure uniformity of data collection in terms of the method of fishing, this analysis covers only recreational fishermen (i.e., anglers) trolling for marlin. Live-bait tournaments for sailfish *(Istiophorus platypterus)* are popular along the Florida east coast and Keys, but are not included in this report. Both tournament and non-tournament fishing activity were included in the survey coverage of the geographical region (Table 1). We define "tournaments" as organized billfishing events that are generally held within a specified period, usually two to four days. Tournaments are often regulated by a board of directors who establish rules of conduct. These rules usually follow guidelines established by the International Game Fish Association (IGFA). This type of fishing is distinguished in our survey sampling from non-tournament fishing at various ports where fishing activity (i.e., duration of effort, time of year) is unregulated. The data include the following: fishing effort (hours spent trolling); species and number of marlin boated, hooked, released, tagged, or lost; length, weight, and sex of marlin landed; and weather conditions (sea state, cloud cover, wind speed and direction). The data for these categories were obtained throughout the survey. Additional information on types of bait used were added to the survey in 1981 but are not included in this report.

Billfish lengths were measured from the tip of the lower jaw to the fork of the tail (lower jaw/fork length — LJFL) to the nearest inch or centimeter. Total round weights of marlin were initially recorded in pounds and later converted to kilograms.

Efforts were made to sample tournament and non-tournament fishing activity in the same location, at about the same dates each year. Since the start of the survey in 1972, however, many new tournaments have been initiated and some have terminated. Not all tournaments, therefore, have been sampled for each year of the survey. In some areas, moreover, the names of certain tournaments have changed, but sampling in these areas was continued at the same locations and dates when possible.

Beardsley and Conser (1981) gave a detailed explanation of this survey through 1978 and also described some of its limitations. We discuss the limitations of the survey methods and how they affect our results in later sections.

Table 1. Major sampling locations (or ports) and years covered in the 4 areas of the NMFS recreational billfish surveys, 1972-1986. Not every sampling location was covered in each area for every year of the survey (see text).

Areas	Sample Location (Port)	Year(s) Covered
U.S. East Coast	Block Island, RI	74
	New England	80-84
	Babylon, NY	80, 82, 84
	Long Island, NY	80, 82-84
	Shinnecock, NY	84
	Cape May, NJ	74, 77, 78, 80-84
	Atlantic City, NJ	80-83
	Ocean City, NJ	80, 82-83
	Wilmington, DE	85
	Ocean City, MD	74-78
	Virginia Beach, VA	75, 76, 80-84
	Oregon Inlet, NC	78-86
	Hatteras, NC	73-85
	Morehead City, NC	75-83
	Beaufort, NC	81-86
	Charleston, SC	83-86
	Georgetown, SC	73-86
	Sea Pines, SC	72-86
	Savannah, GA	73-77, 83
Bahamas	Walkers Cay	72-73, 81-86
	Treasure Cay	86
	Bimini	72-86
	Cat Cay	72-86
	Chub Cay	72-86
Caribbean	Mayaguez, PR	77, 83
	San Juan, PR	74-78, 81-86
	St. Thomas, VI	73-86
	St. Croix, VI	83
	Cayman Islands, BWI	84-85
	Kingston, JA	72-76, 86
	Mariel, Cuba	79
	Boca de Yuma, DR	78
Gulf of Mexico	St. Petersburg, FL	72, 81,86
	Clearwater, FL	86
	Panama City, FL[1]	71-86
	Destin, FL[1]	71-86
	Pensacola, FL[1]	71-86
	Orange Beach, AL	74-86
	Dauphin Island, AL	74-75, 77-86
	Grand Isle, LA[1]	76-86
	South Pass, LA[1]	71-86
	Freeport, TX	76-86
	Port O'Conner, TX	75-86
	Key Allegro, TX	76, 78-79, 81-82
	Port Aransas, TX[1]	72-86
	Port Mansfield, TX	76-80, 82-86
	Port Isabel, TX	73, 75-86

[1]Historical ports where samplers have been hired to sample the entire season.

Statistical Methods

For each species, mean annual HPUE was computed by partitioning the data by each day

of the fishing season ([Σ (H/E)]/n) and then calculating mean yearly values for each area and for all areas combined. Mean annual weights for each species were calculated in a similar fashion. The two sets of data were plotted over time, with mean values ± 2 standard errors. Prior to conducting correlation analysis, the data were analyzed for adherence to critical assumptions. Bartlett's test (Conover 1971) indicated a lack of homogeniety of variance and, although several transformations were tried and the data re-tested, homogeneity of variance could not be achieved. A non-parametric analog to classical analysis — Spearman Rho Rank Correlation (SRRC, Conover 1971) — was used, therefore, to test for trends in fishing success and mean weight of landed marlin over time. Regression analysis was used to determine the relationship between HPUE and CPUE, by area and species.

Areas Surveyed

Although the basic questions originally established in the NMFS recreational billfish surveys have not changed since the initiation of the program in 1972 (some additional questions have been added), the extent of survey coverage (Fig. 1) for tournaments and non-tournaments has changed considerably. These changes have resulted in a net expansion of the number of non-tournament ports and tournaments sampled from 1972 to 1986 (Fig. 2 A). Tournament coverage has undergone considerable expansion, ranging from a low of 24 tournaments surveyed in 1972 to a high of 111 in 1983. Conversely, coverage of non-tournament fishing activity (at ports) remained stable from 1972 to 1979 (ranging from 5 to 8 ports), and coverage was expanded to over 10 ports thereafter (peak coverage in 1983 with 20 ports). Sampling was scheduled throughout the year to coincide with the fishing season in each area, the seasonal availability of marlin, and varied from one area to another but was relatively consistent from year to year. Data from the Florida east coast and Keys were not included in this report because most of the effort in this area targets sailfish using live bait.

U.S. East Coast

Data from the east coast were collected along the western Atlantic seaboard from Block Island, RI, to Savannah, GA (Fig. 1). Sampling in this area involved a cumulative total of 15 major sampling locations since 1972 (Table 1). Sampling on the east coast generally started in June and lasted through September. Survey coverage along the east coast has been the least consistent of all the areas in this geographical region. For example, during the initial year of the survey (1972), only one tournament (in South Carolina) and no ports were sampled in this area. In 1973, an informal agreement was reached with the South Carolina Wildlife and Marine Resources Department (SCWMRD), which resulted in an overall increase in tournament coverage to three tournaments, which were sampled by the SCWMRD. During this same year, the NMFS sampled one tournament in North Carolina and one in Georgia. Tournament coverage doubled (ranging from 8 to 11) during the period 1974 to 1979. No ports were sampled along the east coast during these early years, however, except for one attempt in Maryland in 1974. Port sampling was not reinstated until 1980, when 5 ports were sampled. Tournament coverage was also expanded in 1980 (to 18), and both tournament and port sampling have remained at about these levels.

Bahamas

The Bahamas provides year-round marlin fishing opportunities, with an extended tournament "season" covering about seven months (March through October), compared with about 4 to 6 months along the U.S. east coast, and in the Caribbean Sea and Gulf of Mexico. Sampling in the Bahamas has traditionally involved four major sampling locations since 1972: Walkers Cay, Cat Cay, Chub Cay, and Bimini (Fig. 1; Table 1). Efforts to sample ports were not cost-efficient in the Bahamas because the majority of marlin fishing there occurs during tournaments. Tournament sampling has been very consistent, and ranged from 8 to 11 tournaments during each year of the survey. Walkers Cay was not covered in the survey from 1974 to 1980. This omission has been the only major inconsistency in tournament coverage for this area.

Gulf of Mexico

Data collection in the Gulf of Mexico (Fig. 1) was originally organized at the Panama City Laboratory of the NMFS in 1970 and was incorporated into the present program in 1972 (Gulf data prior to 1972 are not included in this paper). Data were collected from five major ports in 1972: Panama City, Destin, and Pensacola, FL; South Pass, LA; and Port Aransas, TX. The

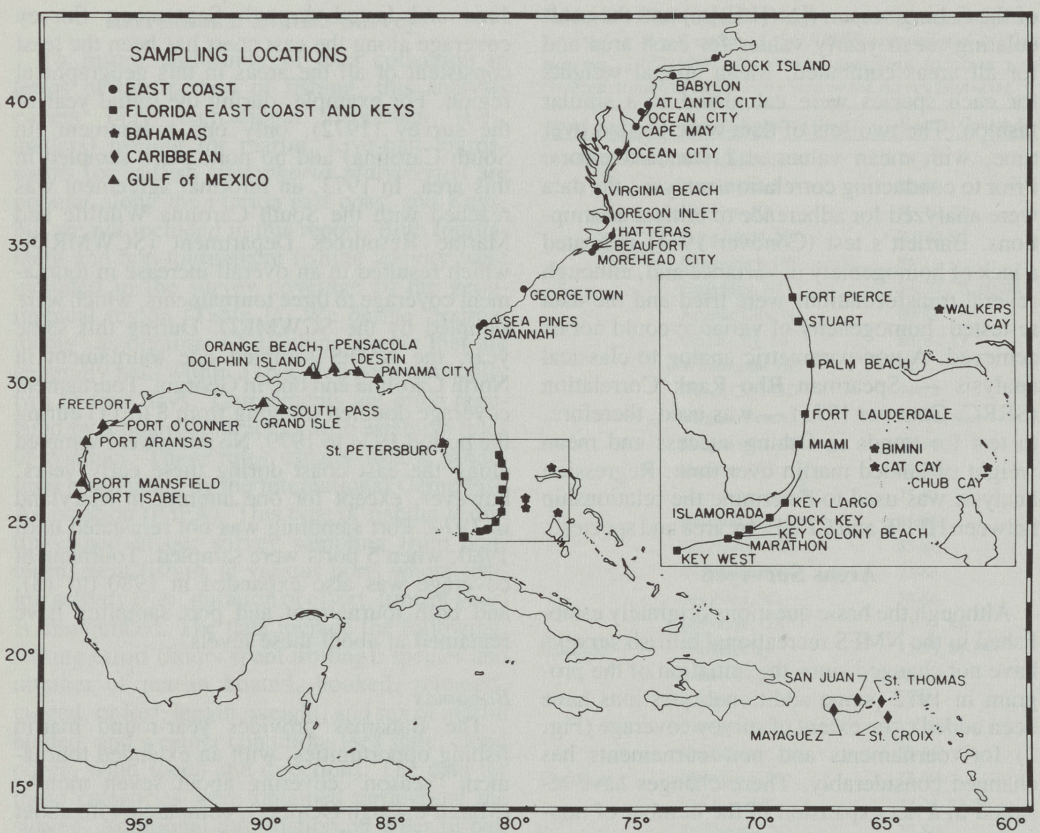

Figure 1. Sampling locations for the recreational billfish surveys of the National Marine Fisheries Service's Southeast Fisheries Center, Miami, FL. 1972-1986.

ports of Mobile, AL, and Grande Isle, LA, were added to the program by 1981, for a total of seven ports (Table 1). Sampling in the Gulf extends from April through October and has differed from the other areas in that samplers were hired each year on a seasonal basis to collect as much billfish data as possible from one sampling location. This strategy included both tournament and non-tournament sampling and, as a result, the data from the Gulf have been more consistent and voluminous than those from any of the other areas of this survey. In addition to the seven ports covered by seasonal samplers, three other sampling locations have been covered in the Gulf over the last decade without resident samplers (Table 1). Tournament sampling has been greatly expanded in the Gulf; it ranged from 2 to 4 tournaments, in the first three years of the survey, to a high of 57 tournaments by 1984. Conversely, port sampling has remained comparatively stable; it ranged from a low of 4 in 1973 to a high of 10 ports covered in 1981 and 1983.

Caribbean Sea

Three major sampling locations were involved in the first five years of data collection in the Caribbean (Fig. 1): Puerto Rico (Mayaquez and San Juan), St. Thomas, U.S. Virgin Islands, and Jamaica (Table 1). Jamaica was no longer included as a primary sampling location after 1976. Efforts were also made to collect data from other locations, but these were sampled only on a sporadic basis and were very limited in scope. For example, one tournament was covered in Mariel, Cuba, in 1979; one tournament was sampled in Boca de Yuma, Dominican Republic, in 1978; and a series of tournaments were sampled during Million Dollar Month in the Cayman Islands, BWI, in 1984-1985. Sampling in the Caribbean was restricted to tournaments held from July through September,

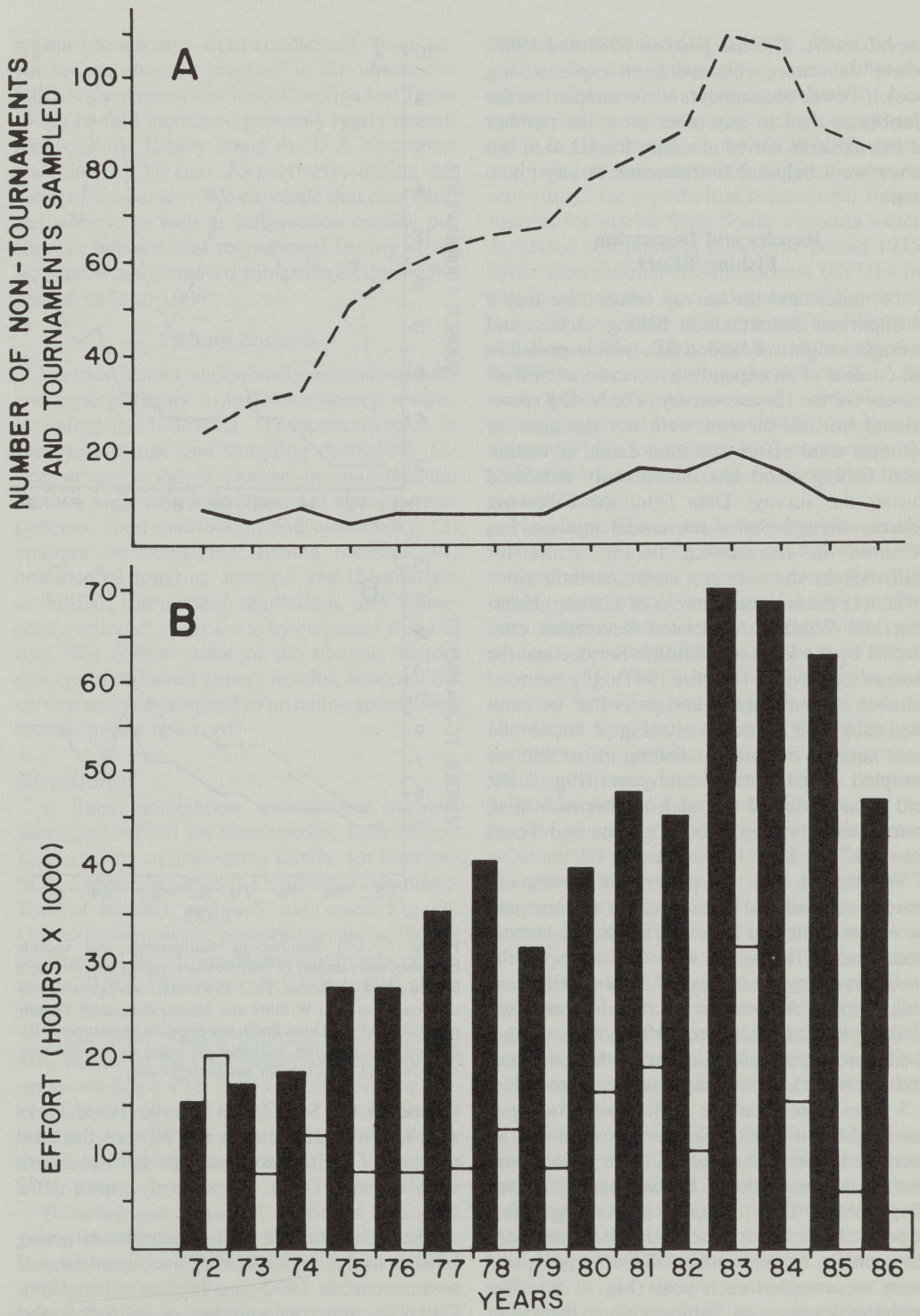

Figure 2. (A) Number of non-tournaments (ports) and tournaments, and (B) hours of fishing effort for non-tournament (port) and tournament sampling from the NMFS recreational billfish surveys, 1972-1986. Solid line indicates non-tournaments and dashed line indicates tournaments in A, open bar indicates non-tournaments and solid bar indicates tournaments in B.

except for St. Thomas ports in 1981 and 1982, where data were obtained from captains' log books. Fewer tournaments were sampled in the Caribbean than in any other area; the number of tournaments varied annually from 2 to 6, but never went below 2 tournaments in any given year.

Results and Discussion

Fishing Effort

To understand the survey results, we feel it is important that trends in fishing success and average weights of landed fish be interpreted in the context of an expanding recreational billfish fishery for the 15-year survey. The NMFS recreational billfish surveys were not designed to estimate total effort and total catch; nevertheless, fishing effort has undoubtedly increased during the survey. Data from the following sources suggest that a substantial increase has occurred in recreational fishing effort for billfishes in the western north Atlantic since 1972: (1) the national surveys of Fishing, Hunting, and Wildlife Associated Recreation conducted by the Fish and Wildlife Service and the Bureau of Census (Martin 1987); (2) the total number of tournaments and ports that we sampled each year of the survey (Fig. 2 A); (3) the total number of hours of fishing effort that we sampled at tournaments and ports (Fig. 2 B); and (4) a census of the total number of billfish tournaments held in South Carolina and Texas from 1972 to 1987 (Fig. 3 A and B).

We believe that the pattern of greatly expanded recreational fishing effort documented by national surveys generally applies to recreational marlin fishing, as well. For example, the successive national surveys of Fishing, Hunting, and Wildlife Associated Recreation conducted at five-year intervals since 1955, indicate that total recreational fishing effort (both fresh water and salt water) has increased at a rate more than 1.5 times faster than the U.S. growth in population (Martin 1987). Similarly, we found an increase in total fishing effort (hours of trolling) during the recreational billfish survey period (Fig. 2 B). This increase in fishing effort appears, however, to be closely associated with the increase in the number of tournaments and ports we sampled each year (Fig. 2 A). The apparent increase in fishing effort, therefore, could simply be reflecting the increase in sampling intensity of the survey. This possibility seems remote, based on results of a census con-

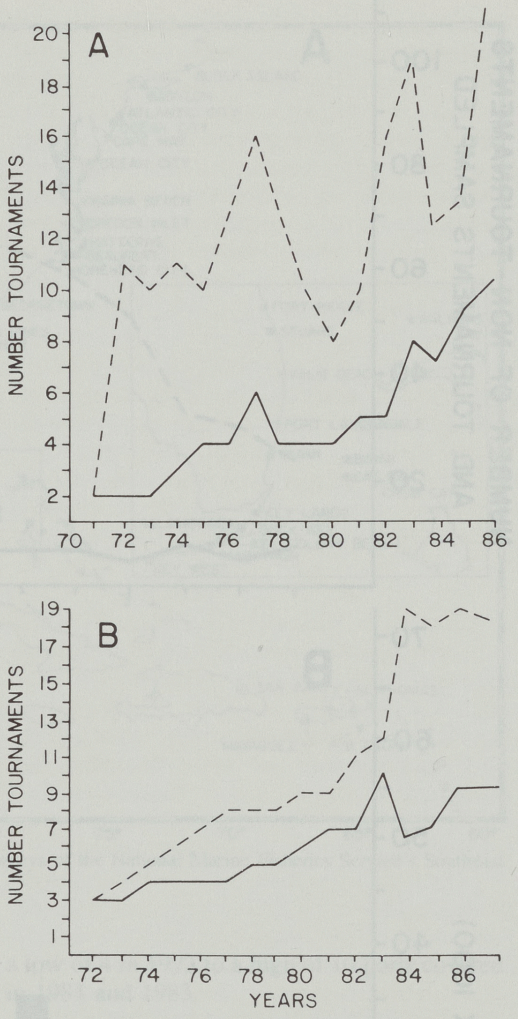

Figure 3. (A) Number of tournaments that include billfishes and number of billfish tournaments only in South Carolina and (B) Texas, 1972-1987. Data were provided by the South Carolina Wildlife and Marine Resources Department (A) and the Texas Parks and Wildlife Department (B). Dashed line indicates billfishes included in tournaments, solid line indicates billfish tournaments only.

ducted by the SCWMRD and the Texas Parks and Wildlife Department (TPWD) of the total number of billfish tournaments held in South Carolina and Texas, respectively, since 1972 (Fig. 3 A and B).

The total number of tournaments targeting billfish (only) in South Carolina, went from 2 tournaments in 1972 to a high of 10 in 1986. Likewise, the total number of billfish (only) tournaments held in Texas rose from 3 tournaments in 1972 to 10 by 1987. Corresponding data are not available from other states in the

region (no surveys were conducted). Even so, we believe that the increase in the number of billfish tournaments in South Carolina and Texas (5- to 10-fold increases) probably typify overall trends of the fishery along the U.S. east coast and Gulf of Mexico, respectively, during the years of the survey. We conclude that data from our survey, as well as information outside our survey, indicate that recreational fishing effort for marlin has increased substantially during the period 1972 to 1986.

Fishing Success

Various factors undoubtedly act individually and synergistically to influence survey results, including the following: (1) inconsistencies in survey coverage and sampling during the 15-year survey period; (2) changes in environmental factors, such as temperature, sea state, current patterns, food distribution and availability; (3) changes in recreational fishing methods; (4) commercial longline activity; and (5) changes in billfish tournament regulations and fishermen's attitudes. This list is by no means exhaustive. We review some of the obvious factors that could influence survey results, although the survey was not designed to provide explanations for the trends observed.

Blue Marlin

A linear association was evident between years and HPUE for blue marlin, with respect to increasing or decreasing trends, for three out of five area categories (i.e., all areas combined, Gulf of Mexico, and U.S. east coast; Fig. 4). One exception to the general increase in fishing success was the strong decreasing trend in mean annual HPUE ($SRRC = -0.93$, $P \leq 0.001$) along the U.S. east coast.

There were notable decreases in HPUE for blue marlin in the Caribbean, Bahamas, and all areas combined after 1981 (Fig. 4). Fishing success also declined in the Gulf of Mexico during the last years of the survey period, but the decrease did not approach historical lows as in other areas.

Browder and Prince (1987) used a general linear model to analyze the same data set to develop indices of abundance for blue marlin and white marlin. They found either no trend or slightly increasing trends in standardized HPUEs and CPUEs [by area, month, and sampling type (tournament or port sampling)] for blue marlin in the same geographical region and overlapping time period (1972-1985). They did not analyze the data separately by area within the region. However, a separate analysis of blue marlin fishing success along the U.S. east coast, by D.L. Hammond of the SCWMRD (pers. comm.), corroborates the findings from the present study. He reports that recreational fishing success for marlin from South Carolina waters decreased substantially during the period 1975-1986. Recreational fishing success (CPUE) for blue marlin in the La Guaira area of Venezuela from 1961 to 1981 was reported by Machado and Jaen (1982). They found a large reduction in fishing success during the last half of the study period (6-fold decrease), with fluctuations. Prince and Bertolino (1986) found recreational CPUEs for Atlantic blue marlin from the 1972-1984 sample areas to be similar to those reported here.

No single factor explains why blue marlin fishing success along the U.S. east coast decreased during this period, particularly when fishing success in other areas of the region have been stable or have increased. Hammond (pers. comm.) speculates that the decrease in fishing success might be linked to increasingly poor weather conditions during the last decade. Hammond apparently believes that when sea conditions are greater than 6- to 10-foot seas, fishing efficiency and productivity decrease proportionately. Spiller et al (1988) report that harvest sampling efficiency can be improved substantially by canceling sampling during inclement weather. Browder and Prince (1987) also felt that environmental conditions were important factors. They used sea state and cloud cover as independent variables in evaluating their effects on blue marlin fishing success. Both sea state and cloud cover were judged as highly significant independent variables in blue marlin models, but these variables explained little additional variation in fishing success than models without them.

Another possible explanation for the apparent decrease in fishing success for blue marlin on the U.S. east coast is inconsistent tournament coverage and sampling in this area. As stated previously, the U.S. east coast coverage and sampling was the least consistent of the areas covered in the survey. Inconsistent or non-coverage of some of the more important blue marlin tournaments (with the most experienced blue marlin fishermen) could conceivably account for these results. This factor would be

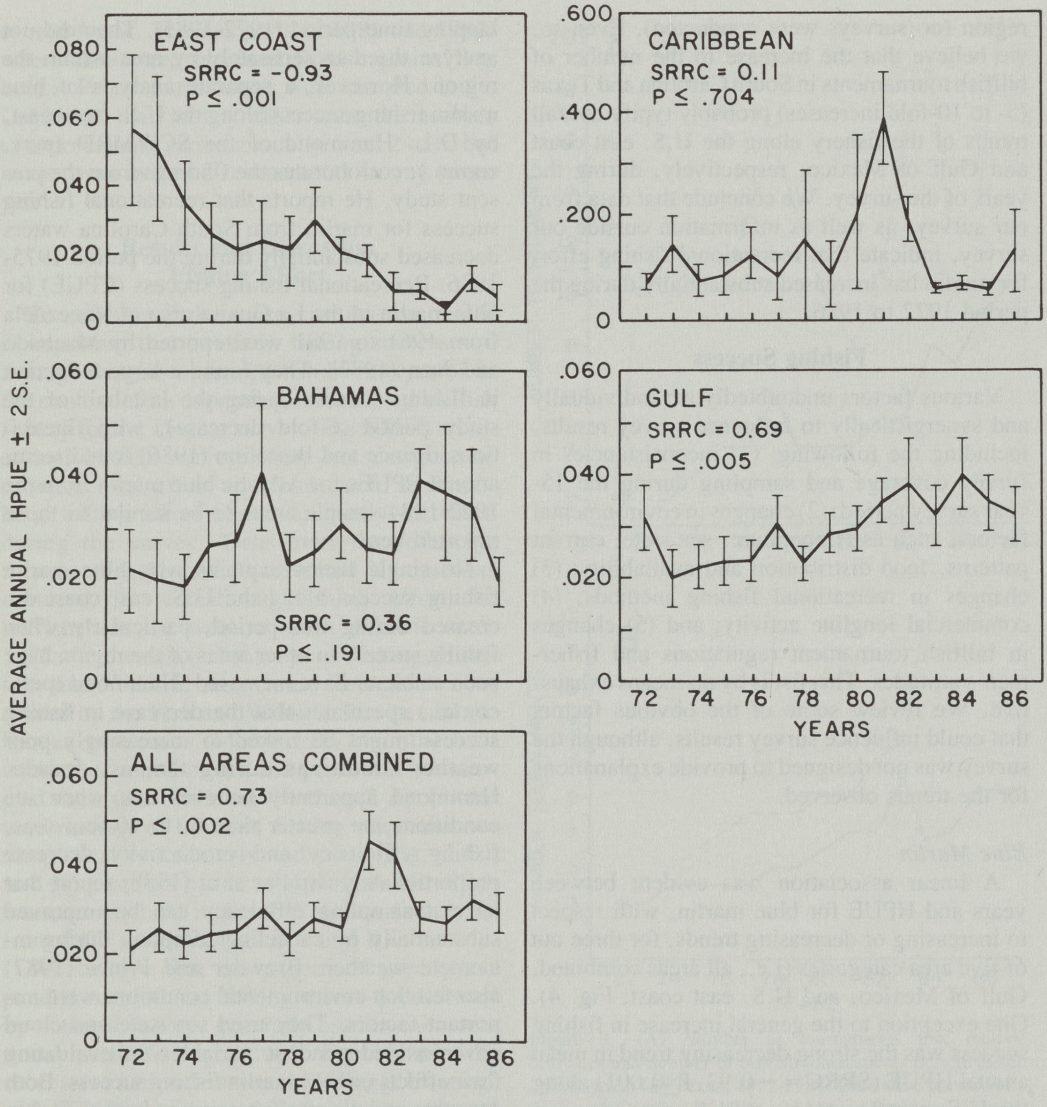

Figure 4. Average annual hook-per-unit effort (±2 standard errors) for blue marlin from the NMFS recreational billfish surveys of the U.S. east coast, Caribbean Sea, Bahamas, Gulf of Mexico, and all areas combined, 1972-1986. Spearman Rho Rank Correlation (SRRC) and probabilities are given for each area.

particularly true in later years of the survey when decreases in HPUE occurred (1980-86). Survey coverage of three of the most important blue marlin tournaments in this area (namely, the Hatteras Blue Marlin, Big Rock Blue Marlin, and Capt. Fanny Blue Marlin tournaments), however, suggests that inconsistent sampling was probably not a major factor since these tournaments were sampled from 1973 to 1985, 1975 to 1983, and 1981 to 1986, respectively. Larger standard errors were generally evident, nevertheless, in the early years of the study period, when fewer tournaments and less fishing effort were sampled (Fig. 4).

Changes in marlin fishing techniques took place region-wide in the early 1980s and this factor could have affected the results of the survey. Trolling with natural baits at 5 to 7 knots has gradually been replaced by faster trolling (8 to 12 knots) with artificial lures. This change in technique was not adopted uniformly in all areas within the region, and this inconsistency

might account for some of the differences in fishing success between areas. This observation may be particularly relevant to the Gulf of Mexico, which was probably the first area to adopt high-speed trolling with artificial lures in the early 1980s. The upward trend in HPUE for blue marlin from the Gulf since the early 1980s suggests that changes in fishing techniques were important factors, since high-speed trolling covers more area during a fishing day and thus increases the chance of a billfish encounter. Beardsley and Conser (1981) reported that recreational catchability for blue marlin in the Gulf of Mexico could not be assumed to have been constant during the period of the survey they analyzed (1971-1978).

The biology and life history characteristics of blue marlin, as well as the other istiophorids, should be considered when interpreting results of the survey. For example, are survey results in the Caribbean, which is closest to the geographical center of blue marlin distribution in the northwest Atlantic, more meaningful than in areas at the northern boundary of the distribution, where this species occurs only seasonally (i.e., U.S. east coast)? Squire (1987) suggested, in order for catch rates from localized recreational billfisheries to be valid measures for monitoring stocks, that the centers of distribution of such stocks must be near the recreational fishery. Tagging studies show that blue marlin are the most far-ranging of the istiophorids (Scott et al in press), and commercial landings indicate that many blue marlin are captured in the mid-Atlantic (Conser 1985). Yet, most recreational billfishing takes place within 100 miles of the coastline. These factors certainly deserve consideration when interpreting the results of this survey.

The influence of commercial longline activity in the region should not be overlooked as a possible influence on survey results. Beardsley and Conser (1981) found that commercial longline CPUE and recreational CPUE for white marlin were correlated when the respective fleets were fishing the same general area simultaneously. Commercial longline effort and blue marlin and white marlin landings over the last 3 decades reached a peak in the early 1960s, and then declined to relatively stable rates during the mid-1970s and through the 1980s (Conser 1989). The degree to which past commercial fishing may have affected the present survey is unclear.

White Marlin

In general, fishing success for white marlin fluctuated with little trend during the first part of the survey and then declined during the last eight years. There was a significant linear association between years and white marlin HPUE for only one out of the four area categories (i.e., Bahamas; Fig. 5). Mean annual HPUE for white marlin in the Bahamas ($SRRC = -0.57$, $P \leq 0.026$) had an historic high of 0.032 in 1975 and decreased to an historic low of 0.005 by 1986 (Fig. 5). No significant trends were found for the other area categories (i.e., the U.S. east coast, Gulf of Mexico) but all areas combined had substantial declines (2- to 4-fold) during the last eight years of the survey. For example, mean annual HPUE along the U.S. east coast went from the historic high of 0.29 in 1979 to a low of 0.02 by 1986. Data from the Caribbean were not available from 1972 to 1973 and from 1980 to 1982.

Browder and Prince (1987) found trends in region-wide standardized HPUE and CPUE for white marlin from 1979 to 1986 similar to those found in this study. Thus, both standardized and nonstandardized HPUE for white marlin from the northwest Atlantic region showed from 2- to 4-fold reductions during the last 7 years of the survey. White marlin HPUEs from this survey were incomplete for the Caribbean but Machado and Jaen (1982) presented data on white marlin fishing success from the recreational fishery near the La Guaira area of Venezuela for 1961-1981. They found substantial reductions (with fluctuations) in fishing success during this 20-year period, with the lowest rates occurring during the most recent years. A more recent analysis of the Venezuelan data by Venezuelan fisheries scientist Jose Javier Alio (pers. comm.) indicates that fishing success for white marlin has continued to decrease.

The various factors discussed previously that might have affected survey results for blue marlin, probably also apply to white marlin as well.

HPUE vs. CPUE by Species and Area

Regression analyses were used to determine the relationships between HPUE and CPUE from 1972 to 1986 for blue marlin (Fig. 6) and white marlin (Fig. 7). The r^2 values ranged from 0.59 to 0.81 for blue marlin and 0.78 to 0.98 for white marlin. The obvious positive relationships shown by the slopes in all cases suggest that most of these data can be used to make

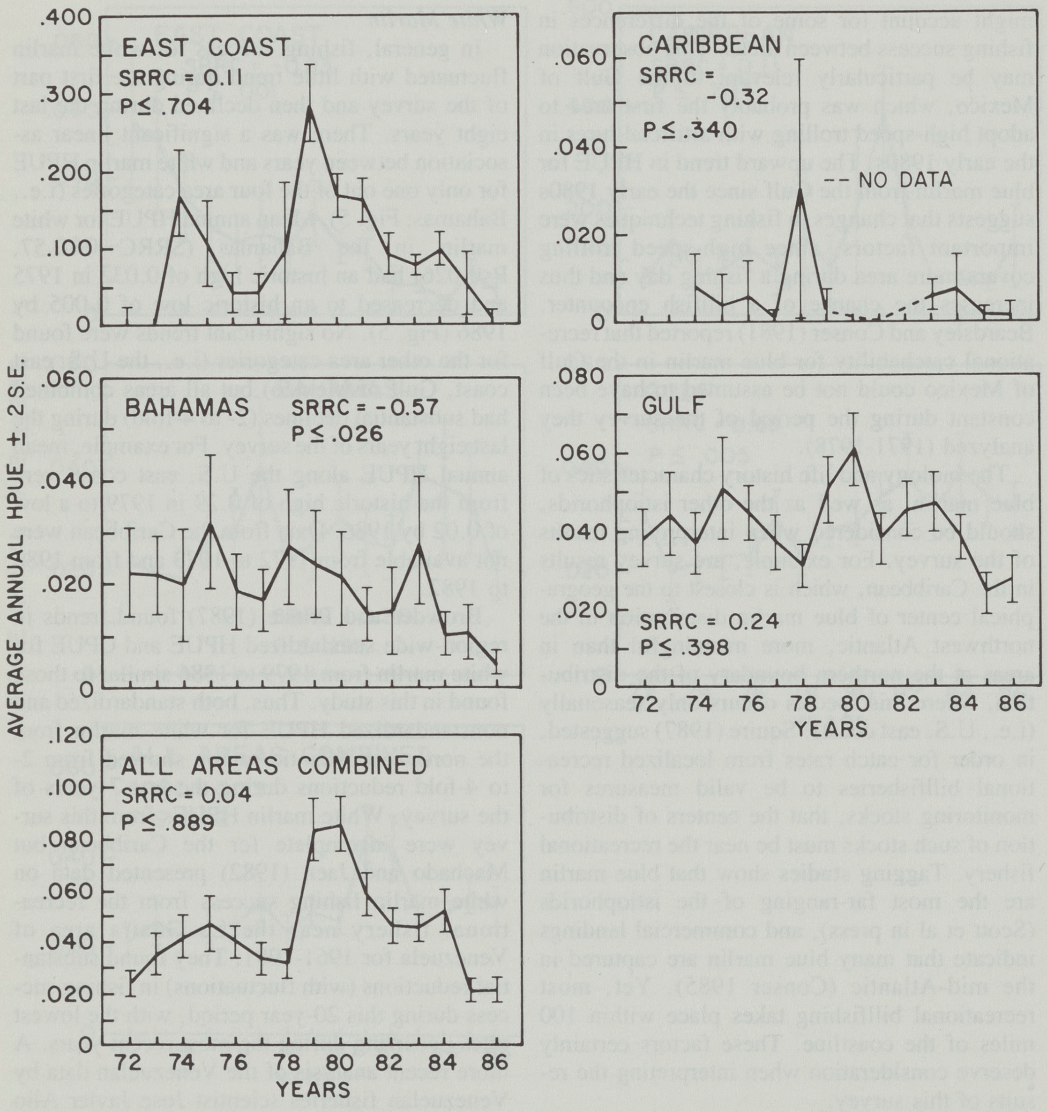

Figure 5. Average annual hook-per-unit effort (±2 standard errors) for white marlin from the NMFS recreational billfish surveys of the U.S. east coast, Caribbean Sea, Bahamas, Gulf of Mexico, and all areas combined, 1972-1986. Spearman Rho Rank Correlation (SRRC) and probabilities are given for each area.

reasonable estimates of HPUE, when the latter are not available. Estimates of HPUE from CPUE will be useful in maintaining the integrity of the present HPUE data set since funding levels for future surveys are uncertain and it is more time consuming and costly to obtain HPUE than CPUE data. An ability to make these conversions will be even more important in the future owing to a change in survey policy, which now accepts volunteer CPUE data submitted by recreational clubs and tournaments (Prince et al 1987).

Beardsley and Conser (1981) reported that HPUE is a more reliable measure than CPUE in recreational billfisheries because weight of fishing line, which varies among tournaments and individuals, affects the proportion of hooked billfish that are actually boated. Since the vast majority of billfish jump out of water when hooked, species identifications can be made of

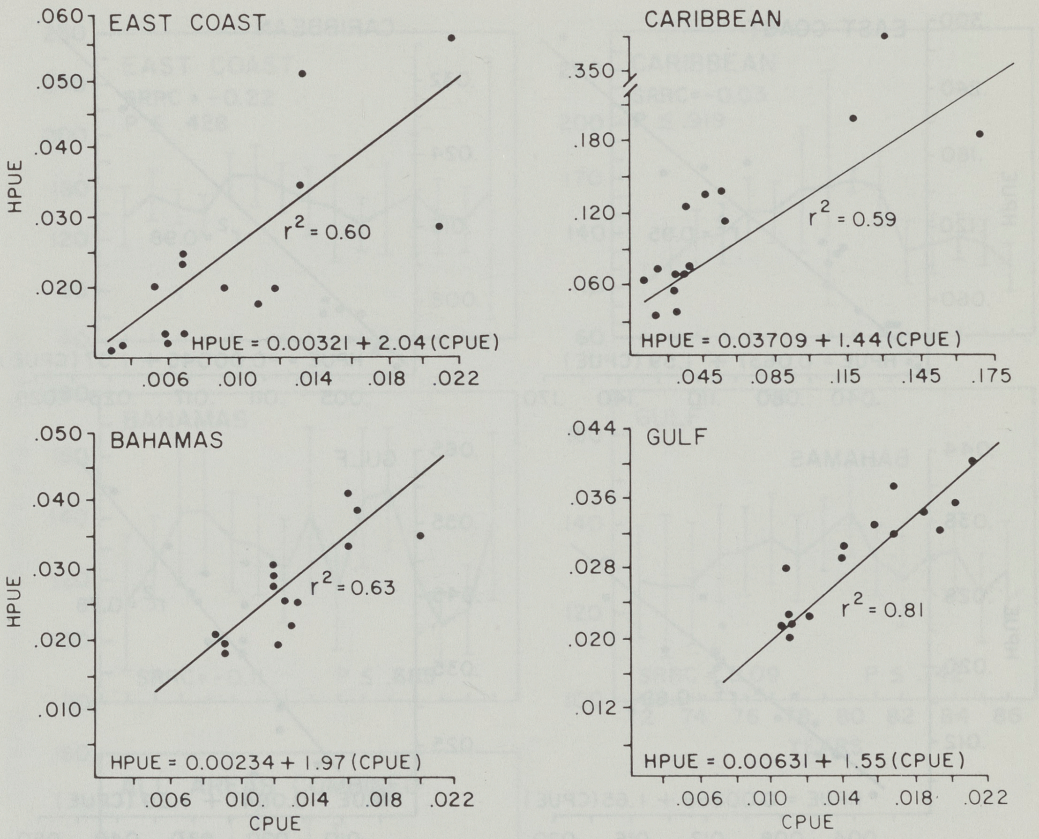

Figure 6. The relationship between catch-per-unit-effort and hook-per-unit-effort for blue marlin from the NMFS recreational billfish surveys of the U.S. east coast, Caribbean Sea, Bahamas, and Gulf of Mexico, 1972-1986. Regression equations for estimating HPUE from CPUE and r^2 are given for each area.

hooked billfish for HPUE calculations. We agree with Beardsley and Conser (1981) that HPUE is preferable for billfishes and have used this parameter throughout this paper. Changes in fishing techniques discussed previously (slow and fast trolling) probably have not affected the utility of HPUE as we applied it to the Atlantic recreational marlin fishery.

Average Weights of Landed Marlin

Average weights of landed blue marlin and white marlin were determined separately by sex because of the apparent differences in size between sexes for these species (Yeo 1978). The changes in fishermen's attitudes concerning release policies, and related changes in tournament regulations on minimum capture weights, have affected the results of the survey on weights of landed fish (Prince et al 1987).

Blue Marlin

In general, the average weight of landed female blue marlin fluctuated without a conspicuous trend (Fig. 8). Significant linear associations were not found between years and average weights for female blue marlin for any of the areas. In all areas combined, there was an apparent, overall decreasing trend, although not statistically significant ($SRRC = -0.31$, $P \leq 0.251$). Decreases in average weights to near historic lows were shown from 1980 to 1985 in the Bahamas, Caribbean, Gulf of Mexico, and all areas combined. Three out of four areas also had slight to moderate increases in average weights during 1986.

The trends in average weights of male blue marlin fluctuated by area. There were significant linear associations between years and average weights of male blue marlin for two out of the

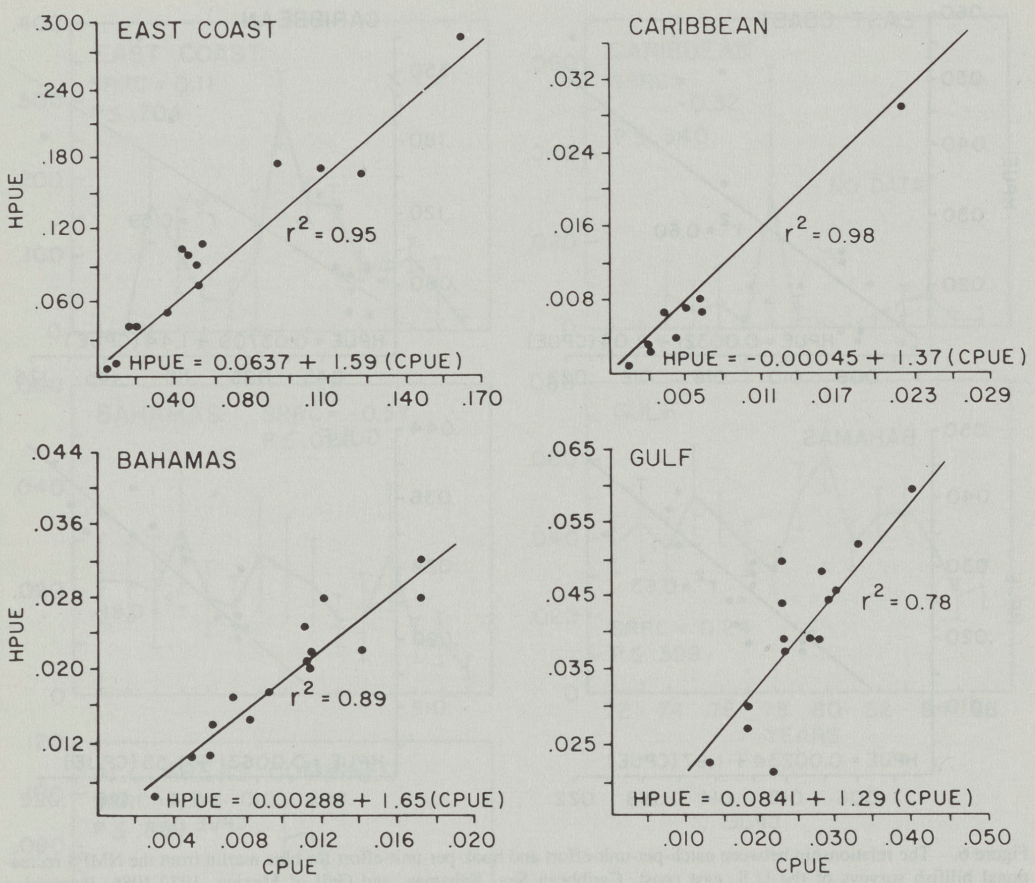

Figure 7. The relationship between catch-per-unit-effort and hook-per-unit-effort for white marlin from the NMFS recreational billfish surveys of the U.S. east coast, Caribbean Sea, Bahamas, and Gulf of Mexico, 1972-1986. Regression equations for estimating HPUE from CPUE and r^2 are given for each area.

five area categories (Fig. 9). Male blue marlin landed from the Bahamas showed a significant weight decrease (SRRC = −0.69, $P \leq 0.004$); it went from a high of about 80 kg in 1972 to an historic low of 58 kg by 1983, while the next three years showed slight increases (Fig. 9). When all areas were combined, a significant decrease in average weight of landed fish was evident for the entire region (SRRC = −0.60, $P \leq 0.019$). Average weight of landed male blue marlin in the Gulf of Mexico showed a slight decrease, although not statistically significant. The corresponding data from the Caribbean and the U.S. east coast were relatively stable; several years of data were unavailable from these areas. Rodriguez et al (1988) documented a large reduction in the average weight of blue marlin (sexes combined) from the Cuban longline fishery in the tropical and central Atlantic — from more than 145 kg in 1973 to 60 kg by 1985.

To assess the impact of changes in release policies and fishermen attitudes, the numbers of released and boated blue marlin from 1972 to 1987 were plotted by area and for all areas combined (Fig. 10). The minimum retention regulations of tournaments (releasing small fish and keeping large fish) would affect estimates of average weight of landed fish by biasing the weights upwards. A bias existed during the entire survey for blue marlin, but was most severe from 1980 to 1986 (Fig. 10). Average weights of landed blue marlin are conservative (relative to the hooked population), therefore, and the declines for various categories would likely have been more severe without the influence of this bias. The slight increases in average weights of

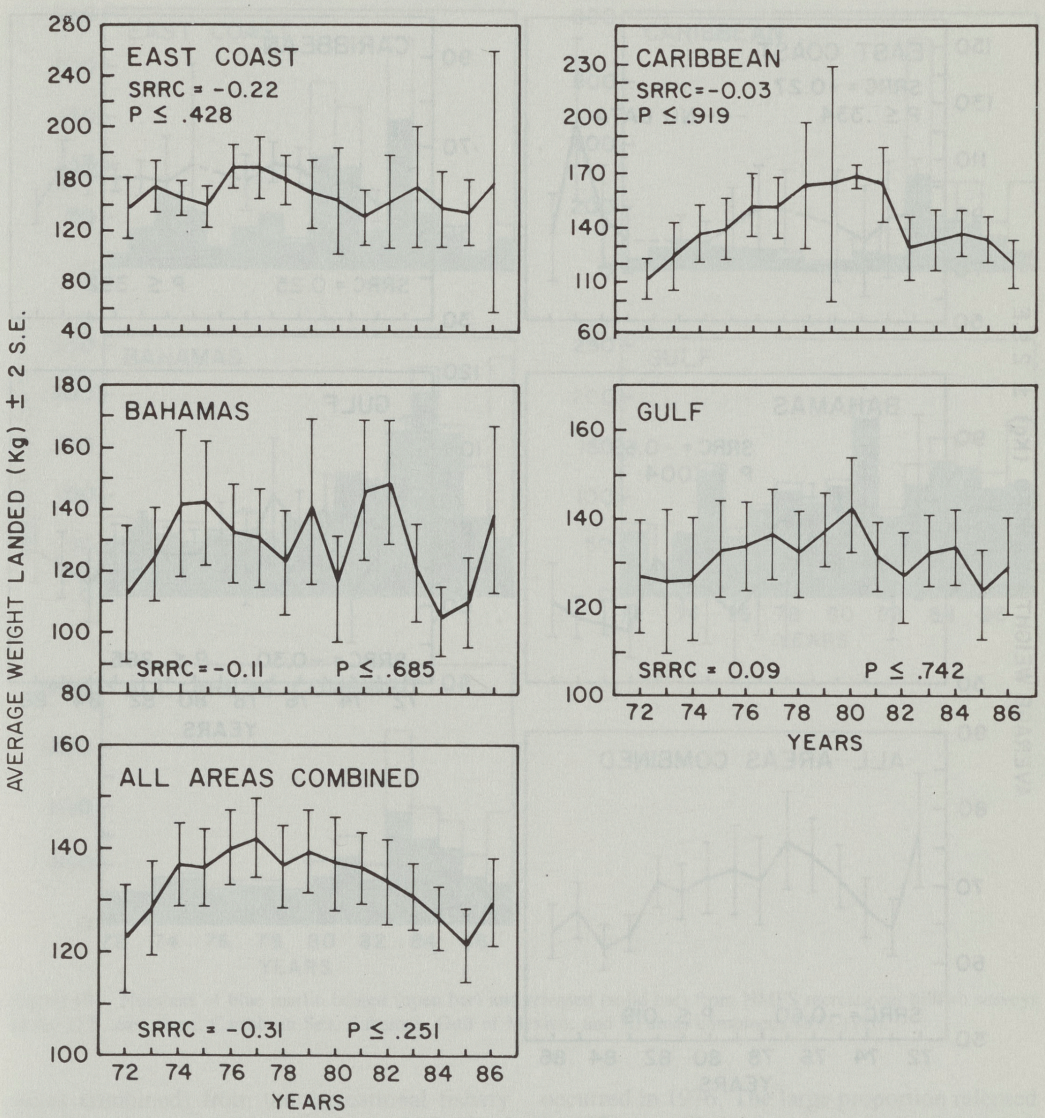

Figure 8. Average weight (kg) of female blue marlin landed (±2 standard errors) from NMFS recreational billfish surveys of the U.S. east coast, Caribbean Sea, Bahamas, Gulf of Mexico, and all areas combined, 1972-1986. Spearman Rho Rank Correlation (SRRC) and probabilities are given for each area.

landed blue marlin that occurred during the last few years of the survey were also probably a result of tournament release policies.

White Marlin

Data on average weights for female white marlin from the U.S. east coast and Caribbean were not available in sufficient quantity to monitor trends (Fig. 11). Significant negative linear associations between years and average weights were found, however, in three out of five area categories. A significant decreasing trend was evident for the Bahamas ($SRRC = -0.81$, $P \leq 0.001$), where weights averaged an historic high of almost 44 kg in 1979 and fell to an historic low of 26 kg by 1986. The Gulf of Mexico also had a significant decrease in average weight, although not as severe as in the Bahamas ($SRRC = -0.71$, $P \leq 0.003$; Fig. 11). When all areas were combined, the region

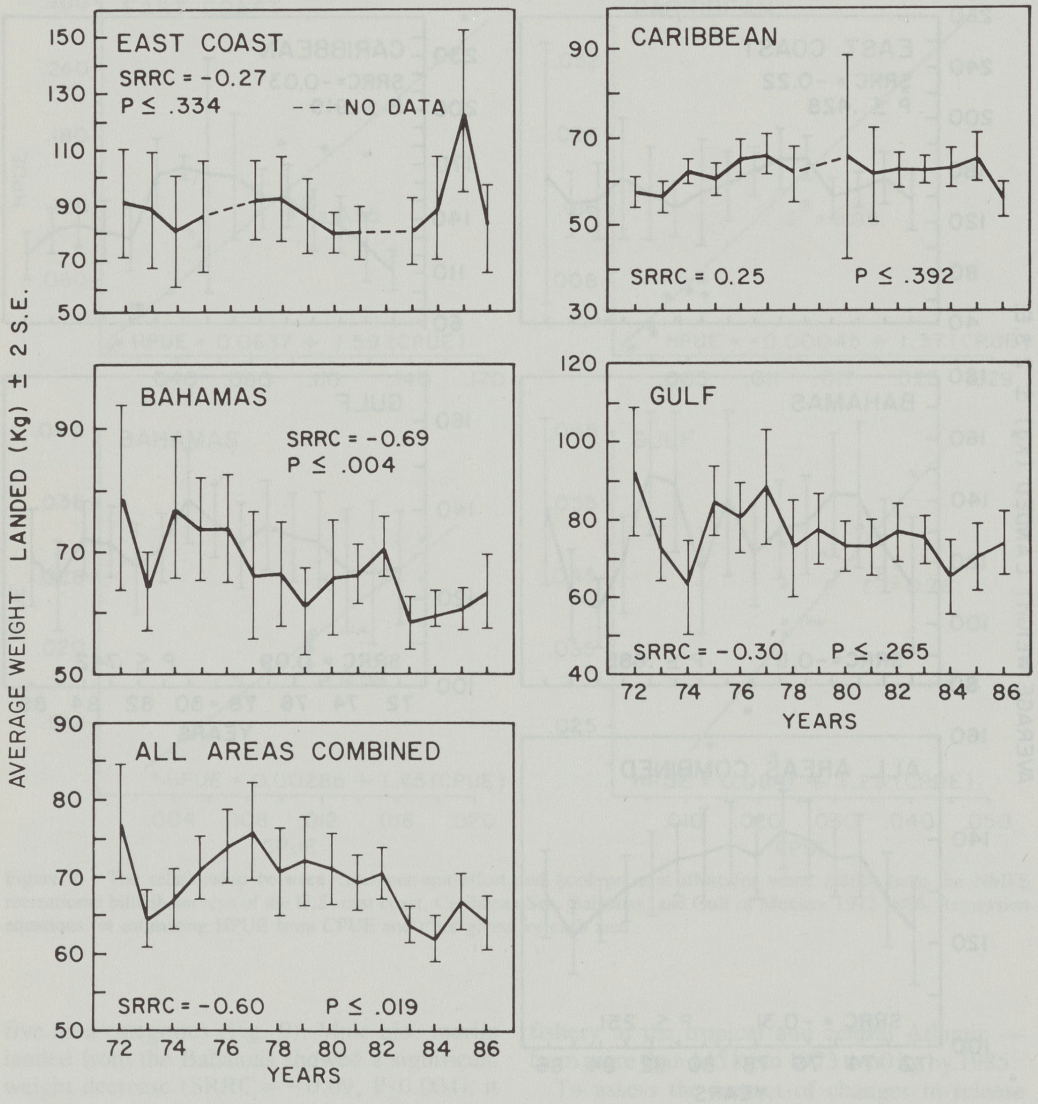

Figure 9. Average weight (kg) of male blue marlin landed (± 2 standard errors) from NMFS recreational billfish surveys of the U.S. east coast, Caribbean Sea, Bahamas, Gulf of Mexico, and all areas combined, 1972-1986. Spearman Rho Rank Correlation (SRRC) and probabilities are given for each area. Dashed line indicates lack of data.

exhibited a significant decreasing trend (SRRC = −0.80, P≤0.001) throughout the 15 years of the survey.

Overall, declines in average weights for male white marlin were similar to those for females but were not as pronounced — data from the U.S. east coast and Caribbean were not obtained in sufficient quantity for analysis (Fig. 12). Significant negative linear associations were found between years and average weight of male white marlin for two out of five area categories. The Bahamas had a significant decrease in weight of landed fish (SRRC = −0.53, P≤0.043). When all areas were combined, there was a significant decrease in average weight for the region (SRRC = −0.62, P≤0.013). During the last two years of the survey, however, average weights for male white marlin from the Bahamas, Gulf of Mexico, and all areas combined increased substantially from historic lows in 1984. Beardsley and Conser (1981) reported a decline in average size of white marlin (both

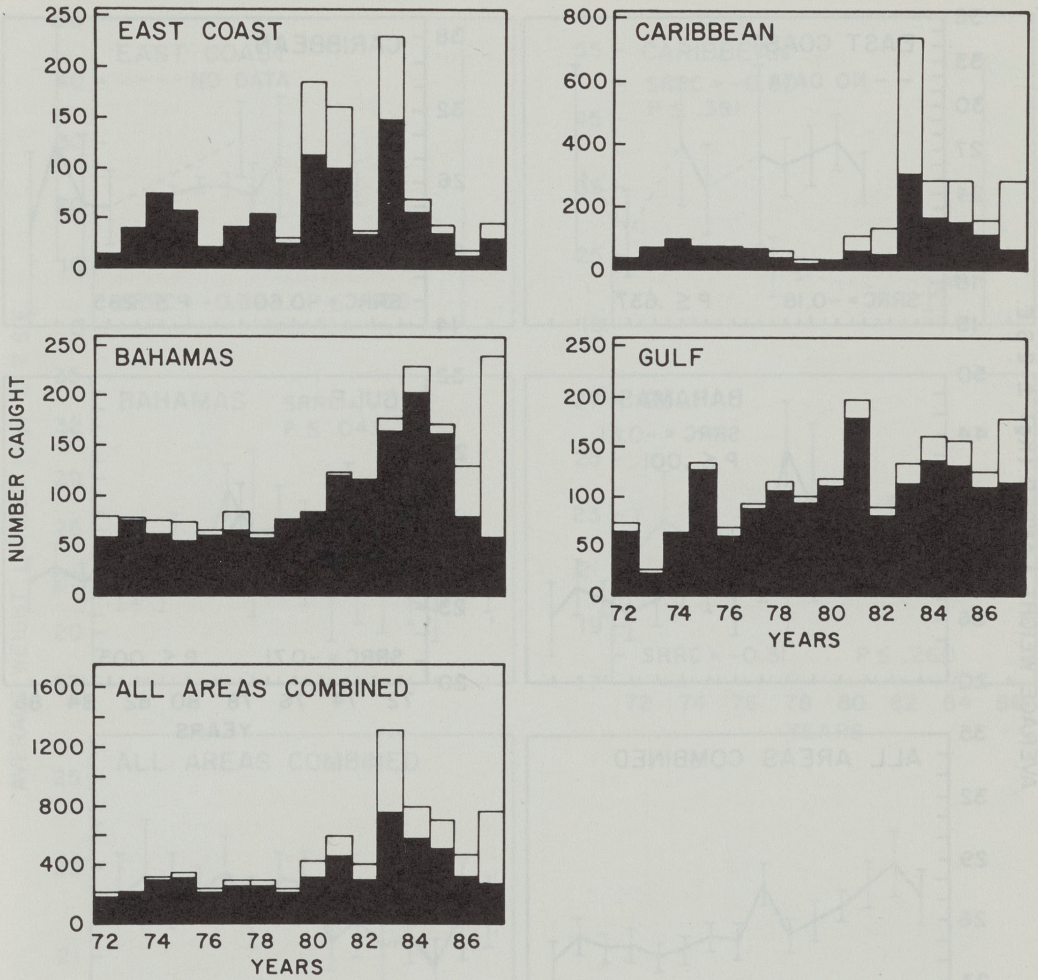

Figure 10. Numbers of blue marlin boated (open bar) and released (solid bar) from NMFS recreational billfish surveys of the U.S. east coast, Caribbean Sea, Bahamas, Gulf of Mexico, and all areas combined, 1972-1986.

sexes combined) from the recreational fishery for the western north Atlantic and Gulf of Mexico from 1955 to 1968. Average size of these fish (separated by sex) apparently stabilized during the next decade.

Policies for releasing white marlin (Fig. 13) have resulted in a higher proportion being released, compared to blue marlin, during the early years of the survey (i.e., prior to 1980). Release policies in the Gulf of Mexico were the most consistent of all areas, and about equal proportions of white marlin were released in this area during each year of the survey. Large numbers of white marlin were released in the Bahamas during the early years of the survey; the peak in average weights for pre-1980 sampling occurred in 1976. The large proportion released in 1976 was likely a major contributing factor to the historic high average weights recorded for both sexes in 1976 and 1977 (Figs. 11 and 12). Average weights of white marlin landed are conservative relative to those hooked, because of release policies. The average weight would certainly have been lower had all fish been landed each year. This bias probably affected more years of average weight data for white marlin than for blue marlin because greater numbers of the former were released during early years of the survey. The increases in average weights of male white marlin from the Bahamas and Gulf, in 1985 and 1986, are a direct result of recent release policies and tour-

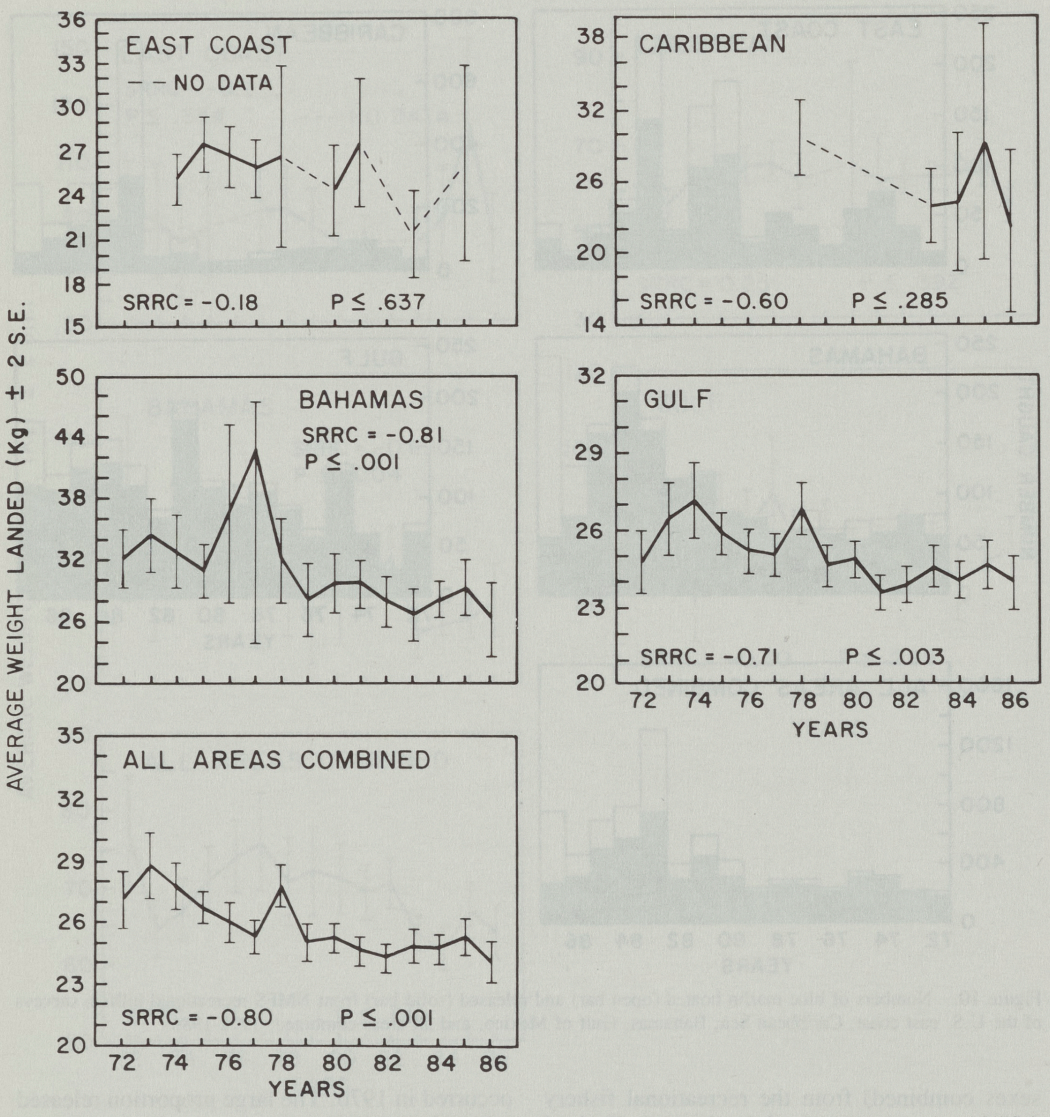

Figure 11. Average weight (kg) of female white marlin landed (±2 standard errors) from NMFS recreational billfish surveys of the U.S. east coast, Caribbean Sea, Bahamas, Gulf of Mexico, and all areas combined, 1972-1986. Spearman Rho Rank Correlation (SRRC) and probabilities are given for each area. Dashed line indicates lack of data.

nament regulations regarding weights of landed fish. Only the largest of the males would meet the minimum retention weights for this species. The declines in average weights of female white marlin from these areas in 1986, despite retention of only the largest females, would likely have been more severe had this bias not been present.

Conclusions

The primary objective for the initial design of the recreational survey for billfishes was to monitor trends in fishing success and average weight of landed fish. Many different factors undoubtedly affect survey results. It was beyond the scope of this analysis to provide explanations for all aspects of the trends observed and the relationships of many of these factors to survey data are still unclear.

Much of the evidence for the trends reported here is essentially circumstantial; therefore, conclusions from our survey data should be drawn

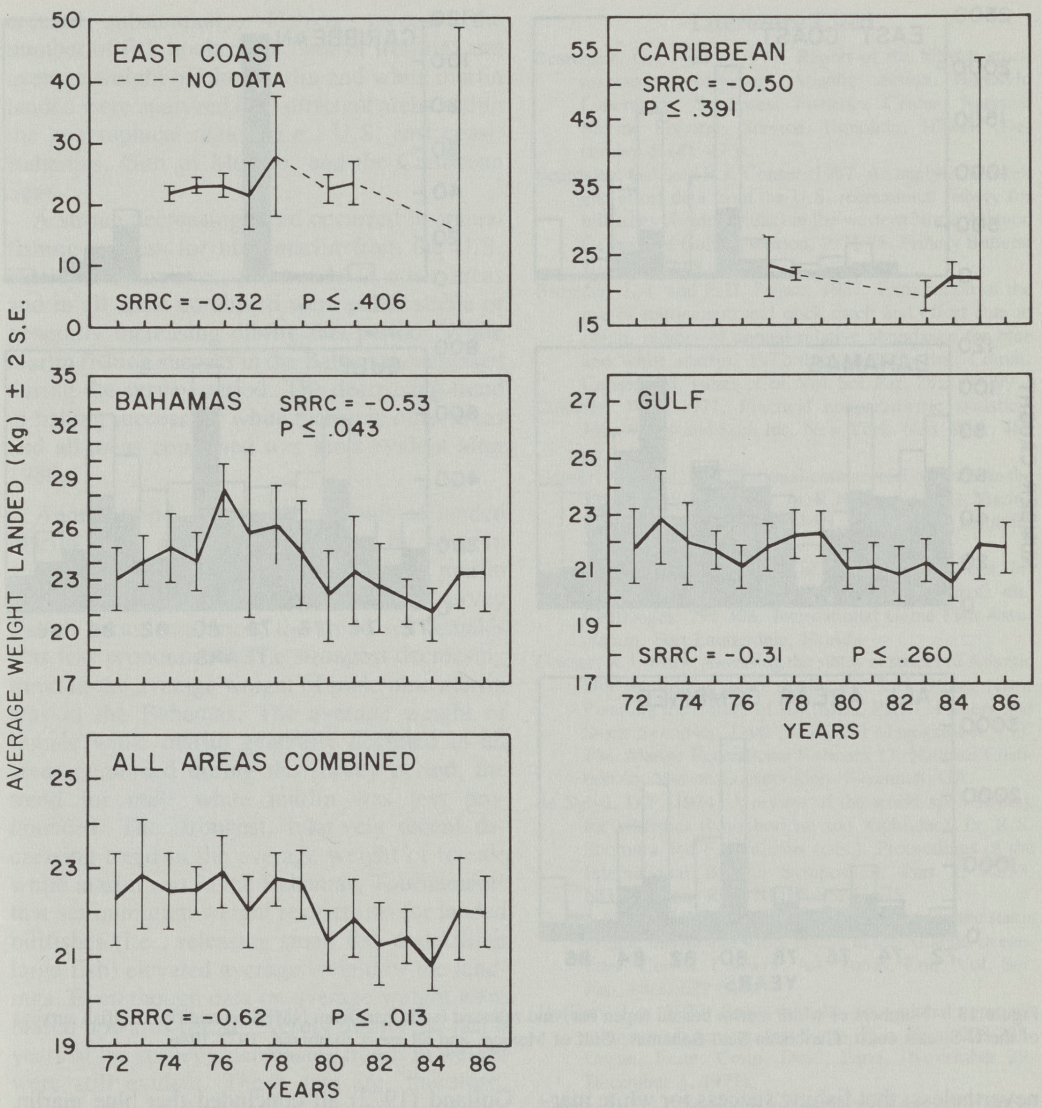

Figure 12. Average weight (kg) of male white marlin landed (±2 standard errors) from NMFS recreational billfish surveys of the U.S. east coast, Caribbean Sea, Bahamas, Gulf of Mexico, and all areas combined, 1972-1986. Spearman Rho Rank Correlation (SRRC) and probabilities are given for each area. Dashed line indicates lack of data.

with extreme caution. For example, even though region-wide results of nonstandardized HPUE for blue marlin and white marlin presented in this study were similar to standardized HPUE for these species and years reported by Browder and Prince (1987), these data should be considered only as indirect evidence about billfish populations. Browder and Prince (1987) found that their model explained only 20% of the variation for blue marlin HPUE, while the model accounted for 40% of the variation for white marlin HPUE. In addition, it seems clear that recreational data cannot be relied upon exclusively for insight into billfish populations because these fisheries seldom extend beyond 100 miles from shore. Also, our recreational survey didn't start until 1972, which was during a period of reduced, but stable, commercial longline fishing — commercial longline effort and landings had peaked earlier during the 1960s (Conser 1989).

Certain categories of the analysis indicate,

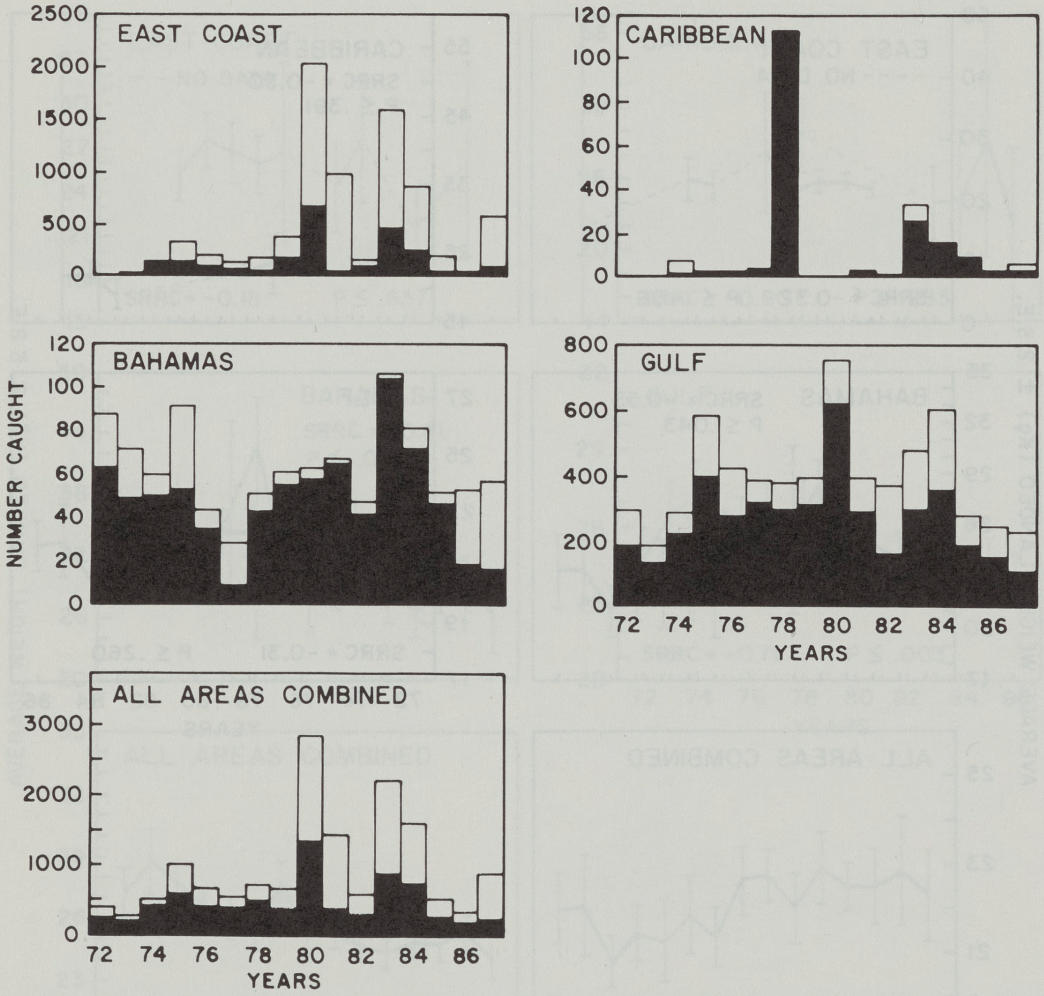

Figure 13. Numbers of white marlin boated (open bar) and released (solid bar) from NMFS recreational billfish surveys of the U.S. east coast, Caribbean Sea, Bahamas, Gulf of Mexico, and all areas combined, 1972-1986.

nevertheless, that fishing success for white marlin, and to a lesser extent blue marlin, was decreasing, particularly during the last years of the survey. In addition, a substantial decline occurred in the average weight of white marlin landed; the same was true for blue marlin in certain areas, especially in recent years. These declines were detected despite a bias that acted to increase the average weight of the landed fish (relative to those hooked) and was also strongest in the last years covered by the analysis. Fishing effort for marlin greatly increased during the period when these trends in fishing success and average weight of landed fish were detected. Studies by Conser (1985), Farber and Conser (1983), Beardsley (1977), Joseph (1973), and Gulland (1972) all concluded that blue marlin and white marlin are fully exploited in the Atlantic Ocean. Our data from the recreational fishery are consonant with conclusions made by others, particularly with respect to white marlin.

Summary

Fishing success and average weights of blue marlin and white marlin landed in the recreational fishery in the western Atlantic Ocean, Gulf of Mexico, and Caribbean Sea (1972-1986) are described based on a survey conducted by the National Marine Fisheries Service's Southeast Fisheries Center. Results of the survey and several lines of evidence outside the survey indicate that fishing effort during this period in-

creased substantially. Fishing success (the number of fish hooked per hour of trolling) and average weight of blue marlin and white marlin landed were analyzed by 4 different areas within the geographical region (i.e., U.S. east coast, Bahamas, Gulf of Mexico, and the Caribbean Sea).

A strong decreasing trend occurred in annual fishing success for blue marlin from the U.S. east coast; however, the trends in other areas and in all areas combined were either stable or generally increasing during this period. White marlin fishing success in the Bahamas decreased during the survey period. The decreasing trend in fishing success for white marlin in other areas and all areas combined was most evident after 1980.

Annual trends in average weights of landed marlin were analyzed separately by sex. In general, average weights of male blue marlin declined during the last 6 years of the survey for all areas combined; the trend for females was less pronounced. The strongest decreasing trend in the average weight of male blue marlin was in the Bahamas. The average weight of female white marlin generally declined in all areas combined during the survey period; the trend for male white marlin was less pronounced. The strongest, relatively recent decreasing trend in the average weight of female white marlin was in the Bahamas. Tournaments that set minimum weight restrictions for landed billfishes (i.e., releasing small fish and killing large fish) elevated average weight of the landings. Even though data on average weight were biased upwards (most severely during the last 6 years of the survey), decreasing trends in weight were still evident. These data are, therefore, conservative and any declining trends would have been more extreme had these regulations not been adopted.

The results of our 15-year survey of the recreational marlin fishery is consonant with conclusions made in other studies, that these species are fully exploited in the Atlantic Ocean, particularly white marlin.

The relationship between hook-per-unit-effort (HPUE) and catch-per-unit-effort (CPUE) was determined by regression analysis for each of the four study areas for each species. In cases where only CPUE data were available, most of the relationships were strong enough to allow reasonable estimates of HPUE.

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Angelo R. Bertolino earned a B.S. degree in biology (1973) from the University of Massachusetts. He is presently a fisheries biologist with the National Marine Fisheries Service's Southeast Fisheries Center (Miami Laboratory), and has 14 years' experience working with bluefin tuna, billfishes, and swordfish in both commercial and recreational fisheries. His present responsibilities include developing and monitoring a multi-species data base for the U.S. northwest Atlantic longline fishery.

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A Comparison of Two Sampling Methods for Analyzing Virginia's Recreational Marlin/Tuna Fishery

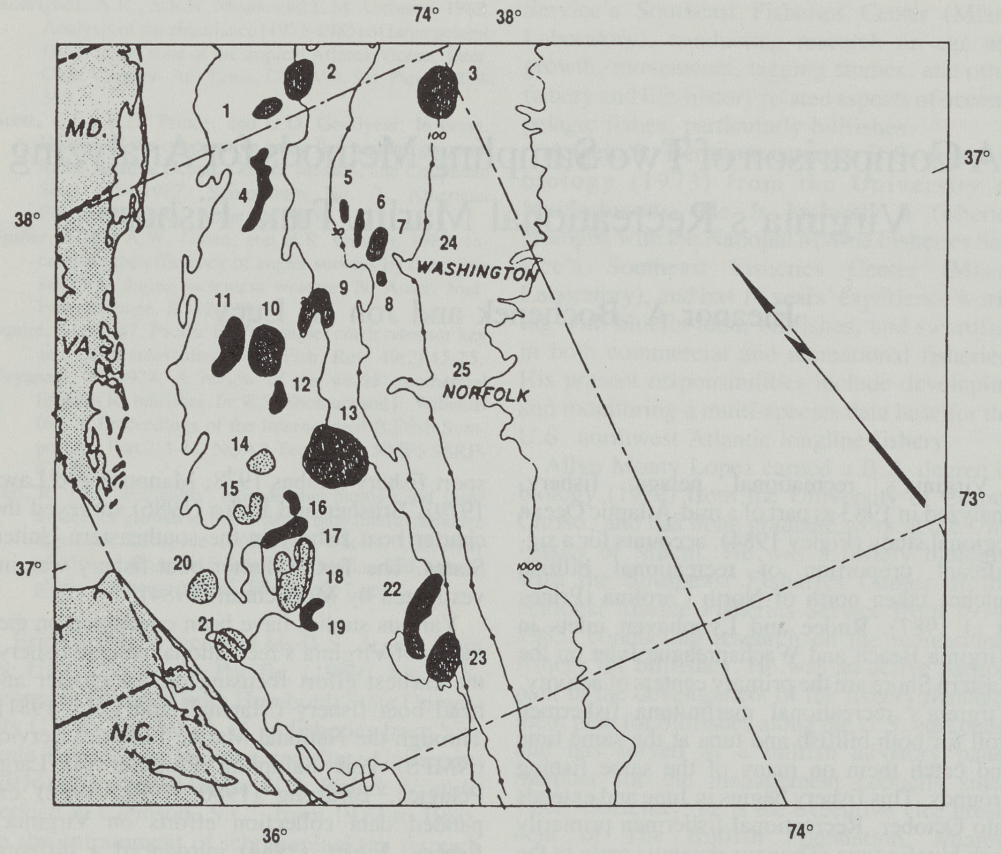
Eleanor A. Bochenek and Jon A. Lucy

Virginia's recreational pelagic fishery, analyzed in 1983 as part of a mid-Atlantic Ocean regional study (Figley 1984), accounts for a significant proportion of recreational billfish catches taken north of North Carolina (Prince et al 1987). Rudee and Lynnhaven inlets in Virginia Beach and Wachapreague Inlet on the Eastern Shore are the primary centers of activity. Virginia's recreational marlin/tuna fishermen troll for both billfish and tuna at the same time and catch them on many of the same fishing grounds. This fishery begins in June and extends into October. Recreational fishermen primarily seek bluefin tuna *(Thunnus thynnus)* early in the season, followed by yellowfin tuna *(Thunnus albacares),* white marlin *(Tetrapturus albidus),* and blue marlin *(Makaira nigricans).* Sailfish *(Istiophorus platypterus),* bigeye tuna *(Thunnus obesus),* and albacore *(Thunnus alalunga)* are rarely caught. The fishing grounds range from approximately 32 to 128 km (17 to 69 nmi) off the coast of Virginia, Maryland, and North Carolina (Fig. 1).

Researchers have not well documented the lower mid-Atlantic region's recreational pelagic fishery, especially off Virginia. Figley and Long (1982, 1983) and Brown and Ofiera (1987) studied New Jersey's canyon fishery. Investigators have studied components of the recreational pelagic fishery of the western north Atlantic Ocean and the Gulf of Mexico (Nakamura and Rivas 1974; Beardsley and Conser 1976; Hamm and Slater 1979; Pristas 1979, 1981, 1982; Lopez 1981; Lopez et al 1984; Williams et al 1984; Prince and Bertolino 1987; Prince et al 1986, 1987). In North Carolina, emphasis has been placed on analyzing the charter boat sport fishery (Abbas 1978, Mannoch and Laws 1979). Brusher and Palko (1986) surveyed the charter boat fishery in the southeastern United States. The Texas charter boat fishery was investigated by McEachran (1984).

Various studies have been conducted on elements of Virginia's recreational pelagic fishery, the earliest effort focusing on the charter and head boat fishery (Marshall and Lucy 1981). Through the National Marine Fisheries Service (NMFS) Port Sampling Program for Large Pelagics, Birdsong (1980, 1981, 1982) expanded data collection efforts on Virginia's fishery. Figley (1984) introduced a different sampling approach to study the 1983 fishery, utilizing telephone and mail surveys to estimate total fishing effort and catch. Bochenek (1989) initiated the most comprehensive multiple-year study of Virginia's pelagic fishery, focusing on the 1983-85 fishing seasons. The Virginia data base has been expanded to include the 1986 and 1987 seasons (Bochenek et al 1988, Lucy et al 1988).

State and federal governments require a better understanding of the pelagic recreational fishery. This fishery continues to expand and has an impact on the various state and federal economies. Large numbers of commercially and recreationally important species such as yellowfin tuna, bluefin tuna, white marlin, blue marlin, and associated pelagic fishes, are harvested by anglers. Data on catch and effort, number of anglers and boats, and socioeconomic aspects of the fishery must be obtained in order to manage these species properly. Complete information is necessary for accurately measuring the optimum yield (OY). Managers have utilized



Tuna and Billfish Grounds Off Virginia

1. Jackspot
2. The Fingers
3. Poor Man's Canyon
4. Lumps
5. First Lump
6. Second Lump
7. Rockpile
8. 29 Fathom Lumps
9. 20 Fathom Fingers
10. 21 Mile Hill
11. No Name
12. 26 Mile Hill(Hambone)
13. The Fingers
14. Triangle Wrecks
15. Fishhook
16. Hot Dog
17. Southeast Lumps
18. Horseshoe
19. Boomerang
20. V Buoy
21. 4A Buoy
22. Cigar
23. Honey Hole
24. Washington Canyon
25. Norfolk Canyon

Figure 1. Chart showing major fishing areas for Virginia's marlin/tuna fishery.

only commercial landings in the past, and roughly estimated or ignored the recreational catch to assess a given stock. Sampling techniques must be further refined for estimating recreational catches of these important pelagic species since many stocks of these species continue to decline and conflicts still exist between commercial and recreational fishermen.

The main objectives of this study were: (1) to evaluate and compare dockside and telephone survey techniques as effective methods for quantifying Virginia's recreational pelagic fishery, and (2) to estimate marlin/tuna fishing fleet size and catch rates and total catches for the recreational pelagic fishery with emphasis on billfish.

Methods

During 1985, two sampling strategies were used to obtain catch and effort data on Virginia's recreational pelagic fishery: the random telephone survey of Figley (1984); and the dockside interview technique for large pelagic of the National Marine Fisheries Service (NMFS). Results of the data collection effort were compared to determine how each method characterized the fishery.

Telephone Survey

Figley's (1984) random telephone survey was used and modified. Study participants were obtained from fishing club rosters, sign-up sheets placed in marinas and tackle shops throughout Virginia which were known to cater to offshore fishermen, and from contacts made at dockside during the 1983 and 1984 fishing seasons (Bochenek 1989). An index card was kept on each boat captain; listing his name, address, phone number, boat name and length, and whether the boat was a charter or private fishing vessel. When a boat had more than one captain, the phone number and name of the second captain was also placed at the bottom of the card. If a captain owned more than one tuna/marlin fishing vessel, each vessel was listed along with the above information on the card. Cards were filed in alphabetical order by the primary captain's last name. When the captain was called on the telephone for the first time, he was asked whether he planned to make at least three trips for tuna/marlin from a Virginia port during the 1985 season. A minimum number of three trips was set to eliminate boat captains who fish infrequently for marlin/tuna. If the captain did not plan to fish that year or fished only once or twice he was placed in an inactive file and called again the next year. For active boat captains, a separate card was filled out for each boat listing the boat name, charter or private vessel, boat length, the primary and secondary captain's names, and were filed alphabetically by boat name. This boat list was later used for determining fleet size.

Random telephone interviews were conducted for various wave dates (sampling periods) from June through October in 1985. The 1983 and 1984 studies of this fishery (Bochenek 1989, Figley 1984) indicated that June, July, and August were the peak fishing months. Wave dates, therefore, varied in length depending upon the intensity of fishing activity. Every wave date always began on a Monday and ended on a Sunday so that weekends would fall within the same wave date. Wave dates were weekly during the heaviest fishing period (June through August). The first wave date was June 1 through June 9 and subsequent wave dates were each a week long (second wave 6/10 — 6/16) through August. Wave dates were biweekly for September and one month for October. The 1983 random telephone survey of this fishery (Bochenek 1989, Figley 1984) indicated that biweekly wave dates for September and a monthly wave date for October would adequately represent the fishery.

Forty-five captains of charter and privately-owned boats who fished for tuna or billfish were contacted for each wave date. When captains owned/fished more than one vessel, the captain would be counted more than once for that wave date. For example, Captain Smith owns two boats and his name would be counted twice toward the total of 45 captains contacted for that wave date. A random numbers table was used to select, from the file, 60 boat captains by their last name to be called on Monday through Thursday evenings the week following the last Sunday in the wave date (e.g., wave 6/10 — 6/16, telephone calls were made 6/17 — 6/20 for this wave). When 45 captains had been contacted, the remaining uncalled captain's cards were refiled. If a boat's primary captain could not be reached, an attempt was made to contact other known captains fishing the boat. Only during June and July, captains' names were selected randomly without replacement so that nearly all identified captains in the fleet would be contacted at least once. For August through October, boat captains were sampled with replacement

but the same boat captain was never called more than once in each month. After being contacted, the wave date was marked on the back of each card and the card refiled. The same captain was contacted no more than three times during the fishing season.

Boat captains were asked to recall the number of marlin/tuna trips they had taken aboard their own boats from Virginia ports during a particular wave date. As long as a boat left from a Virginia port, it could fish anywhere off the coasts of Maryland, Virginia, or North Carolina and the trip would be counted for that particular wave date. If a captain owned more than one marlin/tuna vessel trip data were recorded for each vessel. This information was then used to calculate fishing effort (fishing trips). Catch data were then recorded for each trip taken in that particular wave date. If trips were made prior to the specified wave date ("recall trips"), these trips were noted and fishing effort was estimated both by not using recall trips and by using recall trips. Catch data were recorded for the recall trips for as far back as the captain could readily remember the trip information (usually no more than two weeks unless a log book was maintained). If a captain, contacted by telephone, had previously been interviewed dockside about a given fishing trip, wave date fishing effort was recorded but catch data were included only for the dockside interview so as to avoid duplication of catch data between dockside and telephone interviews. The following catch information was collected: number of fish caught and released by species; hours fished; location and date of capture; number of anglers and lines fished; inlet departed from; and trip type (private or charter).

Total fishing effort (fishing trips) was calculated following Figley (1984): for each wave date, the number of trips made by each boat from Virginia ports was divided by the number of days in the wave date. Resulting esimates of individual boat effort were grouped into monthly intervals. Wave dates which overlapped two months were assigned to the month in which the majority of the wave date's days fell (e.g., wave 8/29 — 9/4, assigned to September). An average number of trips made per day per boat was estimated for each month. Total monthly fishing effort was then calculated from the product of: average number of trips per day per boat for a given month, estimated total number of boats in Virginia's marlin/tuna fleet, and the number of days included in the wave dates designating each month. Total estimated fishing effort for the season was derived by summing monthly effort estimates.

Average monthly catch per boat trip (the unit of fishing effort) was calculated for each species using catch information obtained for each trip taken during the wave dates for that month and catch data recorded for recall trips that fell within that month. Monthly average catch per boat trip for each species was multiplied by estimated total fleet fishing effort for a given month to derive projected total monthly catch for that species. Overall seasonal catch of each species was determined by summing projected monthly catches.

Dockside Survey

Dockside interviews were conducted from June through early October at Wachapreague and Rudee inlets. The 1983 and 1984 studies (Bochenek 1989 and Figley 1984) demonstrated that these two inlets were the main centers of activity for Virginia's marlin/tuna fleet. Trip information was collected weekly (Thursday through Sunday) at the public boat ramp and marinas at Rudee Inlet and daily at the marinas and boat ramps at Wachapreague. Rudee Inlet was sampled only Thursday through Sunday each week due to limited manpower and monetary constraints and to the fact that this weekly period has been shown to be the peak time for offshore trips from this inlet. Data were collected at all major Virginia tuna/billfish tournaments. The telephone interview survey instrument was also used to record catch data at the docks. Fishing effort (trips) was calculated using Figley's method (1984) and Bochenek's method (1989). Bochenek's method was: $A/B = C/X$ where: A = number of different boats that fished that month from interviews; B = number of trips those boats made that month; C = estimated number of boats in the total fleet; and X = estimated number of trips made that month. Bochenek's method for estimating fishing effort was also applied to telephone data.

For dockside and telephone data, the number of hours trolled was rounded down to the nearest whole hour. Fishing effort (number of trips) and billfish catches are reported in this paper and catches of other pelagic species are reported in Bochenek (1989). Neither telephone nor dockside data were normally distributed. Various transformations were attempted, but none normalized the data. The non-parametric Mann-

Whitney U-test (SPSS Inc. 1983) was utilized to compare calculated catch/boat trip and fishing effort.

Boat Population Estimate

At the end of the fishing season, a questionnaire was mailed to all identified active boat captains. If a captain owned more than one vessel, he received a form to fill out for each vessel. After one month, postcards were mailed to all captains, reminding them to return their forms. Captains were asked to name ten boats from their home ports which were known to fish for marlin/tuna during the season. All active boats identified during the year by dockside and/or telephone interviews were considered "marked" boats. From the mail questionnaire, any new boats named, i.e., those previously unidentified during the year, were designated "unmarked" boats for purposes of the boat population estimate. All unmarked boats were checked against the file of inactive boats and if any of the unmarked boats listed were actually inactive boats they were removed from the unmarked boat list. Boat population estimates were then calculated using the Frequency of Capture Method and the Lincoln-Peterson Index (Giles 1971); these two estimates were then averaged (Figley 1984). On the economic questionnaire, boat captains were also asked to record the number of trips their boats made for marlin/tuna during 1985. This question was used to validate estimated fishing effort for both dockside and telephone data.

Results and Discussion

Fleet Characteristics

As reported in telephone interviews (P) and dockside interviews (D), marlin/tuna vessels carried a mean of 5.3 (SD 10.9) (P) and 5.4 (SD 10.5) (D) anglers per trip; fished an average of 5.9 (SD 5.5) (P) and 6.3 (SD 7.9) (D) lines; and trolled an average of 6.0 (SD 1.5) (P) and 6.1 (SD 1.4) (D) hours per trip. Four hundred and fifty-three questionnaires were mailed to boat captains identified as active in the marlin/tuna fishery and a response rate of 44% was achieved. Virginia's recreational marlin/tuna fleet was estimated at 774 boats, of which 68 were charter vessels. The fleet estimate likely excluded boats which had no name, since the mail survey requested that captains "name" other boats in the fishery.

Fishing Effort

In 1985, a total of 674 boat captains were contacted by telephone, accounting for 86 charter and 218 private marlin/tuna trips (Table 1). A total of 34 captains called on the telephone were also interviewed dockside. The greatest overlap in such contacts occurred during tournaments. In such cases, catch information was recorded only in the dockside data set to avoid duplication of catch data. Future studies might obtain catch data for both dockside and telephone interviews and compare the results for consistency.

Figley (1984) included recall trips to estimate fishing effort for Virginia's 1983 pelagic fishery. In the current study, recall trip data was also used to estimate fishing effort, to maintain consistency with the 1983 data. Fishing effort was also calculated excluding recall trip data to determine what effect such trips had on effort estimates. No significant difference was found when comparing monthly fishing effort (trips/day/boat) with and without recall trips (Table 2a). Projected total fishing effort was 5,527 trips using recall trip data and 4,586 trips without recall data (Table 3). These projections were based upon data collected through telephone interviews.

When monthly charter and private boat effort (trips/day/boat, without recall) were compared, there were significant differences in effort be-

Table 1. Number of charter and private trips sampled by month for dockside and telephone interviews.

TELEPHONE INTERVIEWS			
Month	Charter trips	Private trips	Total
May	0	2	2
June	24	68	92
July	31	74	105
August	17	45	62
September	12	27	39
October	2	2	4
TOTALS	86	218	304

DOCKSIDE INTERVIEWS			
Month	Charter trips	Private trips	Total
May	0	2	2
June	182	180	363*
July	151	259	411*
August	110	131	241
September	38	83	121
October	0	0	0
TOTALS	481	655	1138

*Does not add because one trip was not designated charter or private

Table 2a. Mann-Whitney U-test comparing monthly effort (no. trips/day/boat) with and without recall trips for telephone interviews, alpha = .05, 2-tailed test.

Null Hypothesis		Cases	Z	Significance
June trips with recall =		199		
June trips without recall		179		
	Total	378	1.594	ns
July trips with recall =		209		
July trips without recall		180		
	Total	389	1.601	ns
August trips with recall =		202		
August trips without recall		180		
	Total	382	1.935	ns
September trips with recall =		91		
September trips without recall		90		
	Total	181	0.121	ns

ns Not significant

Table 2b. Mann-Whitney U-test comparing monthly effort (no. trips/day/boat) for charter (C) and private (P) telephone interviews, without including recall trips, alpha = 0.05, two-tailed test.

Null Hypothesis		Cases	Z	Significance
June C effort =		29		
June P effort		150		
	Total	179	2.592	*
July C effort =		21		
July P effort		159		
	Total	179	4.981	*
August C effort =		27		
August P effort		153		
	Total	180	2.219	*
September C effort =		10		
September P effort		80		
	Total	90	0.540	ns

ns Not Significant
* Significantly different

tween boat types for June, July, and August but not for September (Table 2b). As documented in 1983 (Figley 1984), 1984 (Bochenek 1989), and the current study, most private boats fish for marlin/tuna on weekends and holidays, while charter vessels tend to fish daily. In addition, the weather becomes a factor by September and October, affecting the number of trips taken offshore; the charter fleet becomes less active.

A total of 1,309 fishing trips was calculated for the 1985 season using Bochenek's method, as compared to 5,527 trips using Figley's technique (Table 3). Bochenek's method appears to underestimate effort for the telephone data since the 774 boats in the fleet had to make at least three trips during the season to be included in the study ($3 \times 774 = 2{,}322$ trips as a minimum number). In addition, dockside interviewers collected information on 1,138 trips while sampling on Thursday through Sunday only at Rudee Inlet and daily at Wachapreague Inlet. Dockside interviewers did not obtain data on trips taken during Monday through Wednesday at Rudee Inlet and missed some trips during the interview process at both inlets. With the random telephone interview procedure, if a large proportion of boat owners contacted did not fish during a particular wave date, far fewer trips would be calculated for that month thereby reducing the month's fishing effort estimate. Figley's method appears to estimate total effort better for the telephone survey procedure.

In 1985, a total of 1,138 dockside interviews were completed on fishing trips; 481 were

Table 3. A comparison of estimated effort (# of trips) for each month between dockside and telephone interview data for 1985, charter and private effort combined, and includes recall trip data. Effort was calculated using Figley's (1984) and Bochenek's technique. No dockside interviews collected in October 1985.

	Figley's Method		
Month	Telephone Effort With recall	Telephone Effort No recall	Dockside Effort
June	1,767	1,454	4,876
July	1,842	1,582	4,356
August	1,373	1,046	5,211
September	466	455	1,842
October	79	49	—
Total	5,527	4,586	16,285

	Bochenek's Method	
Month	Telephone Effort	Dockside Effort
June	436	1,861
July	463	1,552
August	269	1,504
September	119	1,052
October	22	—
Total	1,309	5,969

charter trips. Most trips occurred in July, followed by June and August (Table 1). A greater proportion of dockside interviews reflected charter trips (43.2%) than did telephone interviews (28.2%). Total effort calculated from dockside interviews using Figley's and Bochenek's methods was 16,285 and 5,969 fishing trips, respectively (Table 3). Figley's technique appears to overestimate effort when applied to dockside interview data, since boats in the fleet would have had to average over 20 trips each to account for such effort (16,285 trips). This rate of fishing effort was not supported by mail questionnaire results, wherein captains indicated that their boats averaged 13.5 trips/year (SD 13.1). Total projected seasonal effort was 5,969 trips when Bochenek's method was used to calculate dockside fishing effort. This projection was similar in magnitude to total seasonal effort estimated from telephone sample data using Figley's method (5,527 trips).

At the docks, data collection efforts favor charter trips because the boats are concentrated in a few ports, whereas private boats are widely dispersed among different marinas and launching ramps. The telephone survey procedure reaches boat captains (and boats) who may be unavailable at the docks. Fishing effort is difficult to determine using dockside interviews since the researcher does not know how many boats went fishing for pelagics rather than for other species or were not even fishing. Boat captains are also reluctant to provide trip information if they did not catch fish, often quickly leaving the docks, thereby possibly biasing the dockside data set toward trips in which fish were caught.

Actual Catches (Includes both kept and released fish)

White marlin. No white marlin catches were recorded in the June telephone sampling effort, although dockside interviews recorded 5 white marlin landed with a mean catch/boat trip of 0.01 fish (Tables 4 and 5). July, August, and September were the peak months for white marlin catches recorded in dockside interviews; July was the peak month for catches of white marlin recorded in telephone interviews (Tables 4 and 5). More white marlin landings were reported from dockside than from telephone interviews. These higher catches are likely attributed to numerous marlin tournaments occurring during August and September, resulting in higher catches from dockside data sampling effort. However, when white marlin catch rates were compared between dockside and telephone data sets, there was no significant difference between the two (Table 6). In addition, there was no significant difference in charter and private catch rates of white marlin between and within dockside and telephone data sets (Table 6).

Prince et al (1987) reported a total of 307 white marlin landed on the east coast from Virginia northward during the 1985 fishing season. In the current study, a total of 120 white marlin were documented as caught by boats fishing from Virginia ports during 1985 (combined catches from dockside and telephone sampling procedures). Therefore, Virginia fishermen were estimated to have caught 39% of the entire Northeast Region's catch of white marlin.

Blue marlin. A total of 21 and 8 blue marlin were landed by fishermen as reported in dockside and telephone data, respectively (Tables 4 and 5). More blue marlin catches were recorded from dockside than from telephone interviews, which may again be the result of dockside data including more marlin tournament trips. Mean blue marlin catch/boat trip estimates were so low that statistical tests were not performed on the data.

Virginia marlin/tuna fishermen landed 29 blue

Table 4. Monthly actual catches of white marlin, blue marlin, and sailfish landed (from dockside interviews). No. Caught = kept + released.

Species	Mean catch Per Boat Trip	Standard Deviation	No. Caught	No. Released
JUNE DOCKSIDE INTERVIEWS (363 TRIPS)				
Blue marlin	0.00*	0.05	1	0
White marlin	0.01	0.12	5	3
Sailfish	0.00*	0.05	1	0
JULY DOCKSIDE INTERVIEWS (411 TRIPS)				
Blue marlin	0.03	0.16	10	4
White marlin	0.08	0.28	29	16
AUGUST DOCKSIDE INTERVIEWS (241 TRIPS)				
Blue marlin	0.03	0.18	8	3
White marlin	0.14	0.38	33	23
Sailfish	0.00**	0.06	1	0
SEPTEMBER DOCKSIDE INTERVIEWS (121 TRIPS)				
Blue marlin	0.02	0.13	2	1
White marlin	0.28	0.68	34	2
Sailfish	0.01	0.09	1	0

*Actual value 0.003
**Actual value 0.004

Table 5. Monthly actual catches of white marlin, blue marlin, and sailfish landed (from telephone interviews using recall trips); no billfish catches were reported from interviews during June (92 trips) and October (4 trips). No. Caught = kept + released.

Species	Mean catch Per Boat Trip	Standard Deviation	No. Caught	No. Released
JULY TELEPHONE INTERVIEWS (105 TRIPS)				
Blue marlin	0.03	0.16	3	2
White marlin	0.09	0.37	10	6
Sailfish	0.02	0.14	2	0
AUGUST TELEPHONE INTERVIEWS (62 TRIPS)				
Blue marlin	0.03	0.18	2	1
White marlin	0.08	0.27	5	4
SEPTEMBER TELEPHONE INTERVIEWS (39 TRIPS)				
Blue marlin	0.08	0.27	3	2
White marlin	0.10	0.39	4	3

marlin (combined catches for dockside and telephone sampling procedures). Prince et al (1987) reported 82 blue marlin landed (combined telephone and dockside sample catches) for Virginia northward. Boats fishing from Virginia ports, therefore, landed an estimated 35% of the Northeast Region's catch of blue marlin.

Sailfish. Sailfish are rarely caught off Virginia, as indicated by both dockside and telephone data (Tables 4 and 5), with a total of only

Table 6. Mann-Whitney U-Test comparing catch/boat trip (CPUE) for telephone (TEL) and dockside (DOC) interviews conducted during 1985 season; alpha = 0.05, C = Charter trip, p = private trip.

Null Hypothesis	Cases	Z	Significance	one or Two Tailed
TEL white marlin CPUE = DOC white marlin CPUE	1273	0.779	ns	two
C TEL white marlin CPUE = P TEL white marlin CPUE	227	0.061	ns	two
C DOC white marlin CPUE = P DOC white marlin CPUE	1101	1.021	ns	two
C TEL white marlin CPUE = C DOC white marlin CPUE	529	0.598	ns	two
P TEL white marlin CPUE = P DOC white marlin CPUE	799	0.166	ns	two

ns Not Significant

5 sailfish landed. Virginia waters represent the northern-most range of this species. Sailfish catch rates were so low that statistical tests were not performed on the data.

Projected Catch

Incorporating recall trips into calculations of projected catches from the telephone data set did not alter the magnitude of estimated total catches of billfish (Table 7). Projected total catches of white marlin were 326 fish using telephone data (Figley's technique) and 651 fish using dockside data (Bochenek's technique) (Table 8). Bochenek's method resulted in a higher estimate when used to calculate projected catches for white marlin from dockside interviews. Since actual catch rates determined for white marlin from dockside and telephone interview data sets were not significantly different, it is unclear why Bochenek's method of projecting catches produced a higher estimate. For blue marlin, projected total catch estimates were similar for telephone (Figley's technique) and dockside (Bochenek's technique) data, with 133 and 112 estimated, respectively (Table 8). Projected total catch for all pelagic species landed for telephone data, using Figley's technique for estimating effort, was 42,995 fishes; for dockside data, using Bochenek's method for estimating effort, it was 43,628 fishes.

Table 7. Projected total catches for billfishes landed from telephone interviews using Figley's (1984) method. Catches estimated using recall and without using recall trips. No billfish catches reported in June and October interviews.

Species	Catches without recall	Cathes with recall
	JULY	
Blue marlin	44	52
White marlin	142	166
Sailfish	30	35
	AUGUST	
Blue marlin	34	44
White marlin	85	111
	SEPTEMBER	
Blue marlin	36	37
White marlin	48	49
	TOTAL CATCH	
Blue marlin	114	133
White marlin	275	326
Sailfish	30	35

Marlin Releases

Telephone data indicate higher release rates than do dockside data for actual catches of white marlin and blue marlin (Table 9). This difference may be due to the fact that dockside data included a greater proportion of tournament interviews than did those collected by telephone. During tournaments, more billfish are brought to the docks to be weighed than otherwise. For white marlin released by Virginia anglers, the telephone data indicated a higher release rate (68%) and dockside data a lower release rate (44%) than estimated release rates of 45% (1986) and 61% (1983) for the U.S. recreational fishery (SAFMC 1987). Applying these release rates to projected catches indicated that a total of 222 (telephone data) and 286 (dockside data) white marlin were released. For blue marlin,

Table 8. Projected total catches for billfishes landed by month for phone and dockside interviews for 1985 using Figley's method (1984) and Bochenek's method. NA = Unable to calculate due to lack of data. Telephone data includes recall trips. No billfish catches were reported in October inteviews.

	PHONE		DOCKSIDE	
Species	**Figley**	**Bochenek**	**Figley**	**Bochenek**
		JUNE		
Blue marlin	0	0	14	5
White marlin	0	0	68	26
Sailfish	0	0	14	5
		JULY		
Blue marlin	52	13	113	40
White marlin	166	42	335	119
Sailfish	35	9	0	0
		AUGUST		
Blue marlin	44	9	172	50
White marlin	111	22	729	211
Sailfish	0	0	21	6
		SEPTEMBER		
Blue marlin	37	9	29	17
White marlin	49	12	516	295
Sailfish	0	0	15	9
		TOTAL CATCH		
Blue marlin	133	31	328	112
White marlin	326	76	1,648	651
Sailfish	35	9	50	20

the telephone data indicated a 71% release rate compared to a 38% rate from dockside data (Table 9). Release rates of 35% (1983) and 32% (1986) were estimated for blue marlin for the U.S. recreational fishery (SAFMC 1987).

Summary

During 1985, Virginia's recreational marlin/tuna fleet was estimated at 68 charter and 706 privately-operated vessels and made approximately 5,750 trips from Virginia ports. Of these trips, 1,138 and 304 were sampled by dockside and telephone interviews, respectively.

When comparing white marlin actual catch/boat trip, there was no significant difference between dockside and telephone data, indicating that both methods give similar results for actual catch. A total of 19 and 101 white marlin were landed as reported in telephone and dockside interviews, respectively. There was no significant difference in charter and private catch rates of white marlin between and within dockside and telephone data sets. Therefore, charter and private catches were combined to determine projected total catch for the fishery.

Bochenek's (1989) and Figley's (1984) methods were used to calculate total fishing effort. Bochenek's method appears to provide reasonable estimates of total effort (boat trips) using the dockside data, but not for estimates of total effort using the telephone data. In contrast, Figley's technique appears to provide reasonable fishing effort estimates for telephone data but not for dockside data. The data indicate that recall trip information is not needed for calculating total effort (boat trips).

Table 9. Catch-and-release data for white marlin, blue marlin, and sailfish during 1985; dockside (Bochenek's method) and telephone (Figley's method) interview actual and projected catches (kept and released fish) and releases. Recall trips included in telephone data; number released fish in parentheses.

	Actual Catch		% Released		Projected Catch	
Species	**Phone**	**Dock**	**Phone**	**Dock**	**Phone**	**Dock**
White marlin	19(13)	101(44)	68%	44%	326(222)	651(286)
Blue marlin	7(5)	21(8)	71%	38%	133(94)	112(43)
Sailfish	2(0)	3(0)	0%	0%	35(0)	20(0)

Projected total catch of white marlin was 651 for dockside data using Bochenek's technique and 326 for telephone data using Figley's method. It is unclear why white marlin projected total catches differ by a factor of two. However, blue marlin projected total catches were not markedly different using the two fishing effort calculation methods. Projected total catches for all pelagic species landed using these methods to calculate effort were 42,995 fishes for telephone data and 43,628 fishes for dockside data.

Overall, the telephone survey appears to be the better method for analyzing the recreational marlin/tuna fishery. This method provides reasonable estimates of both fishing effort and projected total catch. If telephone calls are not feasible in a given area then the dockside survey technique using Bochenek's method for calculating fishing effort can be used.

Conclusions

Both the telephone survey using Figley's technique (1984) and dockside survey using Bochenek's method appear to provide reasonable estimates of projected total catch for the recreational marlin/tuna fishery. The dockside method, however, is labor intensive, costly, and fraught with problems in estimating fishing effort. In 1985, one port sampler covered Wachapreague every weekday and weekend, one port sampler covered Rudee Inlet on Thursdays and Fridays and two or three port samplers covered Rudee Inlet on weekends and during major tournaments. Only two researchers were required to make telphone interviews. Dockside interviews bias fishing effort toward charter boats. Manpower constraints also limit the number of port locations which can be sampled. Many private boats and even some charter boats are missed in the dockside sampling effort.

Therefore, the telephone survey technique using Figley's method for estimating effort appears to be a better method for analyzing Virginia's recreational marlin/tuna fishery. Recall trips are not needed to estimate monthly fishing effort. A regularly updated list of marlin/tuna boat captains and boats must be maintained. New boat owners, names and addresses, and length-weight data can be collected at the docks during major tournaments. If telephone interviewing will not work in an area and dockside sampling methods must be relied upon to study the pelagic fishery, Bochenek's method appears to produce a better estimate of fishing effort than Figley's technique.

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The Jamaican Billfish Fishery And Blue Marlin Catch Data From Recreational Fishery Sources, 1976 — 1988

Guy C. McN. Harvey

Since the initiation of international billfish tournaments during the late 1950s, Jamaica has continued to offer some of the finest recreational blue marlin *(Makaira nigricans)* fishing to be found anywhere. While blue marlin are caught by the small charter boat fleet all year round, fishing tournaments have been successfully held each year during the prime season of their availability, which is in September and October. In addition to the annual tournaments and charter boat operations, blue marlin are caught commercially by artisanal fishermen who troll (or drift) for marlin in small dugout or fiberglass canoes.

Blue marlin are found all around the island, especially near offshore oceanic banks and along the insular shelf edge. Blue marlin are chiefly caught, however, along the island's north coast where deep water (>200 m) is found within ½ km of the shore (Fig. 1). The four annual international blue marlin tournaments are held out of Montego Bay, Falmouth, Ocho Rios, and Port Antonio (Fig. 1). Anglers seldom need to travel more than 5 km offshore in the hunt for marlin and prefer to run east and west along the dropoff, less than 1 km from shore.

Charter Boat Industry

The charter boat industry is poorly developed relative to existing charter boat industries in the Bahamas, U.S.V.I., and Venezuela, being confined largely to the two centres of tourism on the north coast, namely Montego Bay and Ocho Rios. Currently there are only 20 charter boats available as follows: Negril, 1; Montego Bay, 8; Falmouth, 2; Ocho Rios, 7; Port Antonio, 2; (Fig. 1). Kingston's Royal Jamaica Yacht Club has a large fleet of privately-owned sport fishing vessels but none are available for charter and these constitute the bulk of recreational fishing effort. Blue marlin are the focus of the charter and recreational fishery as there is a low incidence of other billfishes; however, until recently no records were kept of efforts or catches. The only data of any significance are being collected by the author during tournaments.

Tourism is now one of the pivotal sectors in Jamaica in view of the decline of the bauxite industry, and one aspect of tourism, i.e. billfish fishing, has considerable potential as an earner of foreign exchange. Consider, for example, that it has been estimated that between US$4,000 and 5,000 is spent in Florida, Puerto Rico, or Hawaii (Thornton pers comm) to catch a single billfish. With the latent abundance of billfish (blue marlin), the island's economy stands to benefit greatly from upgrading the island's few marinas, especially since the passing of Hurricane Gilbert in September, 1988, and the increased promotion of this sport fishery by the Jamaica Tourist Board. Under the auspices of the ICCAT-funded billfish port sampling programme, I will be collecting effort and catch data from charter boats on a regular basis, which will enable more accurate assessment of the level of exploitation of billfish resources.

Some of the most reliable and important data on distribution and catch rates was provided, recently, by Capt. Frank "Skip" Smith of the "Madam-Hooker"; Jerry Dunaway's fishing team. Based in Port Antonio, the "Hooker" fished 35 days between 27 September – 21 November 1987, along the coast and around the two adjacent offshore banks (Fig. 1), Henry Holmes and Grappler. Capt. Smith furnished

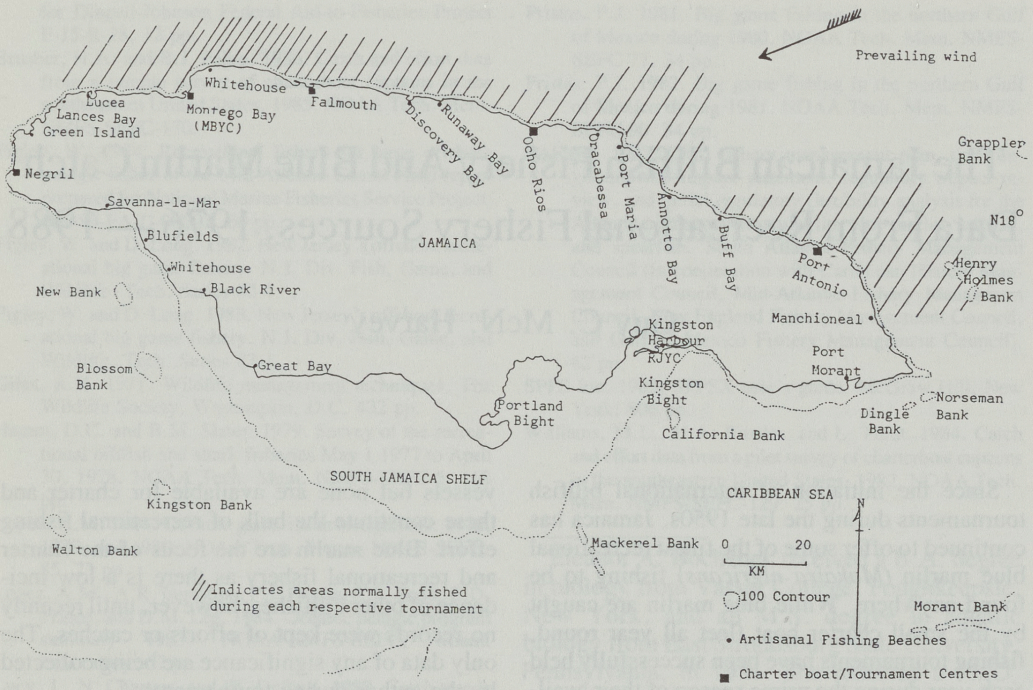

Figure 1. Jamaica, indicating offshore pelagic fishery — recreational and commercial.

information on dates, times, locations, conditions, lure or bait used, with the catch rates summarized as follows:

# Days fished	35
# Days no fish raised	4
# Blue Marlin raised	71
# Blue Marlin hooked	55
# Blue Marlin boated	19
# Tagged and released	11
# Hooked on live bait	30
# Hooked on lures	25

The majority of blue marlin hooked and lost were being fought on 4-lb and 8-lb class tackle while in pursuit of world records.

Commercial Fishery

Artisanal fishermen operating out of fishing beaches along the north and west coast (Fig. 1) troll primarly for scombrids, dolphin fish, and billfish in the deep ocean. The narrow shelf along this part of the coast is considered overfished, and the trap and benthic fishery is exhausted, which has resulted in the re-direction of effort toward exploitation of offshore stocks (Aiken 1984). Again no records are kept, but fishermen consistently report that blue marlin are available all year, with a marked increase in abundance in August to November, and in January to March. Artisanal fishermen use heavy hand lines (150-kg breaking strain) and fish bait is preferred to artificial lures. The marlin caught are sold to hotels or for smoking, and the dressed fish may fetch up to J$7.00 per lb or US$1.25 per lb (0.9 kg). At present, there is no local shore-based longline fishery for billfish, nor do fishermen attempt to fish for swordfish *(Xiphias gladius)* at night. One reason for the lack of a longline fishery is that there is no locally established market for shark meat; traditionally, sharks compose the greatest percentage of the catch in most longline operations (Berkely pers. comm. and Aiken 1985).

The basic operating unit of the commercial fishery is the canoe (up to 9 m long, usually powered by a 40 h.p. outboard engine) which is manned by three fishermen using handlines. Bamboo outriggers are employed to spread the lines in the same way as for a sport fishing boat. Blue marlin are caught incidentally along the south coast when these fishermen, trolling for tuna, have hooked fish overtaken by a feeding marlin.

Due to the scattered distribution of fishing beaches and the absence of any central landing

places, data collection concerning any aspect of the Jamaican fishing industry is generally difficult (Harvey 1982, 1986). More billfish catch data are now being obtained due to the increase in cooperation from both charter boat captains and artisanal marlin fishermen. Estimation of fishing effort is difficult and factors affecting shore based fishing effort from small boats include weather, availability of fuel (subsidized by the government), availability of outboard engines and spare aprts. Thus, a day fished may be anywhere from 4 to 10 hours of effort.

As a result of the ICCAT billfish sampling programme, log books and tape measures are to be distributed to the fishermen at fishing beaches involved in directed offshore pelagic fishing with the hope that information will be forthcoming on a voluntary and continuous basis. By way of a control, the chief buyers of fresh marlin have agreed to pass on data about purchases, which should coincide with the fishermen's log data.

A recent addition to the annual tournament calendar has been the inclusion of a one-day local canoe tournament (usually held on the "lay-day" during each tournament). These occasions have been popular since their initiation in 1984 and are well attended by artisanal marlin fishermen, attracting 25-45 entries in each location.

Catch records and biological data have been maintained during the blue marlin tournaments since 1959, particularly in Port Antonio, by visiting scientists such as Drs. Donald DeSylva and Steven Berkeley of the University of Miami, as well as personnel from the N.M.F.S.' Southeast Fisheries Center, Miami. Data collection has been my responsibility for the last 10 years. Following a 5-year slow period from 1976-1981, during which time the prevailing political situation hindered sport-fishing effort and tourism generally, tournaments were rejuvenated and some held in spring and summer. This circumstance provided information on gonadal activity and feeding habits at times other than the peak period of availability.

Biological Data

Traditionally, Jamaican fishing competitions have been "kill" tournaments; thus, they continue to provide a special opportunity for fish biologists to work on many samples at the same time under controlled conditions. The continued high catch rates at all tournaments have enabled the sampling of 690 blue marlin from 1976-1988, bearing in mind that only one tournament was held annually from 1976-1981, (Table 1). Overall catch rates have greatly improved in both Montego Bay and Port Antonio tournaments since the introduction of artificial lures during the 1982-1983 season (Table 1). Increased catches have helped promote tournaments both locally and abroad, and the increase in number of sport fishing vessels owned by Jamaicans has boosted participation.

All fish were sampled for total (overall) length, fork length, weight, sex, stage of gonadal development and stomach contents. Other parameters, such as use of lures versus fish-bait, time of "hook-up," and body deformities, were also recorded. One of the most basic patterns of a fish population is demonstrated by its size-frequency distribution, which is a record of the sizes and sex of fish in the population. As mentioned previously, the blue marlin examined have been caught mostly at one time of year (Sept.-Oct.), when small males far outnumber females. The distinct difference in size between males and females (sexual dimorphism), however, is recognized in blue marlin worldwide.

Most of the small fish are males (Fig. 2) with 95% of the males weighing between 75 lbs and 175 lbs (32.9 — 79.4 kg). Females dominate the larger size classes and reach weights much greater than males. Most females (90%) weighed between 175 lbs and 550 lbs (79.4 kg — 310 kg) but they may attain weights of over 1,000 lbs (454 kg). Previous age and growth studies indicate that the size difference between sexes in blue marlin is the result of different growth rates. Small females have also been found, indicating that this species does not undergo a sex change from male to female as they grow.

The majority of males (79%) are in a ripe or running-ripe condition all year round. In September/October, the few females sampled have had spent or ripe ovaries, but the majority have been sampled with running ripe ovaries. In September 1987 during the Port Antonio tournament 9 of 10 females of 204 — 490 lbs had gonosomatic indices of 3.4 — 5.8% and were in a running-ripe condition. Previous studies have indicated that blue marlin are "batch" spawners, i.e., they may spawn several times during the course of a protracted spawning season, with Pacific blue marlin spawning several

Table 1. Blue marlin catches in Jamaican tournaments, 1976-1988.
MBYC = Montego Bay Yacht Club PA = Port Antonio OR = Ocho Rios BM = Blue Marlin
FA = Falmouth WM = White Marlin SPF = Spearfish SF = Sailfish T&R = Tag and Release

Year	Location	Dates	Anglers	Boats	Days fished	Hours fished	No. Hookups reported	Marlin hooked per hour	Marlin Landed/ hour trolling	Marlin/ Boat	No. BM Landed	% BM caught on lures	Heaviest BM (Lbs.)	Other Billfish
1976	MBYC	Sept. 8-11	21	6	3½	288	12	.042	.017	0.83	5	0	145	1SF
	PA	Oct. 4-8	—	16	5	752	50	.066	.019	0.87	14	0	232	
1977	MBYC	Sept.	42	8	3½	322	9	.028	.012	0.50	4	0	160	
	PA	Oct.	—	14	5	658	53	.080	.012	0.57	8	0	147	1SF
1978	MBYC		47	11	3½	423	13	.031	.012	0.45	5	0	147	
1979	MBYC	Sept. 25-28	37	9	3½	346	15	.043	.009	0.33	3	0	134	
1980	MBYC	Sept.	29	8	3½	308	17	.055	.006	0.25	2	0	142	
1981	MBYC	Sept	45	12	3½	462	14	.030	.013	0.50	6	0	145	
1982	MBYC	Oct. 16-19	36	10	3½	385	35	.091	.057	2.20	22	0	242	
	PA	Sept. 27-Oct. 1	203	42	5	2058	96	.047	.014	0.66	28	15	519	
1983	MBYC	Sept. 15-19	66	15	3½	577	40	.069	.021	0.80	12	50	298	
	PA	Oct. 10-14	292	58	5	2842	240	.084	.025	1.24	72	61	270	
1984	OR	May 14-16	80	20	3	635	42	.066	.028	0.90	18	95	590	
	MBYC	Sept. 20-24	95	16	4½	784	30	.034	.009	0.43	7	65	335	1SF
	PA	Oct. 1-5	229	51	4	2244	211	.094	.022	0.98	50	96	334	1WM
	OR	Oct. 11-13	88	22	3	693	42	.60	.024	0.77	17	100	169	1SF
1985	OR	Apr. 30-May 3	90	15	4	630	23	.036	.005	0.2	3	100	185	3 × WM
	MBYC	Sept. 9-14	98	17	4½	1156	112	.096	.026	1.76	30	85	189	
	PA	Sept. 23-27	225	50	4	2195	270	.123	.031	1.36	68	97	248	
	OR	Oct. 11-13	80	20	4	802	32	.040	.017	0.70	14	100	268	
1986	OR	May 20-24	45	10	4	420	39	.093	.031	1.30	13	100	395	1SF,1WM
	MBYC	Sept. 8-13	115	24	4½	816	67	.082	.042	1.41	34	90	268	
	OR	Sept. 22-27	85	18	4½	789	98	.124	.042	1.83	33	100	170	1SPF
	PA	Oct. 6-10	245	63	4	2421	265	.109	.043	1.67	105	100	262	1WM, 1SF
1987	FA	May 21-23	43	9	3	216	21	.097	.042	1.00	9	100	207	1WM
	OR	May 25-30	68	9	5	342	25	.073	.029	1.11	10	100	450	1WM
	MBYC	Aug. 24-28	95	20	4	581	29	.050	.024	0.70	12	100	480	+2BM T&R
	OR	Sept. 7-11	82	14	4	420	56	.13	.083	2.00	35	100	241	
	PA(a)	Sept. 21-25	350	64	4	1728	79	.046	.020	0.53	34	100	455	
	PA(b)	Oct. 3-4	19	6	1½	66	12	.182	.12	1.33	8	86	149	
1988	PA(a)	Feb. 26-27	50	9	2	108	4	.037	.018	0.22	2	50	126	1WM
	FA	May 26-28	43	10	3	173	14	.081	.029	0.50	5	100	175	
	OR	NO LONGER BEING HELD												
	MBYC	Sept. 4-10	85	11	5	550	47	.085	.047	26	21	100	137	1SF, 1WM
	PA	Oct. 17-21	CANCELLED DUE TO DAMAGE SUSTAINED DURING HURRICANE GILBERT											

times in June-August (Hopper 1986).

In Jamaica and elsewhere, anglers and boat captains report that they frequently see a single large (female) marlin accompanied by two or more smaller marlin (presumably male), and that multiple hook-ups (two or more fish striking simultaneously) are fairly common. This suggests that the presence of several males may be needed to ensure successful fertilization during the breeding season. A male blue marlin of 72 lbs (32.6 kg) was shown to be sexually active, whereas 43-lb, 45-lb, 61-lb, and 70-lb (31.75-kg) females were shown to be inactive. An active 173-lb (78.5kg) female had a gonosomatic index of 3.5% in September, 1986, and an active female of 140 lbs (63.5 kg) had a gonosomatic index 2.96% in September, 1984. Females sampled in April and May in Jamaica have inactive gonads; however, a 250-lb female sampled in Cayman in June 1988 had a gonosomatic index of 3.9%. Females have yet to be sampled in June in Jamaica.

Stomach Contents

Since the introduction of artificial lures to Jamaica in 1982-1983, there has been a marked increase in the number of blue marlin boated with their stomachs not everted, thus providing information on stomach contents. When using natural bait, billfish tend to be hooked in their oesophagus or stomach and evert their stomach outside the mouth, ejecting all stomach contents,

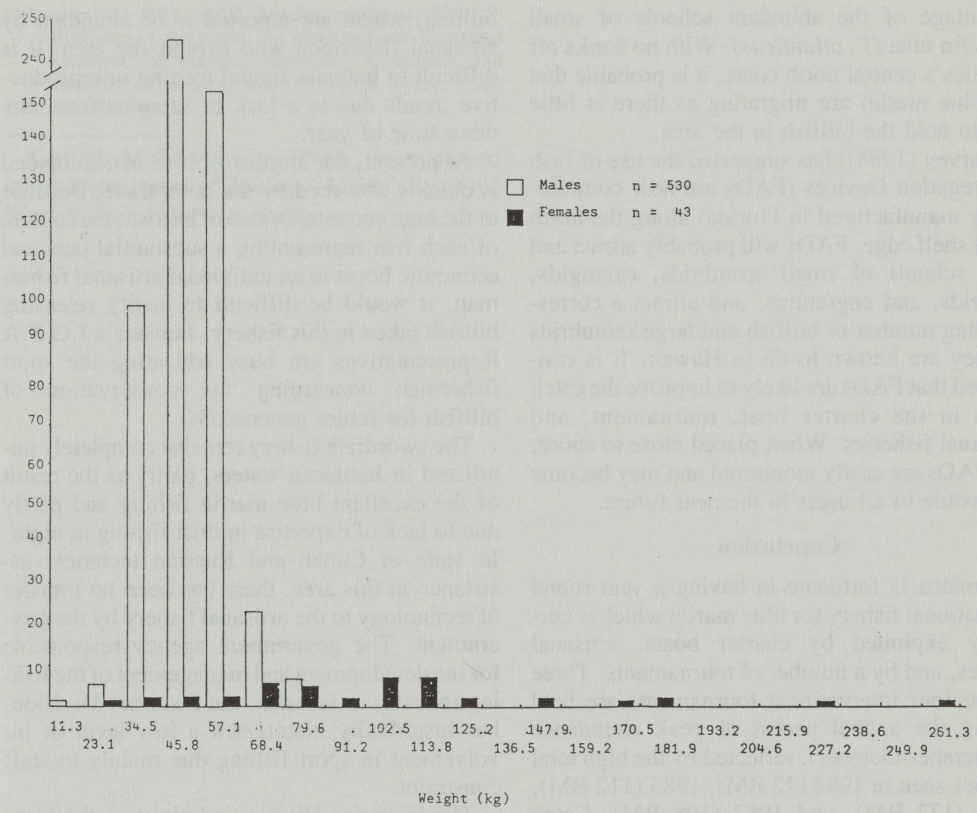

Figure 2. Blue marlin — Jamaica 1976-1986 Tournament Data. Size frequency distribution by sex, body weight in kg.

in an effort to get rid of the hook.

The blue marlin is known to feed in and near surface waters, but sometimes takes food in relatively deep waters as has been suggested by the finding of a number of deepwater species during this study. Some of the largest food items found since 1982 include a 19-lb (8.6-kg) yellowfin tuna *(Thunnus albacares)* in a 248-lb (112.5-kg) marlin, an 18-inch (45.7-cm) swordfish in a 159-lb (70.5-kg) marlin, a 34-inch (86 cm) lancetfish *(Alepisaurus ferox)* in a 114-lb (51.7-kg) blue marlin. Some specimens had up to sixteen 14-inch (35.5-cm) skipjack tuna *(Katsuwonus pelamis)* in their stomachs. Small food items such as juvenile surgeonfish *(Acanthurus* spp), triggerfish *(Balistes* spp.), filefish *(Aluterus* spp.), pufferfish *(Sphoeroides* spp.), and jacks *(Caranx* spp.) of 2 to 3 cm are readily consumed.

In contrast to other reports (Nakamura 1985), not one flying fish (Exocoetidae) has been collected from marlin stomachs in Jamaica since 1982. Flying fish abound in Jamaican coastal offshore waters, especially in the areas that are frequented by blue marlin, and they are one of the most important food items for dolphin *(Coryphaena hippurus)* and wahoo *(Acanthocybium solanderi)*. There appears to be no simple explanation for the absence of flying fish from blue marlin stomachs sampled in this area of the Caribbean where flying fish are visibly abundant. Blue marlin caught along Jamaica's north coast depend heavily on tuna-like fishes, deep-water snake mackerel *(Gempylus serpens)* and cephalopods.

A high incidence of the bigeye scad or goggle-eye jack *(Selar crumenophthalmus)* in 1982 from MBYC stomach contents was due to the presence of a very large shoal of this bait fish along the insular shelf just east of Montego Bay, at the time of the tournament. As marlin are seldom sampled at any other time of year, it is not known, if feeding patterns and composition changes. It is reported, that blue marlin visiting the offshore banks to the south of the island (Fig. 1) in November-February each year take

advantage of the abundant schools of small blackfin tuna *(T. atlanticus)*. With no banks off Jamaica's central north coast, it is probable that the blue marlin are migrating as there is little bait to hold the billfish in the area.

Harvey (1986)) has suggested the use of Fish Aggregation Devices (FADs are now commercially manufactured in Florida) along the north coast shelf edge. FADs will probably attract and hold schools of small scombrids, carangids, clupeids, and engraulids, and attract a corresponding number of billfish and large scombrids as they are known to do in Hawaii. It is considered that FADs are likely to improve the catch rates in the charter boat, tournament, and artisanal fisheries. When placed close to shore, the FADs are easily monitored and may become accessible to all users in the near future.

Conclusion

Jamaica is fortunate in having a year-round recreational fishery for blue marlin which is currently exploited by charter boats, artisanal canoes, and by a number of tournaments. Three of the four international tournaments are held during the annual period of peak abundance (September-October), reflected by the high total catches seen in 1984 (72 BM), 1985 (112 BM), 1986 (172 BM), and 1987 (108 BM). Catch rates have improved since 1982 due to a more favourable political climate, attracting more participants, and the use of state-of-the-art fishing tackle. Since 1983, each of the four locations have attracted the maximum of participating boats that each facility can comfortably accommodate.

In this overview, an attempt has been made to show that there is a small but active fishery for blue marlin in Jamaican coastal waters. Accurate records are available only for a limited period each year, from the recreational fishery, there being no historical records for the artisanal and charter boat fisheries. Little is known about the movements and migrations of blue marlin in this region of the Caribbean due to the absence of a national tagging programme. No recaptures of tagged fish have been reported in Jamaica. Due to the abundance of sexually active females off the NE coast of Jamaica each year in September to November, however, it is suggested that their appearance in this area is governed by a reproductive cycle rather than by a feeding cycle. Perhaps oceanographic conditions favour the rapid growth and survival of larval and juvenile billfish, which are reported to be abundant by artisanal fishermen who exploit the area. It is difficult to indicate annual feeding or reproductive trends due to a lack of samples from any other time of year.

At present, the number of blue marlin landed is quickly absorbed by the hotel trade. Because of the high economic value of billfish, the capture of each fish representing a substantial personal economic boost to an individual artisanal fisherman, it would be difficult to justify releasing billfish taken in this fishery. Jamaica's I.G.F.A Representatives are busy educating the sport fishermen concerning the conservation of billfish for future generations.

The swordfish fishery remains completely unutilized in Jamaican waters, partly as the result of the excellent blue marlin fishing and partly due to lack of expertise in drift fishing at night. In spite of Cuban and Russian technical assistance in this area, there has been no transfer of technology to the artisanal fishery by the government. The government agency responsible for the development and management of the fishing industry in Jamaica, the Fisheries Division, has historically maintained a low level of involvement in sport fishing due mainly to staff constraint.

The Fisheries Division administers the Fishing Industry Act of 1975, which requires that all anglers and fishing vessels involved in sport fishing in Jamaica be licensed and registered.

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Striped Marlin in the Northeast Pacific — A Case for Local Depletion and Core Area Management

J.L. Squire and D.W.K. Au

Commercial and recreational fishermen have been fishing billfish along the west coast of the Americas from California to Chile for several decades. Game-fish fishermen using rod-and-reel have fished for sailfish *(Istiophorus platypterus)* in major catch areas off Mexico, Costa Rica, and Panama; for blue marlin *(Makaira nigricans)* and black marlin *(Makaira indica)* off Panama, Ecuador, and Peru; and for striped marlin *(Tetrapturus audax)* off southern California USA, Baja California Sur-Mexico, and Ecuador. There are also commercial harpoon fisheries for swordfish *(Xiphias gladius)* off southern California and Chile and hook-and-line fisheries for marlin and sailfish at localities along the east coasts of the Pacific Ocean. Since 1980, a commercial offshore drift-gill-net fishery has expanded off California, increasing the catches of swordfish and incidentally-caught striped marlin. These are localized fisheries that are dwarfed by Japanese longline operations in the eastern Pacific that began after 1960.

This paper reviews the development of the eastern Pacific longline fishery for striped marlin and its impacts upon recreational fishing. It presents some arguments for "core area" management of the striped marlin resource for providing a suitable level of catch necessary for both longline and recreational rod-and-reel fisheries.

Eastern Pacific Billfish Fisheries

Commercial Fishery

After World War II, the Japanese expanded their longline fishing operations from the western Pacific into the southwest and central Pacific. They began exploration into the eastern Pacific (east of 130°W) in 1956 and, by 1963, were fishing over most of the tropical and subtropical areas of that area (Fig. 1). During this same period, Japanese exploration and longline fishing for tunas and billfishes had also expanded into the Atlantic and Indian oceans.

In 1963, the Japanese shifted considerable longline effort into the northeast tropical Pacific (north to 27°N lat.), where they had already found concentrations of striped marlin, sailfish,

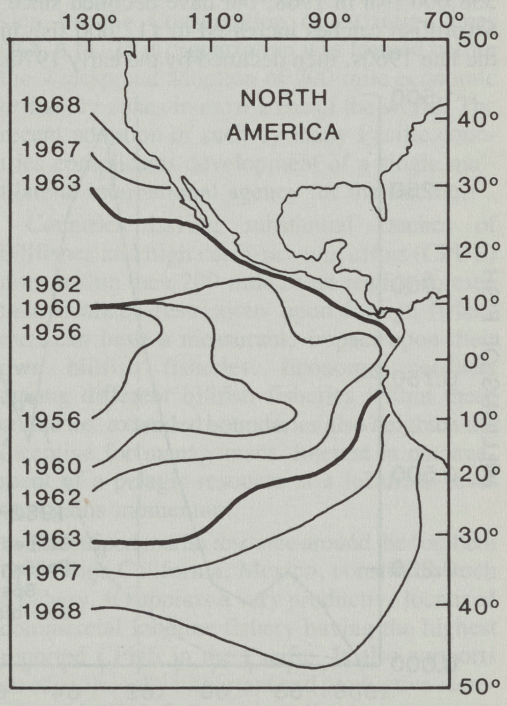

Figure 1. The 1956-1968 expansion of the Japanese longline operations into the eastern Pacific (E of 130°W), adapted from Joseph, Klawe, and Orange, 1974.

and swordfish as well as minor amounts of blue marlin and black marlin. Billfish catches increased in the eastern Pacific (Fig. 2), with the fleet concentrating on sailfish in areas from southern Mexico to Panama and on striped marlin and swordfish in an area from the Clarion and Socorro Islands to the southwestern coast of Baja California Sur, and the lower mouth of the Gulf of California. During 1962-1980, the catch of tunas and billfishes in the eastern Pacific amounted to 23.8 million fish, of which approximately 69% were tunas and 31% billfishes.

Fishery statistics of this expansion into the eastern Pacific have been collected by the Japan Fisheries Agency, which requires that all Japanese longliners prepare daily fishing logs. The results are published annually and give the total species catches and hook effort by 5° longitude and latitude intervals (Anon 1962-1980). Unfortunatly, the Japan Fishery Agency has not released these detailed catch-and-effort data for the years since 1980.

Striped marlin, swordfish, and sailfish catch trends in the Japanese longline fishery are shown in Figure 3 for the period 1956-1980. Striped marlin catches peaked in the eastern Pacific at 338,000 fish in 1968, but have declined since. Swordfish catches increased to 112,000 fish in the late 1960s, then declined by the early 1970s to 28,000 fish, due in part to findings of methylmercury in the fish (the "mercury problem"). Sailfish catches rose rapidly to 417,000 fish in 1965, but declined to 19,000 fish by 1980.

The catches noted preceding are less than the true totals by the amounts caught by Korean and Taiwanese longliners, tuna purse seiners (incidental catch), recreational anglers fishing from Peru to California, and by the commercial swordfish fleet. Some of these fisheries are expanding. The new drift-gill-net fishery off California landed over 25,000 swordfish in 1986, well above the 1978-1980 annual average of 4,500 fish taken by the traditional harpoon fishery.

Even so, the Japanese longline fleet and its associated joint-venture operations still comprise the major fishery for billfish in the eastern Pacific. Moreover, it is the only oceanic longline fishery there that has maintained acceptable fishing records over a long period of time.

Rereational Fishery

The billfish catch in the eastern Pacific taken otherwise than by longline is relatively minor. The recreational catch of striped marlin off California takes about 800 fish per year. [In contrast, an estimated 1,500 other striped marlin have been taken incidentally there in recent years

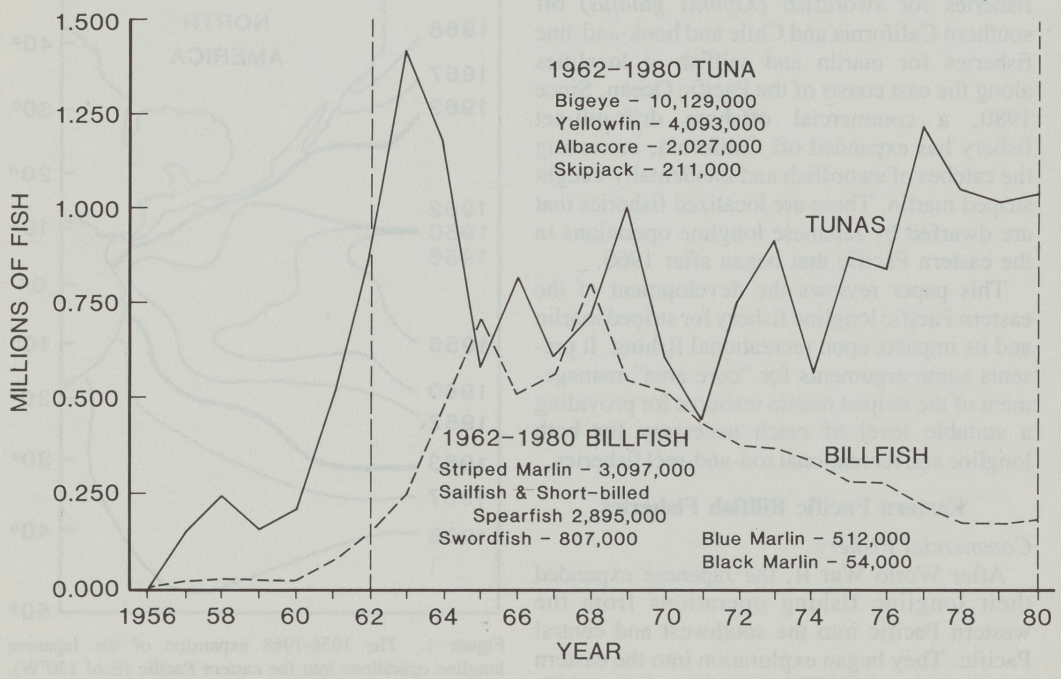

Figure 2. Catch by year for billfish and tuna, 1956-1980, by Japanese longline east of 130°W.

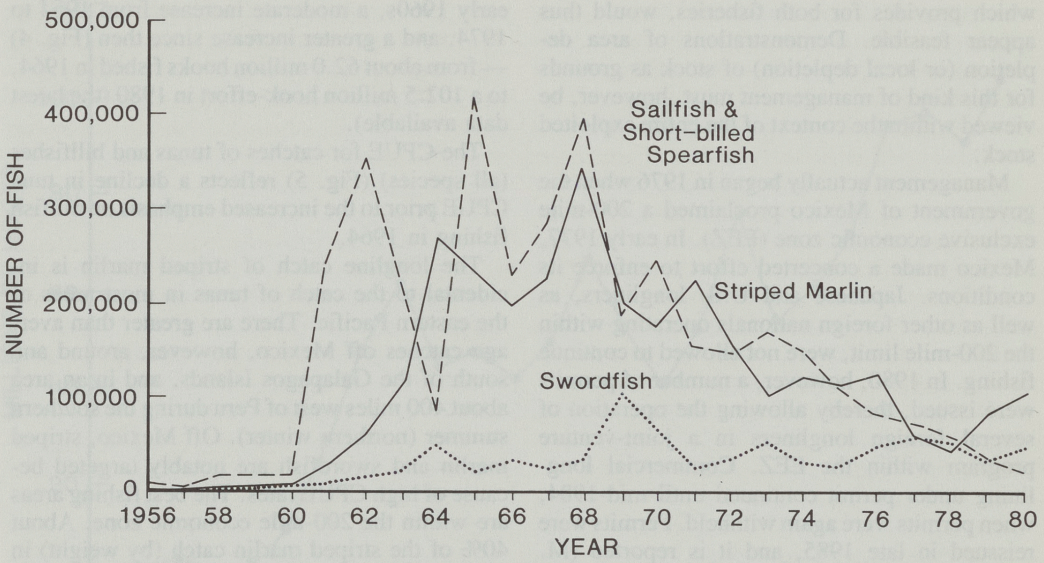

Figure 3. Eastern Pacific Japanese longline catch of sailfish and short-billed spearfish, swordfish, and striped marlin.

by the drift-gill-net fishery for swordfish and thresher shark *(Alopias* sp.).] A preliminary estimate of the recreational catch off Mexico (Joseph, unpubl. MS[1]) indicated 40,000 to 90,000 billfish taken per year. Most are Pacific sailfish, high production areas of which occur off Acapulco, Zihuatanejo, and northward to Mazatlán. The estimated annual Mexican recreational catch of striped marlin is 7,000 to 15,000 fish, the majority from around the southern tip of Baja California Sur. High angler catch rates for striped marlin (0.4 or more fish per angler day), plus occasional catches of blue marlin and black marlin, attract anglers to that area from the United States and many other countries.

Commercial companies that service recreational anglers are very important to the economy of the southern tip of Baja California, and catch rates must meet anglers' expectations. Recently, operators from the major sport fishing locations there have complained of declines in billfish catches, which they have blamed on newly developed, joint-venture longline fisheries.

The Striped Marlin Fishery

Management Approaches

Although Pacific-wide management of pelagic billfishes has long been considered, it is unrealistic to expect such management in the near future. The only international agency that has investigated management for billfish on an ocean-wide basis is the International Commission for the Conservation of Atlantic Tunas (ICCAT). That organization was formed before the widespread adoption of 200-mile economic or fishery zones in most areas of the world. The recent adoption of such by many Pacific countries complicates development of a single multilateral international agency for the Pacific.

Countries having substantial catches of billfishes and high catch-per-unit effort (CPUE) rates within their 200-mile zones readily foresee that localized restrictions upon foreign fishermen can have a measurable impact upon their own billfish fisheries. Economic conflicts among different billfish fisheries within these countries' extended boundaries also heighten the incentive for management. Interest in management of a pelagic resource at a localized level thus gains momentum.

The striped marlin resource around the southern tip of Baja California, Mexico, constitutes such a fishery. It supports a very productive localized commercial longline fishery having the highest reported CPUE in the Pacific. It also supports an economically important and productive recreational billfish fishery. Localized management that is restricted to this "core area" of striped marlin distribution (core-area management), and

[1]Joseph, J. 1981. Report on the development of a Mexican longline fishery, unpublished.

which provides for both fisheries, would thus appear feasible. Demonstrations of area depletion (or local depletion) of stock as grounds for this kind of management must, however, be viewed within the context of the entire exploited stock.

Management actually began in 1976 when the government of Mexico proclaimed a 200-mile exclusive economic zone (EEZ). In early 1977, Mexico made a concerted effort to enforce its conditions. Japanese and U.S. longliners, as well as other foreign nationals operating within the 200-mile limit, were not allowed to continue fishing. In 1980, however, a number of permits were issued, thereby allowing the operation of several foreign longliners in a joint-venture program within the EEZ. Commercial longlining under permit continued until mid-1984, when permits were again withheld. Permits were reissued in late 1985, and it is reported (M. Comparan, pers. comm.) that approximately 14 longliners were operating under permit in 1987, targeting on striped marlin and swordfish (plus 6 shark longliners which catch striped marlin incidentally). *[NB:* On many of our graphics, we show a dashed line separating the years 1977 to 1980 and 1984 to 1985, indicating the times during which there was enforcement of Mexico's 200-nautical-mile economic zone, when no longline permits were issued.] In August 1987, following strong complaints by sport fishing operators, new regulations were issued that restricted these longline operations to the offshore areas of Mexico's 200-mile zone, out of the high-catch-rate areas.

For slightly over 3 years — the first period when permits were withheld (early 1977 to late 1980) — commercial longlining was nearly nonexistent in that area having the highest striped marlin catch rate in the Pacific (see following) and also a high catch rate for swordfish. It is rare in the annals of high-seas pelagic fishing that a major catch area, or core area of abundance, becomes restricted, bringing catches nearly to zero. Although not designed as such, the government of Mexico had conducted an "experiment" that showed how a widespread offshore fishery affects local fishing.

Catch, Effort, and CPUE

The longline fishery. In the eastern Pacific (E of 130°W) the hook-effort generated by the longline fishery fluctuated but increased after 1961 in three stages: a sharp increase in the early 1960s, a moderate increase from 1964 to 1974, and a greater increase since then (Fig. 4) — from about 62.0 million hooks fished in 1964, to a 102.5 million hook-effort in 1980 (the latest data available).

The CPUE for catches of tunas and billfishes (all species) (Fig. 5) reflects a decline in tuna CPUE prior to the increased emphasis on billfish fishing in 1964.

The longline catch of striped marlin is incidental to the catch of tunas in most areas of the eastern Pacific. There are greater than average catches off Mexico, however, around and south of the Galapagos Islands, and in an area about 400 miles west of Peru during the southern summer (northern winter). Off Mexico, striped marlin and swordfish are notably targeted because of high CPUE rates. The best fishing areas are within the 200-mile economic zone. About 40% of the striped marlin catch (by weight) in the eastern Pacific is generated off Mexico (Joseph, unpubl. MS[1]).

The longline catch of striped marlin in the eastern tropical Pacific increased sharply to 270,000 fish in 1964 (Fig. 3), much of it from increased hook-effort off Mexico. The catch peaked again in 1968 at 338,000 fish, and then declined to 130,000 fish in 1976. As mentioned previously, these Japanese billfish catches are short of the total catch by the amounts of the recreational catch and incidental and directed catches by other fishing fleets. Unfortunately, neither these other catches nor the associated fishing effort are well documented.

Longline catch records show that the geographical area from off Magdalena Bay (on the southwest coast of Baja California) to the Clarion and Socorro Islands, and to the southern portion of the Gulf of California, has the highest catch rates in the Pacific (Suzuki and Honma 1977[2]). The Japanese records (Anon 1962-1980) of catch and hook-effort by 5° longitude and latitude areas show that two areas, 20°N by 110°W and 20° by 105°W (long. and lat. of lower right-hand corner of each 5° area), constitute the most important longline fishing locality for striped marlin in the Pacific (Fig. 7). These two 5° areas, or core areas of striped marlin abundance, accounted for about 23% of the total catch by number of striped marlin in the eastern Pacific (E of 130°W) prior to the establishment

[2]Suzuki, Z. and M. Honma. Stock assessment of billfishes in the Pacific. Working paper, Billfish Stock Assessment Workshop, Honolulu, HI, 5-16 Dec. 1977, unpublished.

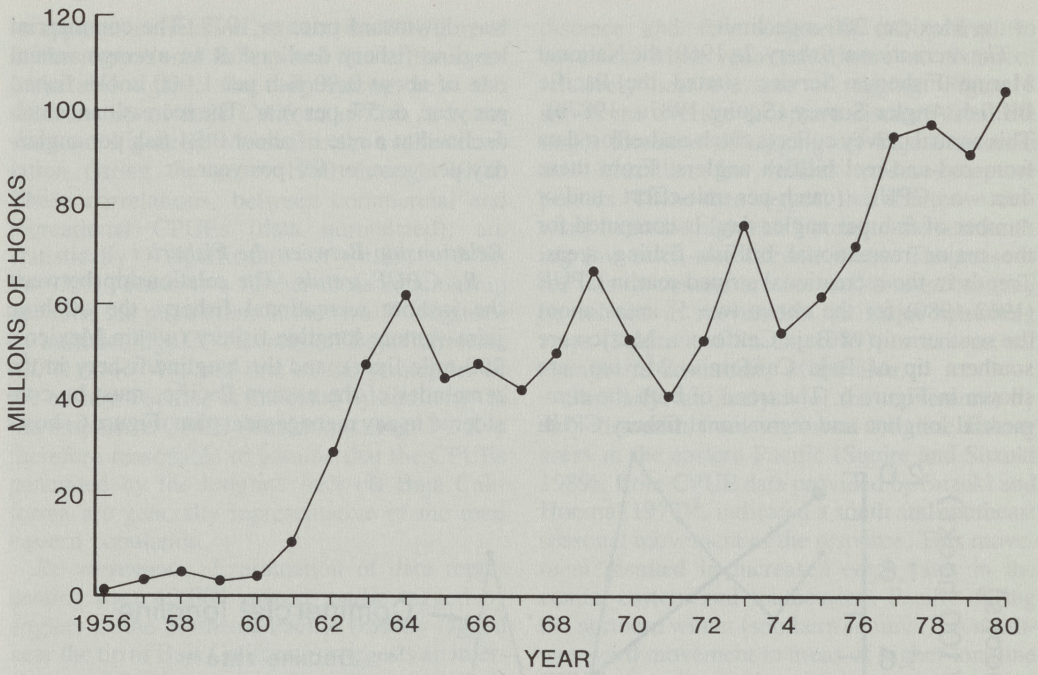

Figure 4. Longline hook effort (Japanese) east of 130°W.

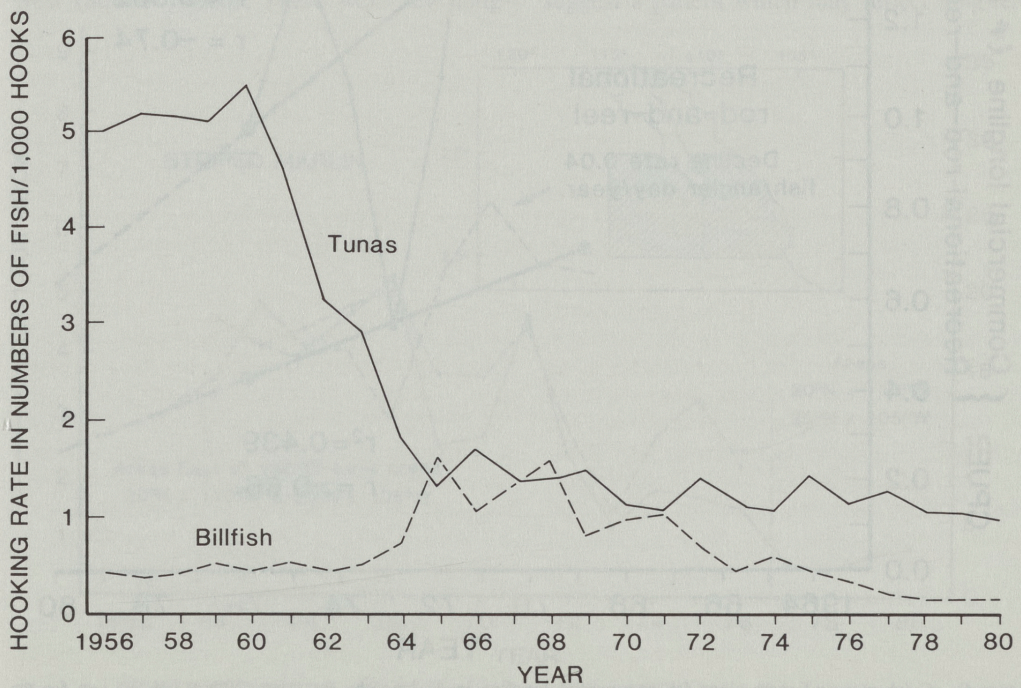

Figure 5. Catch rate for Japanese longline, tunas and billfish in the eastern Pacific in numbers of fish/1,000 hooks.

of the Mexican 200-mile limit.

The recreational fishery. In 1969, the National Marine Fisheries Service started the Pacific Billfish Angler Survey (Squire 1987a, 1987b). This annual survey collects catch-and-effort data from rod-and-reel billfish anglers. From these data, a CPUE (catch-per-unit-effort and/or number of fish per angler-day) is computed for the major recreational billfish fishing areas. Trends in the recreational striped marlin CPUE (1962-1980) for the above two 5° areas about the southern tip of Baja California, Mexico are southern tip of Baja California, Mexico, are shown in Figure 6. The trend of both the commercial longline and recreational fishery CPUE was downward prior to 1977. The commercial longline fishery declined at an average annual rate of about 0.90 fish per 1,000 hooks fished per year, or 5% per year. The recreational catch declined at a rate of about 0.04 fish per angler-day per year, or 6% per year.

Relationship Between the Fisheries

Re CPUE trends. The relationship between the inshore recreational fishery, the offshore joint-venture longline fishery (within Mexico's 200-mile limit), and the longline fishery in the remainder of the eastern Pacific, must be considered in any management plan. Figure 6 shows

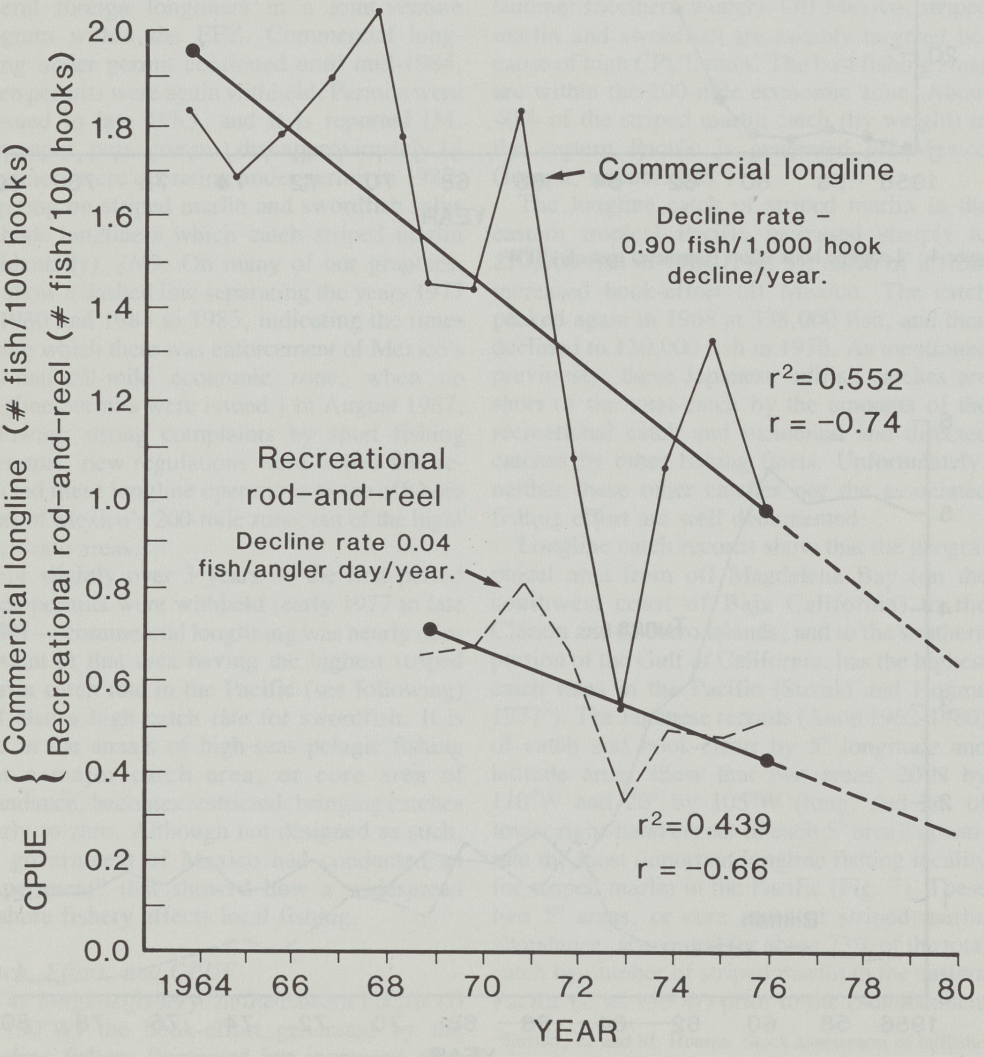

Figure 6. Catch rate and regressions for commercial longline in 5° long. by lat. area (20°N × 105°W) and for the recreational rod-and-reel fishery about the southern tip of Baja California, Mexico.

an apparent correlation between the CPUE trend of the recreational fishery and that of the commercial longline fleet operating near the southern tip of Baja California. This is better shown in Figure 10 which also shows the correlation during the years 1980 through 1986. These correlations, between commercial and recreational CPUEs (data normalized), are statistically significant ($r = 0.89$, 0.96; $Ps < 0.01$). There is a further close relationship between the population in the two 5° longitude by latitude, high CPUE areas off Baja California (20°N × 110°W), and that of the remainder of the eastern Pacific, as indicated by similarity in the respective CPUE fluctuations (Fig. 7). It is therefore reasonable to assume that the CPUEs generated by the longline fleet off Baja California are generally representative of the total eastern population.

Re movements. Examination of data representing over 12,000 striped marlin tagged by anglers in the northeast Pacific (mostly tagged near the tip of Baja California) suggests an interchange of fish between waters off southern Baja California and surrounding areas. There appears to be movement from the southern tip of Baja California to the south and southwest in early summer, and also some movement to the northwest (Squire 1987b). There were few long-distance and few long-term (>2 years) recoveries. Most recoveries were at distances relatively near the area of tagging. Figure 8 shows the average recapture distance from the major locations of tagging off Baja California and Mazatlán for various release-recapture periods. These data suggest that fish move outward from the high-catch areas to the surrounding low-catch-rate oceanic areas. The reasons for this movement are not well known but may be related to movements to major spawning areas (Squire and Suzuki 1989), or to seasonal changes in desirability of the area.

Similarly, an analysis of the movements by striped marlin from important longline fishing areas in the eastern Pacific (Squire and Suzuki 1989), from CPUE data provided by Suzuki and Honma (1977)[2], indicated a south and southeast seasonal movement of the resource. This movement resulted in increased catch rates in the central-eastern and southeastern Pacific during the northern winter (southern summer). A northwestward movement to areas of higher longline CPUE was also evident in the northern spring and early summer.

Re morphometrics. Measurements of striped marlin lengths (eye orbit to fork of tail) in the eastern Pacific (Suzuki and Honma 1977[2]) suggest a pattern which may reflect long-term

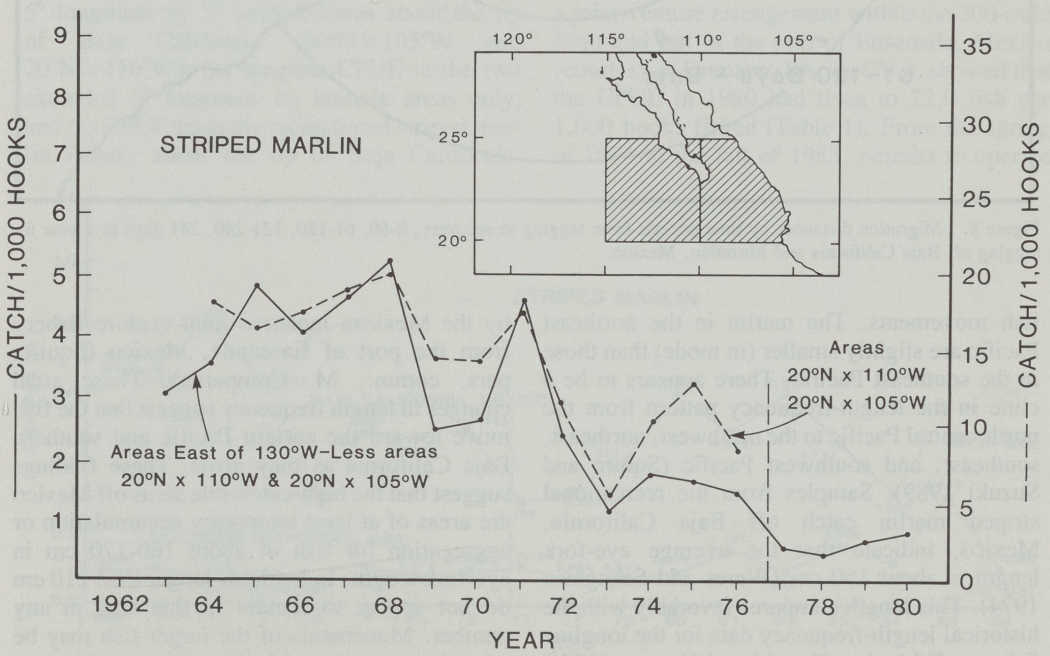

Figure 7. Comparison of CPUE's for the total eastern Pacific (E of 130°W) less 2-5° long. by lat. areas about Baja California and the CPUE for the 2-5° areas combined.

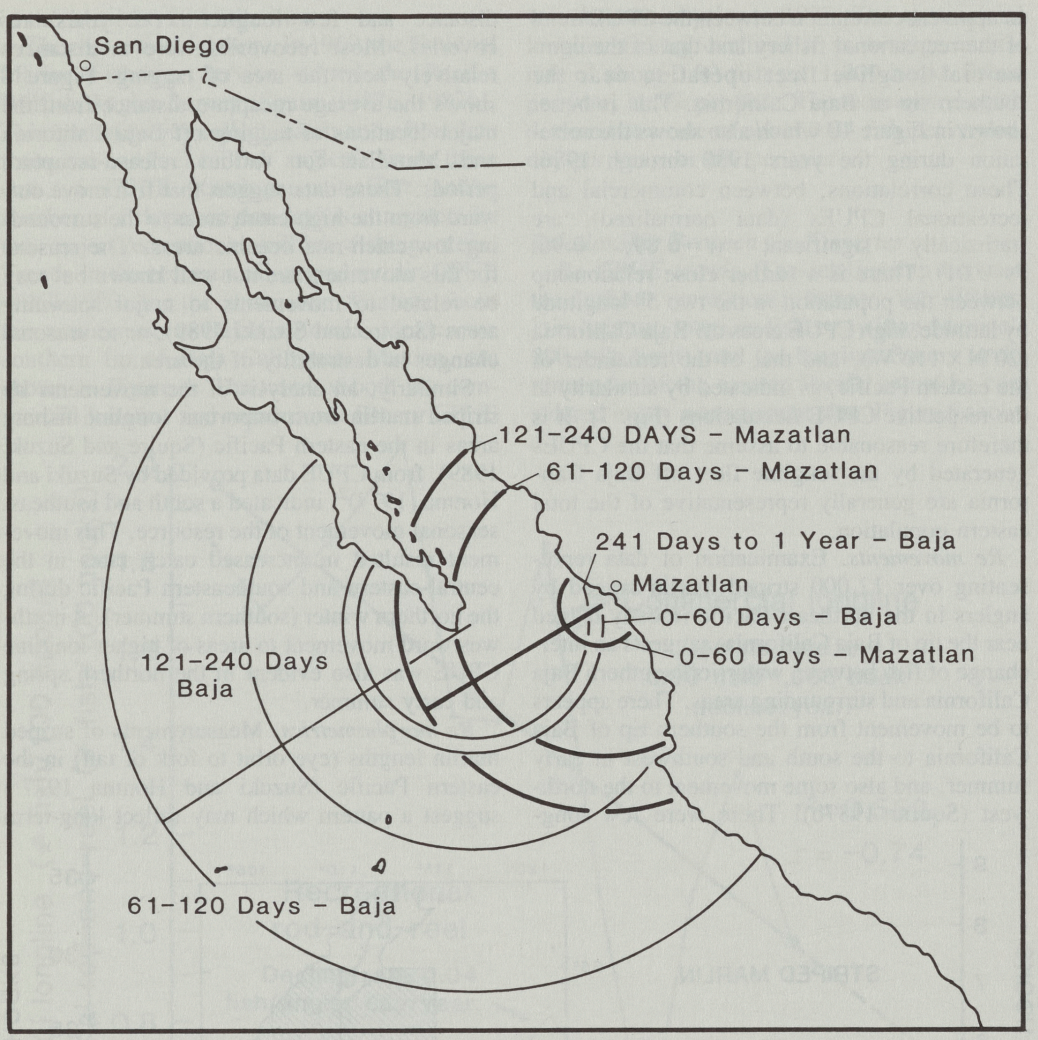

Figure 8. Migration distances by time periods from tagging to recovery, 0-60, 61-120, 121-240, 241 days to 1 year for tagging off Baja California and Mazatlán, Mexico.

fish movements. The marlin in the northeast Pacific are slightly smaller (in mode) than those in the southeast Pacific. There appears to be a cline in the length-frequency pattern from the north-central Pacific to the northwest, northeast, southeast, and southwest Pacific (Squire and Suzuki 1989). Samples from the recreational striped marlin catch off Baja California, Mexico, indicate that the average eye-fork length is about 160 cm (Wares and Sakagawa 1974). This length compares favorably with the historical length-frequency data for the longline fishery off Mexico (Suzuki and Honma 1977[2]) and with length measurements collected recently by the Mexican-Japanese joint-venture fishery from the port of Ensenada, Mexico (Squire; pers. comm., M. Comparan). These areal changes in length frequency suggest that the fish move toward the eastern Pacific and southern Baja California as they grow. These findings suggest that the high-catch-rate areas off Mexico are areas of at least temporary accumulation or aggregation for fish of about 160-170 cm in eye-fork length. Individuals longer than 210 cm do not appear to remain in this area in any number. Movements of the larger fish may be related to maturity and, thus, to spawning seasons and spawning areas.

Local CPUE Changes off Mexico

Billfish angler survey trends. Striped marlin catch rates, determined from the Pacific Billfish Angler Survey (catch per angler-day), are shown in Figure 9. Additionally, and prior to the start of the Angler Survey in 1969, logbook data had been made available by Rancho Buena Vista, an important fishing resort on the East Cape area of Baja California. These records indicated a catch rate (fish per angler-day) of 0.60 for 1965, 0.73 for 1967, and 0.90 for 1968. The Angler Survey then showed a declining CPUE trend for Baja California, 1969 through 1976 (Fig. 9). This trend then reversed, and CPUEs increased in 1978, 1979, and 1980. Since 1980, CPUEs in the Baja California sport fishery have fluctuated at about 0.5 fish per angler-day. The nearby southern California rod-and-reel fishery, which has consistently shown a low CPUE (about 0.1 fish/day), showed little trend. The catch rate increased slightly after 1981, and the highest catch rate recorded was in 1985, slightly over 0.3 fish per day. It returned to the 0.1 CPUE rate in 1986.

The cited changes in angler CPUE reflect similar changes in longline CPUE in adjacent oceanic areas, as previously noted. This situation (Fig. 10) is a composite of, (a) longline CPUE in the eastern Pacific excluding the two 5° longitude by 5° latitude areas about the tip of Baja California (20°N × 105°W and 20°N × 110°W); (b) longline CPUE in the two excluded 5° longitude by latitude areas only; and (c) CPUE from the recreational striped marlin fishery about the tip of Baja California. Examination of the figure indicates the following trends of longline CPUE change as affected by fishery closures.

In the Japanese longline fishery. Total eastern Pacific catch-and-effort data — less data for the two 5° areas off Baja California — show a decline in CPUE from 1964 to 1978, from about 5 to 0.4 fish per 1,000 hooks (nominal effort) fished, with a decline rate of 0.38 fish per 1,000 hooks fished per year. Since the early 1970s, considerable deep-longlining has been conducted in the equatorial area for bigeye tuna *(Thunnus obesus).* This method of longlining reduces the chances of catching billfish. For the two 5° longitude by latitude areas off Baja California — where bigeye tuna fishing is relatively unimportant — the CPUEs declined during the period 1964 to 1976 from about 18 to 9 fish per 1,000 hooks fished, with a decline rate of 1.10 fish per 1,000 hooks fished per year. Then, during the period of restricted fishing, 1979 and 1980, the CPUE rose to near 23 fish per 1,000 hooks fished for both years. [Japanese longline catches within the two 5° areas that are within Mexico's 200-mile economic zone may have been from joint-venture longliners.] After 1980, Japanese longline data were no longer accessible.

In the Mexican joint-venture longline fishery. Sampling of Japanese longliners, operating on a joint-venture arrangement within the 200-mile limit and out of the port of Ensenada, Mexico (courtesy of Comapro SA. de CV.), showed that the CPUE in 1980 had risen to 22.0 fish per 1,000 hooks fished (Table 1). From the spring of 1984 to the fall of 1985, permits to operate

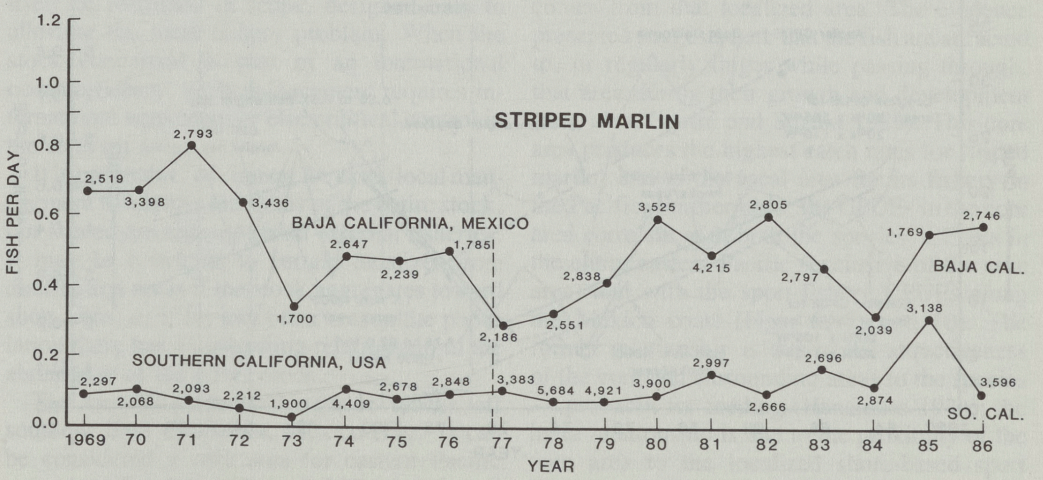

Figure 9. CPUE trend (fish per angler-day) for striped marlin about the southern tip of Baja California, 1969-1985, from the Pacific billfish angler survey. Numbers by the points indicate angler-days.

within Mexico's 200-mile limit were again withheld. During that period, the CPUE rose by about 1.5 fish per 1,000 hooks fished per year.

Table 1. CPUE data obtained from a portion of the joint-venture Japanese fleet operating from Ensenada, Mexico (courtesy Comapro SA. de CV.).

Year	# hooks fished	# fish/1,000 hooks
1980	547,000	22.0
1981	1,899,900	12.0
1982	1,235,000	23.0
1983	188,600	12.0
1985	143,000	16.0
1986	301,300	13.0

The Fishing Areas

Intensive and productive fishing actually occurs in only portions of the approximately 165,000 sq.-n.mi. core area, probably due to environmental conditions (Hanamoto 1974). Figure 11 shows fishing effort distribution for a portion of the joint-venture longline fleet operating in 1982 and 1983. The most productive fishing areas were along the edge of the continental shelf off Magdalena Bay, at the mouth of the Gulf of California, and around the Revillagigedo Islands. Catches were primarily of striped marlin during the summer from off Magdalena Bay to the Revillagigedo Islands, and of both swordfish and striped marlin during the winter months off Magdalena Bay and about the mouth of the Gulf of California.

Summary

Changes in angler-CPUE appear to reflect offshore changes in the exploited population. From 1969 to 1977 (the year after the last full year of unrestricted commercial longline fishing), the angler-CPUE had declined from 0.69 to 0.30 fish per angler day, about 0.04 fish per angler day per year (Fig. 10). During the restricted commercial longlining period from 1977 to 1980, when longline-CPUE increased by about 3.6 fish per thousand hooks per year, the angler-CPUE increased from about 0.3 to 0.6 fish per angler-day. This increase is about 0.15 fish per angler-day per year. Since 1980, when joint-venture longline fishing began, the billfish-angler-CPUE showed a decline, again, from about 0.58 to 0.46 in 1985, a decline rate of 0.02 billfish per angler-day per year. The changing trends in angler-CPUE therefore appear to follow the major changes in the offshore commercial fishery (Fig. 12).

Core-Area Assessment and Management

Concept

Regardless of the status of an oceanic stock, or of any overall management regime implemented, local reductions in CPUE usually precipitate calls for restrictions on fishing. The restrictions are usually aimed at extra-local fisheries, and may be justified if those fisheries control the abundance or availability of fish in the local area. Extra-local management may

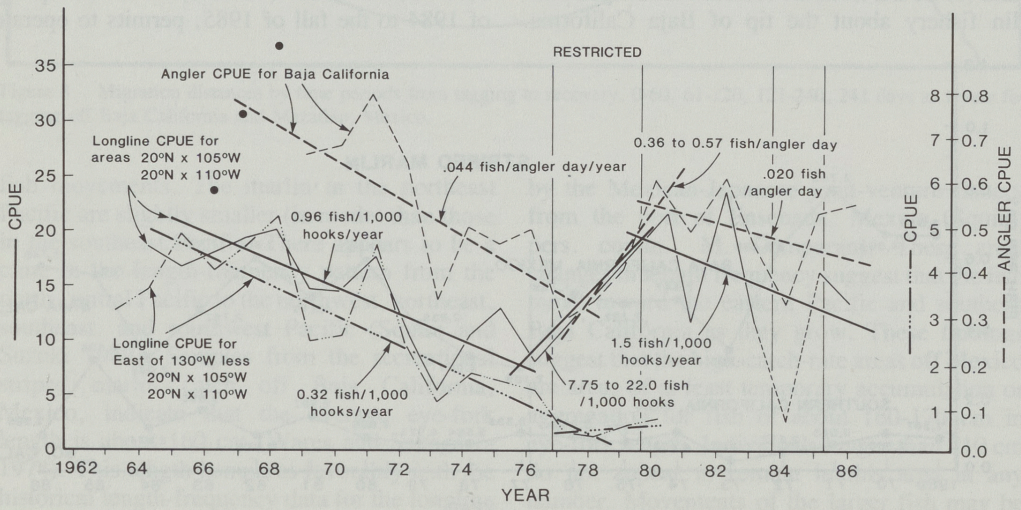

Figure 10. Comparison of CPUE trends for longline in the total eastern Pacific and for rod-and-reel and longline about Baja California.

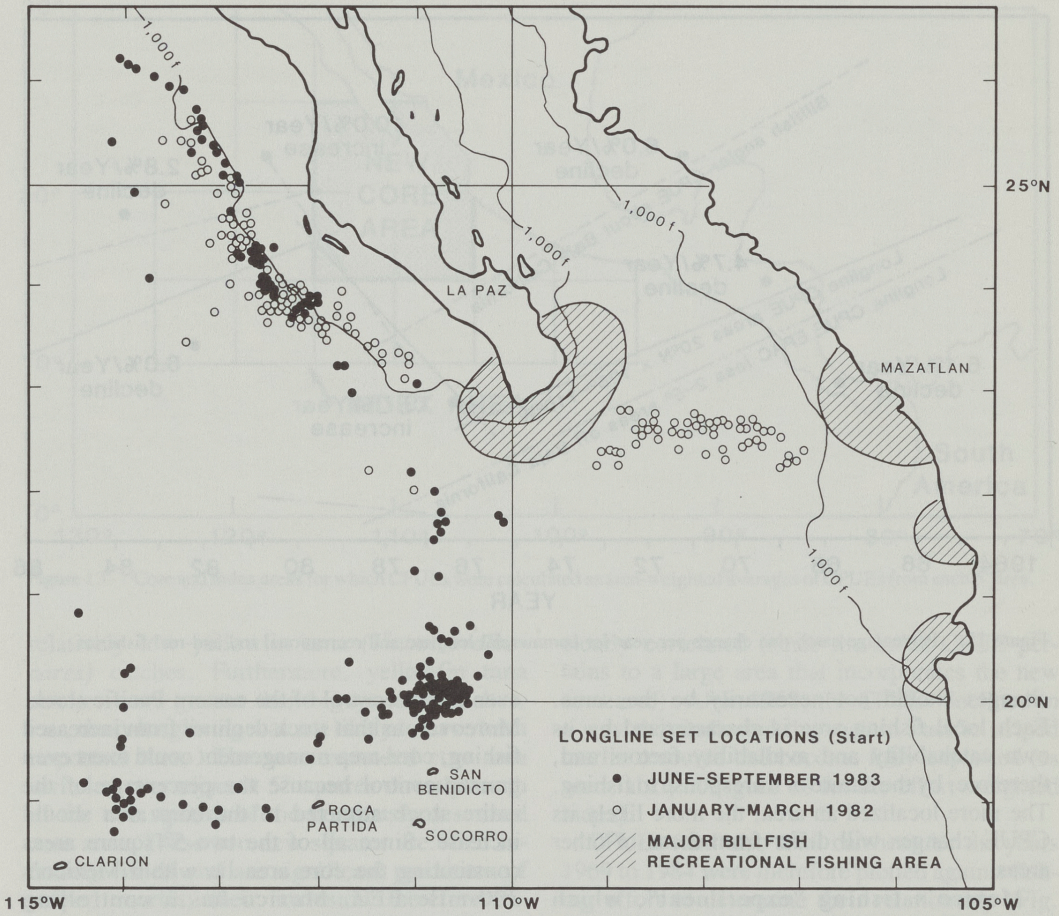

Figure 11. Locations of the start of longline sets (portion of joint-venture fleet) during the winter and spring of 1982 and summer of 1983.

itself be restricted in scope, designed only to alleviate the local fishery problem. When the stock concerned is part of an international oceanic fishery, such management requires international agreement or else political control in the relevant areas.

It is preferable, of course, for extra-local management to address the status of the entire stock, but it need not encompass all external fisheries. It may be restricted to certain localized core distribution areas if the stock aggregates toward such areas, or if for any other reason the population there has a controlling relationship to the abundance of the entire stock.

The two 5° latitude × longitude blocks off southern Baja California, Mexico (Fig. 7) can be considered a core area for eastern Pacific striped marlin. Approximately 23% of all striped marlin caught in the eastern Pacific (E of 130°W) comes from that localized area. The evidence presented suggests here that the fish are attracted to, or regularly linger while passing through, that area during their growth and development (see, also, Squire and Suzuki 1989). This core area produces the highest catch rates for striped marlin, and is the focal area for its fishery in the Pacific. Furthermore, the CPUEs in the core area correlate with both the species' CPUEs in the entire eastern Pacific (exclusive of the core area) and with the sport-fishery CPUEs along the Mexico coast (Figs. 6, 7, and 10). The former relationship is due to the attractiveness of the core and surrounding areas to the species — probably for feeding (Hanamoto 1974); the latter relationship is due to the proximity of the core area to the localized shore-based sport fisheries. While these CPUE trends may be correlated, however, the time rates of these CPUE

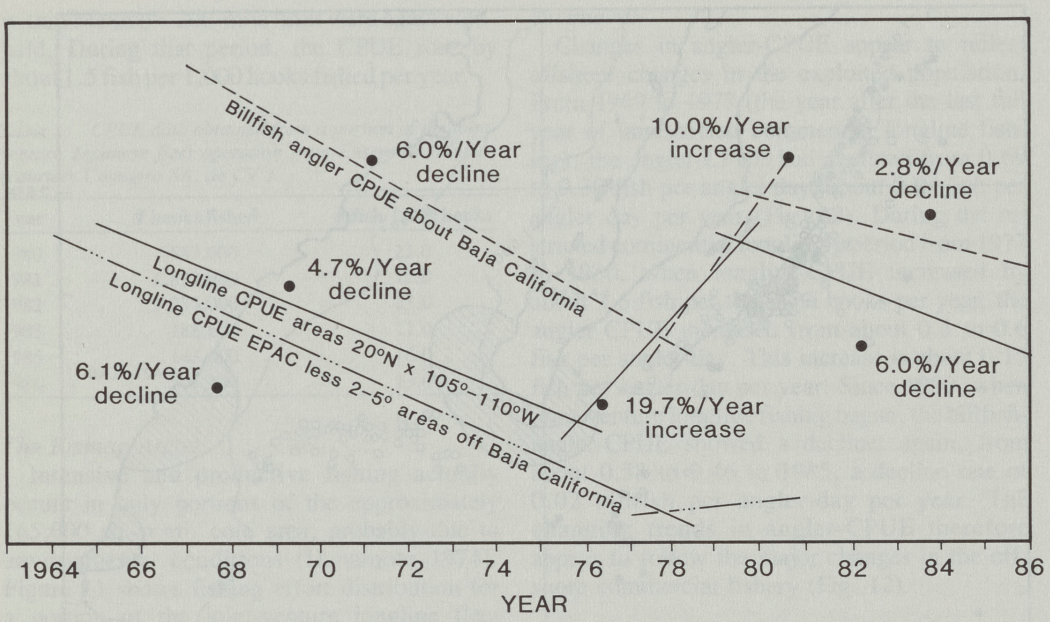

Figure 12. Percentage catch rate change per year for commercial longline and recreational rod-and-reel fisheries.

changes should not necessarily be the same. Each local fishing area is characterized by its own catchability and availability factors and, therefore, by the nature of its response to fishing. The more localized an area, the more likely its CPUE changes will differ from those of other areas.

Mexico's fishing "experiment", which temporarily curtailed the fishery within its 200-mile EEZ, encompassed the core area and showed an effect of fishery interactions. When commercial fishing was stopped, during 1977-1980, the CPUEs rose from a long period of decline to near pre-exploitation levels, both in the core area longline fishery and in the sport fishery (Figs. 10 and 12). These increases all occurred within a 3-year period. Considering the large areal extent of the striped marlin resource, and its overall fishery in the eastern Pacific, together with the limited areal extent of the core and shore-based sport fisheries, this rapid increase in CPUE would appear to reflect effects from the fishing down and rebuilding of localized fishing "hot spots," whose populations are continuously augmented by immigration, rather than overall stock recovery from a decline.

From the foregoing, and evidence previously presented, it is argued that management in the core area off Mexico is feasible (relative to ocean-wide, international management) and can even effect control of the eastern Pacific stock. Moreover, as that stock declines from increased fishing, core-area management could exert even greater control because the percentage of the entire stock attracted to the core area should increase. Since all of the two 5° square areas constituting the core area lie within Mexico's 200-mile EEZ, Mexico has a controlling position to implement core-area management. Such management could endeavor to maintain CPUE levels consistent both with the principles of stock management for the commercial fishery and with needs for an economically viable CPUE level in the adjacent sport fisheries.

Weighted CPUE vs. Fishing Effort

The relationship between striped marlin CPUE and fishing effort was examined using the same Japanese catch-effort data and Mexican-Japanese joint-venture records already described, but here the CPUE was calculated as an area-weighted index (see Beverton and Holt 1957, p. 148). This CPUE was calculated for both an "index" area and for an enlarged core area that consisted of four adjacent 5° square areas (Fig. 13). The index area consisted of 17 whole or partial 5° squares where striped marlin appeared to be the target species in the Japanese fishery. These areas exhibited consistent high catches and catch rates for striped marlin, and

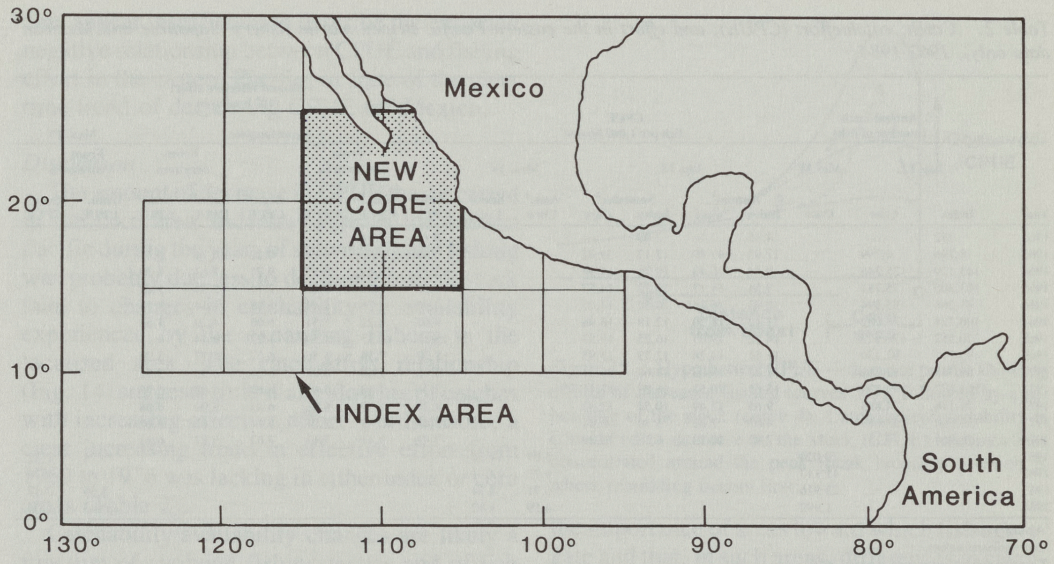

Figure 13. Core and index areas for which CPUEs were calculated as area-weighted averages of CPUEs from each 5° area.

relatively low yellowfin tuna *(Thunnus albacares)* catches. Furthermore, yellowfin tuna catches were greater than bigeye tuna catches, i.e., deep-longlining was not likely to have been important there. The new expanded core area included two adjacent 5° squares directly south of the two squares of the previously described core area. These two new squares are often intensely fished and are significant producers of striped marlin; their inclusion therefore increased the sample size for core-area calculations. In both the index and new core areas, CPUE was calculated only from those 5° squares for which fishing effort, during any time period of interest, was at least 10,000 hooks. This condition was applied to reduce the computing of extreme CPUE ratios.

Results

The time trend in the area-weighted CPUEs (Table 2) was closely similar to that of the simple (effort-weighted) CPUEs previously calculated (Fig. 10). This similarity is an indication of a fishery that is highly focused onto prime fishing areas, i.e., the average catch rate is little altered by inclusion of fishing rates from other areas. In both CPUE series, there was a general decline with time through 1976 or 1977, a rapid rise to near pre-exploitation CPUE levels during the 1977-1980 years of fishery closure, and a decline afterwards in the joint-venture fishery. The area-weighted core- and index-area CPUEs were clearly correlated (since the index-CPUE pertains to a large area that incorporates the new core area). After 1968, the CPUEs declined in a way that indicated the eastern Pacific striped marlin resource had become fully exploited (as seen, also, in Figure 10 for the effort-weighted index).

CPUEs (and also total catches) for the years 1969 to 1984 were therefore plotted against fishing effort to determine their relationship (Fig. 14) in terms of annual index-area CPUE vs. annual effective hooks, the latter calculated by dividing annual catch by annual CPUE. There appears to be a negative regression in the 1969 to 1976 data, although this relationship is obscured if core, not index, area CPUEs are plotted against core hook effort, in turn calculated either from annual or 2nd semestral CPUEs (most striped marlin are taken during the 3rd and 4th quarters of the year).

Reexamining Figure 14, it can be seen that the apparent regression depends strongly upon the 1971 and 1973 data points, which represent good and poor fishing years, respectively (Fig. 10 and Table 2). The more recent data shown cannot be considered very reliable with respect to the stock size-fishing effort relationship. The 1979 and 1980 catch-effort data were sampled from a largely closed near-shore fishery, and the post-1980 data points were based on a tenuous assumption that joint-venture catches were the only catches in the index area. The

Table 2. Catch, catch/effort (CPUE), and effort in the eastern Pacific striped marlin fishery (Japanese and Mexican data only), 1962-1984.

	Annual catch (number of fish)			CPUE (fish per 1,000 hooks)						Annual effective effort (10^6 hooks) in							
	Jap. LL		Mex JV	Jap. LL				Mex. JV		Japan longline						Mex. JV	
										From index area				From core area		From core area	
				Annual[1]		Semester[2]		Ann.[1]	Sem.[2]	Ann.[3]	Sem.[4]	Ann.[5]	Sem.[6]	Ann.[5]	Sem.[6]	Ann.[5]	Sem.[6]
Year	Index	Core	Core	Index	Core	Index	Core	Core	Core	CPUE	CPUE	CPUE	CPUE	CPUE	CPUE	CPUE	CPUE
1962	742	—		4.35	—	2.40	—			0.17	0.31	—	—	—	—		
1963	8,796	6,799		17.93	41.80	17.12	39.02			0.49	0.51	0.21	0.22	0.16	0.17		
1964	145,120	125,346		9.44	16.43	10.76	14.94			15.37	13.49	8.83	9.71	7.63	8.39		
1965	103,300	75,781		9.54	14.17	10.72	14.53			10.83	9.64	7.29	7.11	5.35	5.22		
1966	71,268	53,894		10.03	16.16	10.54	17.05			7.10	6.76	4.41	4.18	3.34	3.16		
1967	100,224	78,082		11.12	18.20	12.19	16.98			9.01	8.22	5.51	5.90	4.29	4.60		
1968	220,552	179,623		14.12	19.03	16.25	19.57			15.62	13.35	11.59	11.27	9.44	9.18		
1969	93,713	82,350		11.61	14.28	12.73	13.95			8.07	7.36	6.56	6.72	5.77	5.90		
1970	89,345	82,312		11.23	13.00	11.68	14.31			7.96	7.65	6.87	6.24	6.33	5.75		
1971	114,877	99,730		15.65	16.53	16.09	17.41			7.34	7.14	6.95	6.60	6.03	5.73		
1972	79,176	74,885		9.65	12.49	10.53	12.32			8.20	7.52	6.36	6.43	6.00	6.08		
1973	57,764	53,689		4.63	7.02	5.30	6.61			12.48	10.09	8.23	8.74	7.65	8.12		
1974	76,964	74,151		7.92	10.79	8.18	10.89			9.72	9.41	7.13	7.07	6.87	6.81		
1981			19,024					5.07	14.36							3.75	1.32
1982			11,117					9.22	14.31							1.20	0.78
1983			23,916					6.71	8.34							3.56	2.87
1984			1,992					4.59	1.92							0.43	1.04

[1]Annual values.
[2]2nd semestral values.
[3]Calculated from index area annual CPUE.
[4]Calculated from index area 2nd semestral CPUE.
[5]Calculated from core area annual CPUE.
[6]Calculated from core area 2nd semestral CPUE.

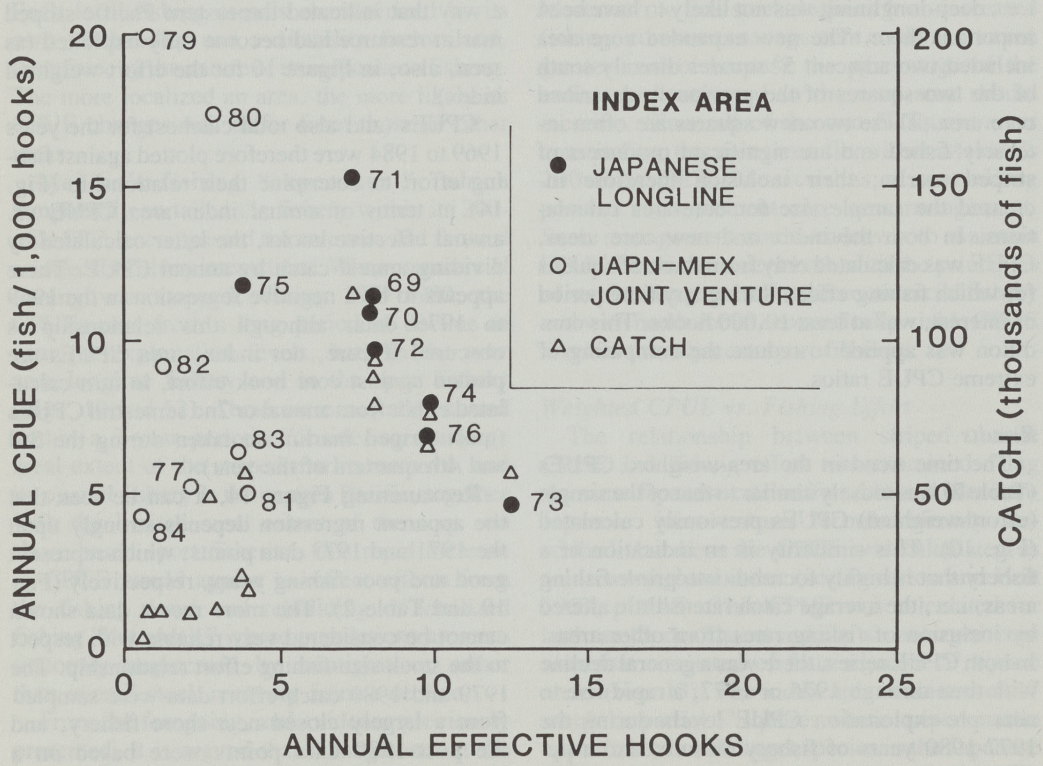

Figure 14. Relationship of index-area annual CPUE and annual catch to annual effective fishing effort. Catch is represented by triangles, annual CPUE by circles.

data appear insufficient to describe the expected negative relationship between CPUE and fishing effort in the eastern Pacific, in spite of the clear time trend of decreasing CPUE off Mexico.

Discussion

The amount of decrease in CPUE that occurred in the core area and elsewhere in the eastern Pacific during the years of active longline fishing was probably due less to declining overall stock than to changes in catchability or availability experienced by the expanding fishery in the localized area. The catch-effort relationship (Fig. 14) suggests little if any slowing of catches with increasing effective effort. Furthermore, a clear increasing trend in effective effort from 1969 to 1976 was lacking in either index or core areas (Table 2).

Catchability/availability changes are likely a function of evolving fishing tactics and of fish behavior. In particular, the rapid rise of CPUE in the small sport and starting-up joint-venture fisheries, after the cessation of longlining in Mexico's EEZ, was likely due to fish populations building up first and quickly in favored localities, which then become the natural focus of any renewed fishing. As these "hot spots" are again fished down, the fishery spreads out to include surrounding larger but lower catchability/availability areas. Overall CPUE thus at first decreases rapidly, then more slowly [such events are predictable from the tenets of optimal foraging theory (see Pyke et al 1977)]. The resulting CPUEs can therefore change rather strikingly with changes in the fishery, but not necessarily as a reflection of changes in overall stock size. Thus, adjacent coastal sport fisheries, located on the inner side of the aggregation area for striped marlin and whose fish are therefore first subjected to an external fishery, are affected (Fig. 15).

The eastern Pacific striped marlin is probably not overexploited. Nevertheless, its catch rates and fishery behavior warrant continual monitoring. This may be accomplished in relatively localized key or core areas where it may also be feasible to implement management measures such as closed seasons or areas, catch limits, etc. Such measures would best be implemented within the context of an international management regime. Lacking that, a coastal state may opt to act unilaterally if, by so doing, it can mitigate declines in the local catch rate. Core-area management off Mexico would recognize

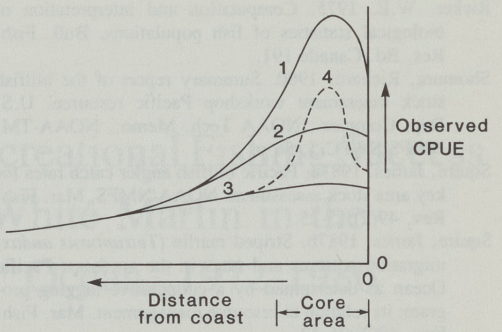

Figure 15. Hypothetical CPUE — distance profile showing effects of increased fishing (curves 1-3), followed by a rebuilding of the stock (curve 4). Catchability/availability is considered to decrease as the stock (CPUE) becomes less concentrated around the peak (peak broadens), which is where rebuilding occurs first.

the importance of areas toward which fish aggregate and that, in such areas, differences in catchability/availability affect fishing tactics and CPUE trends. Quite possibly, and in general, changes in catchability/availability from the fishing down of localized "hot spots" may explain more of the proverbial "good old days" of fishing than the usual "fishing up" explanation (see Ricker 1975, p. 260).

A previous assessment by Bartoo and Ueyanagi (in Shomura 1980), using 1952-1975 data for north, south, and Pacific-wide "stocks," also concluded that there was no evidence for overexploitation. That study treated the entire data series as though it were applicable to a fully exploited stock although, in reality, the fishery had been expanding from west to east in the Pacific, at least up through the mid-1960s.

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Standardized Estimates of Recreational Fishing Success For Blue Marlin and White Marlin in the Western North Atlantic Ocean, 1972-1986

Joan A. Browder and Eric D. Prince

Reliable indices of abundance are important in assessing the status of stocks and determining trends in population size (Cushing 1968). Indices of abundance have not yet been established for blue marlin *(Makaira nigricans)* and white marlin *(Tetrapturus albidus)* in the western north Atlantic Ocean. Most indices of abundance are based upon fishing success (catch rate). To be a reliable indicator, catch rate must be adjusted or "standardized" for the many factors other than abundance that can affect fishing success. Heretofore, only nominal rates of recreational fishing success have been reported for blue marlin and white marlin in the western north Atlantic. Standardized catch rates had not been developed (Prince et al 1989, Beardsley and Conser 1981). In the current study, we used a general linear model (Robson 1966) to standardize recreational catch rates of blue marlin and white marlin for three main factors: region, month, and type of fishing (tournament or non-tournament).

The billfish survey of the Southeast Fisheries Center, National Marine Fisheries Service, was the source of the data. This continuing survey since 1972 provides the longest term and most geographically extensive data on the recreational fishery for blue marlin and white marlin in the western north Atlantic. Catch and effort data are included for areas off the U.S. east coast, the Gulf of Mexico, the Bahamas, and the Caribbean Sea. Beardsley and Conser (1981) described the survey and discussed the potential for obtaining indices of abundance from survey data. A comprehensive review of this survey for 1972-1986, including details of time/area coverage, is presented by Prince et al (1989) elsewhere in this volume.

In our standardization, we combined all data within the range of each species, rather than separately analyzing the data for each region. This approach minimized the possibility that variation in some oceanographic or meteorologic event could distort our standardized catch rates by affecting local availability of the stock to fishing. Because we took this approach, we believe that our standardized catch rates may be valid indicators of stock abundance.

Distribution In The Western North Atlantic

The center of distribution of both blue marlin and white marlin in the western north Atlantic Ocean appears to be the Caribbean Sea. The latitudinal range for each species varies seasonally. The Atlantic range of blue marlin extends from 35°S to 45°N (Rivas 1975). Spawning at different times of the year in the north and south Atlantic suggests that at least two blue marlin populations may be represented. This species normally occurs in waters warmer than 24°C (75°F) but has been found at surface temperatures as high as 30.5°C (87°F) and as low as 21.7°C (71°F). Billfish survey data indicate that recreational catches north of New York are very low, even in summer.

The timing of tournaments suggests that blue marlin are most abundant off the mid-Atlantic coast in the summer, off the east coast of Florida and the Bahamas in the spring, off Puerto Rico and the Virgin Islands in the summer and fall, and off the Florida Keys in the fall. Erdman

(1962) noted that the largest numbers were caught off Puerto Rico during August, September, and October, and the fewest catches were made in December. The fishing season for blue marlin in the northern Gulf of Mexico is April through November (Nakamura and Rivas 1972).

May and June are probable spawning months for blue marlin found in waters off Florida and the Bahamas (de Sylva 1963). Adult fish taken off Cape Hatteras in June appeared to have spawned only a little earlier. In the Caribbean Sea, spawning peaks have occurred in the fall as well as in summer (Yoe 1978).

White marlin are distributed over nearly all of the Atlantic Ocean from latitude 35°S to 45°N, including the Gulf of Mexico and the Caribbean Sea (Mather et al 1975). The species is found at the higher latitudes during warm seasons only. Ueyanagi et al (1970) state that white marlin migrate to subtropical waters to spawn, with peak spawning in early summer. Based on larval collections, de Sylva [recorded in Stephens (1965)] postulated three spawning grounds for white marlin in the western north Atlantic: northeast of the Little Bahama Bank, off Abaco Islands; northwest of Grand Bahama Island and southwest of Bermuda.

Hayasi et al (1970) noted that mature adults appeared in the northern Caribbean Sea and off Florida from April through June. When the Japanese longline fleet was allowed to fish in the Gulf of Mexico, their peak catches during the summer were there and in the northern Caribbean Sea (Mather et al 1972). Based on Japanese longline and recreational fishing information, Mather et al (1975) concluded that the most important inshore concentrations in summer and early fall are on and near the edges of the continental shelf in the northern Gulf of Mexico and off the northeast U.S. coast from Cape Hatteras, North Carolina, to Cape Cod, Massachusetts. Gibbs (1957) noted summer concentrations off the Mississippi Delta that dispersed when the waters cooled in fall. He found another important concentration in the DeSoto Canyon area of the northeastern Gulf of Mexico.

White marlin are available to the sport fisheries in the Gulf of Mexico from early June into October, with peak abundance off the delta in July and at the DeSoto Canyon in August (Mather et al 1975). The northeastern limit of the usual summer coastal occurrence of white marlin is off Nantucket Island, south of eastern Cape Cod. Spring is the peak season for sport fishing for white marlin in the Straits of Florida and the Bahamas. This period also is the most productive for white marlin off Puerto Rico, the Virgin Islands, and the Dominican Republic.

Methods

Description of the Original Data

The survey data set contained the following information relevant to this analysis: (1) number of vessels fishing each day, including those not catching any fish, (2) number of fish of each species hooked by each vessel each day, (3) number of fish of each species caught by each vessel each day, (4) number of hours fished by each vessel on each day, (5) number of hours of fighting time, (6) average wave crest height, and (7) cloud cover. "Hooked" includes those billfish that could be identified but got away. "Caught" includes billfish that were released as well as those retained. The survey records are contained in 15 data files, one for each year, and are in the form of a separate record for each fish.

The data originated from two types of sampling: tournament coverage and port sampling (nontournament). Beardsley and Conser (1981) found significant differences in fishing success from these two types of sampling in the Gulf of Mexico, suggesting that stratification of the data into the two sampling types is warranted. Tournaments covered by the survey are of four types: blue marlin, white marlin, marlin, billfish, and sailfish tournaments. Sailfish tournaments are distinctly different from the others, both in bait used and depths fished, as well as species caught. Fishing occurs closer to shore, live bait is used, and billfish species other than sailfish are seldom caught. Therefore, sailfish tournaments were excluded from our analysis.

We evaluated the need for stratifying the remaining data according to type of tournament, since larger baits and heavier lines are often used for blue marlin. We found that the name given to a tournament — i.e., blue marlin, white marlin, or billfish — does not appear to determine which species are caught. For instance, slightly more white marlin than blue marlin were caught in the Hatteras Blue Marlin Tournament during the years surveyed (Table 1). On the other hand, a much larger number of white marlin than blue marlin were caught in the Pensacola International Billfish Tournament. The Hatteras Blue Marlin Tournament and Pensacola International Billfish Tournament were chosen for

Table 1. Total number hooked and caught, percent lost, and dispostion of catch (boated or released), by species, at two major tournaments sampled by the NMFS billfish surveys: Hatteras Blue Marlin Tournament (1973-1985 and 1988), Pensacola International Billfish Tournament (1972-1987).

Species	Number Hooked	Number Caught	Number Boated	Number Released	Number Lost	Percent Released	Percent Lost
Hatteras							
BM	506	238	236	2	268	0.84	53
WM	387	242	78	164	145	67.77	37
Pensacola							
BM	371	147	141	6	224	4.08	60
WM	889	503	483	20	386	3.98	43
SF	146	96	94	2	50	2.08	34

BM = Blue Marlin; WM = White Marlin; SF = Sailfish.

representation in Table 1 because of their names, their locations, and the number of years they were covered by the NMFS surveys. In locations where the ranges of both marlins species overlap — as is the case with both of these tournaments — both species are usually caught. The name of the tournament is often arbitrary and can vary from year to year. The tournament name appears to have more to do with the awards that are emphasized than with the species caught.

One might think that a larger number of white marlin might be lost (after being hooked) at the blue marlin tournament, where larger hooks may be used. Table 1 indicates, however, that approximately the same percentage of white marlin hooked are lost at both tournaments. At the Pensacola International Billfish tournament, where white marlin dominate the catches, the percentage of blue marlin lost after being hooked is similar to that at the Hatteras Blue Marlin Tournament. We determined that it is not necessary to distinguish between tournaments on the basis of their names.

Port samplers attempt to interview every angler they see, but likely miss some because sampling is not continuous and several docks may be visited by the same angler on the same day. Port sampling is not specific as to species, but rather to billfishes in general, and the target species of the angler is not recorded. Stratification of port data by target species is neither necessary nor possible.

Preparation of the Data

The first working data set was constructed from the survey file by combining the original "per fish" records (one for each fish) into a record for each trip. After preliminary analysis, a second working data set was constructed from the first by combining all the trips for the same sampling-event day (tournament day or post-sampling day) into a single record containing total numbers of fish and hours from all the trips. All 15 years examined were combined into one working file for each species.

The data sets were refined by eliminating, (1) tournaments and locations where sailfish was the principal target or live bait the principal bait, (2) locations with few records (fewer than about 60), and (3) months with few records. Records from the lower east coast of Florida were excluded by these criteria; as were records from St. Petersburg, Florida; Mississippi; and Cozumel, Mexico. The New England area was excluded from the blue marlin analysis because blue marlin are seldom caught there, but was included in the white marlin analysis. The months excluded from the analysis were November, December, January, and February, which had 373, 51, 23, and 122 records, respectively. The data set for white marlin included 94,547 trips, while that for blue marlin included 94,294 trips.

For the analysis, we defined six geographical areas on the basis of the known seasonal-area characteristics of the recreational fisheries for these species: (1) New England (white marlin) or New York to Beaufort, North Carolina (blue marlin); (2) South Carolina to Daytona, Florida; (3) Florida Keys; (4) Bahamas; (5) Caribbean; and (6) Gulf of Mexico. The eight months from March through October were included in the final data set. Two types of sampling were defined: (1) non-tournament sampling, and (2) tournament sampling. Table 2 shows the number of records in each sample-type-area-month stratum.

Data Analysis

We separately standardized both hooked-per-unit-effort (HPUE) and number caught-per-unit-effort (CPUE). Our effort unit was "effective

Table 2. Distribution (total number) of original records in blue marlin file by month, sample type, and area, 1972-1986.

Month	Sample Type	Area 1 NY-NC	2 SC-Day	3 FL Keys	4 Bahamas	5 Carib	6 GOM
All	1 Port	6,342	0	0	0	927	17,986
	2 Tourn.	9,773	2,545	2,406	18,776	7,606	27,922
3 March	1 Port	0	0	0	0	58	38
	2 Tourn.	0	0	0	3,591	0	0
4 April	1 Port	0	0	0	0	30	245
	2 Tourn.	0	4	0	5,489	0	25
5 May	1 Port	164	0	0	0	45	1,736
	2 Tourn.	27	2,032	291	3,229	223	1,709
6 June	1 Port	783	0	0	0	100	3,117
	2 Tourn.	3,497	177	0	3,221	2,023	6,315
7 July	1 Port	2,302	0	0	0	222	4,362
	2 Tourn.	2,304	0	72	3,226	688	9,436
8 Aug	1 Port	2,055	0	0	0	318	4,113
	2 Tourn.	2,422	0	0	20	1,312	6,341
9 Sept.	1 Port	932	0	0	0	103	2,696
	2 Tourn.	1,523	332	0	0	2,148	3,289
10 Oct.	1 Port	106	0	0	0	51	1,679
	2 Tourn.	0	0	2,043	0	1,212	807

NY-NC = New York to North Carolina; SC-Day = South Carolina to Daytona; FL Keys = Florida Keys; GOM = Gulf of Mexico.

fishing time" in hours, defined as the number of hours of trolling, minus fighting time. According to Beardsley and Conser (1981), HPUE may be a more reliable indicator of abundance than CPUE in recreational fisheries for billfishes, because the weight of the fishing line, which varies among tournaments and among individuals, affects the proportion of billfish that, once hooked, are actually boated. It is possible to identify the species hooked, even when it is not boated, because almost all billfish jump out of the water when hooked.

In an approach similar to that of Robson (1966), Farber (1986), Turner (1986), and others, a general linear model (GLM) was developed to distinguish variation in catch rates among years by holding constant three other main sources of variation — sample type, area, and month. Limitations of our analysis system placed constraints on the number of factors we were able to examine. Our knowlege of the fishery suggested that these would be the most important. Prior knowledge of the fishery suggested that type of bait would be a relatively unimportant factor, as long as live-bait samples were excluded.

A regression model was constructed in which a dummy variable represented each alternative of the four parameters — type, area, month, and year. Additional dummy variables were assigned to represent each alternative of two-way interactions between area and type and area and month. One standard for each sample type, area, month, and year was defined, and dummies for the main effects of these standards and their two-way interactions were purposely omitted from the model, a requisite of this procedure. Interactions of year with other parameters were purposely excluded from the model in order that the year effect could be used to calculate the standardized value. In the analysis, each dummy variable was set equal to one or zero, depending on whether a record was from the sample type, area, month, or year represented by that particular dummy variable. The regression analysis produced a regression coefficient for each dummy variable.

The generalized predictor equation, which assumed a log-linear relationship between the dependent variable and the several dummy variables, was as follows:

$$\ln(M\ Y_{hat} + 1) = B_o + \text{sum}(B_t D_t) + \text{sum}(B_a D_a) + \text{sum}(B_m D_m) + \text{sum}(B_y D_y) + \text{sum}(B_{at} D_{at}) + \text{sum}(B_{am} D_{am}) \quad (1)$$

where Y_{hat} = prediction of relative abundance
D_t = dummy variables for type $t = 1, 2$
D_a = dummy variables for area $a = 1,\ldots,6$
D_m = dummy variables for month $m = 3,\ldots,10$
D_{at} = dummies for area-type
D_{am} = dummies for area-month
B_o is the constant and the B vectors are the regression coefficients for the variants of each factor. Only one condition of each factor can be met by each situation; therefore, for each prediction of the dependent variable (Y_{hat}), only one regression coefficient for each factor parameter is "turned on" (i.e., multiplied by $D = 1$ rather than $D = 0$).

Standardized HPUE or CPUE (Y_{hat-y}) is calculated from the regression constant and the regression coefficient of the dummy variable for each year, as follows:

$$Y_{hat-y} = [[e\ (B_o + \text{sum}\ (B_y D_y))] - 1] / M \quad (2)$$

As this equation indicates, the effect of each year on the dependent variable is the sum of the constant and the regression coefficient for that year. Y_{hat-y} is a "standardized" estimate of HPUE or CPUE because factors other than year are held constant. A time series of estimates for each year indicates the annual variation in the data.

Ninety percent confidence limits around Y_{hat-y} were calculated on the basis of the variance of B_o and of each B_y and the covariance of B_o and B_y. The covariance of B_o and each B_y, when not directly available from statistics output, can be calculated as:

$$\text{Covar}\ (B_o B_y = -\text{Mean}\ (D_{yn})\ \text{Var}\ (B_y \quad (3)$$

where D_{yn} is the vector of values of a specific year dummy variable.

The original model consisted of the following main effects and interactions: sample type, area, month, year, area × sample type, and area × month. The standards selected for the model were: sample type = tournament, area = Gulf of Mexico, month = August, and year = 1983. The final model included the following: sample type, area-1 × type-1, area-5 × type-1, and area × month for all area × month interactions in the model. The same model design was used for all four dependent variables (blue marlin HPUE and CPUE and white marlin HPUE and CPUE.

This model, when applied to the first working data set, which consisted of a record for each trip, explained only 3.7% of the variation in the number of blue marlin HPUE. An analysis of resulting residuals indicated that their distribution departed greatly from a normal distribution (Fig. 1A).

A second working data set, in which the data

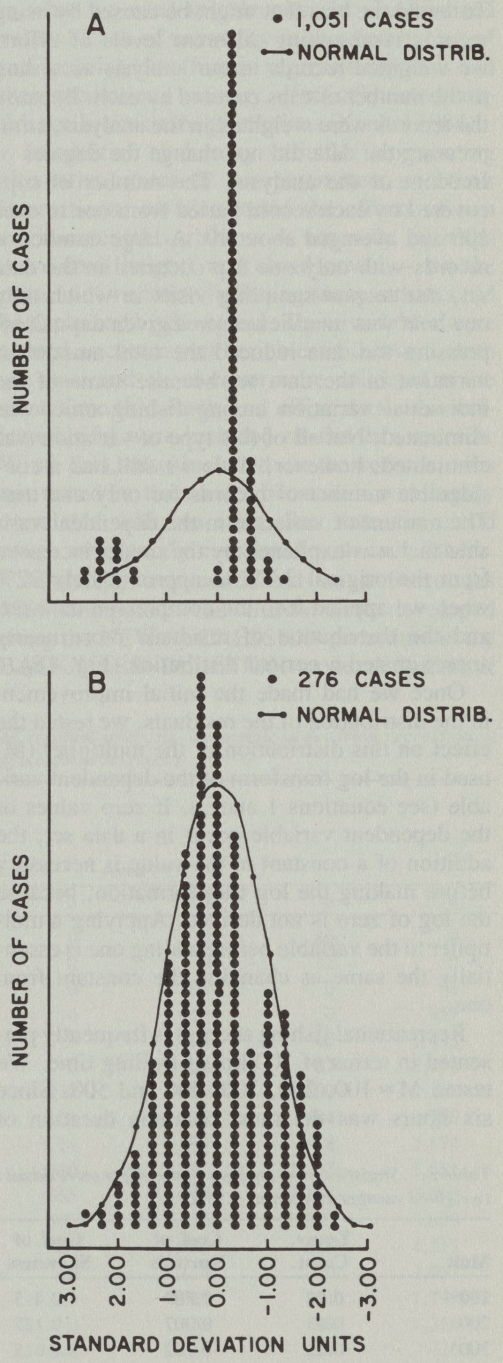


Figure 1. Distribution of standardized residuals from regression of blue marlin HPUE on dummy variables, using "trip" records (A) and "day" records (B).

were compressed into a record for each sampling-event day, was created in an attempt to improve the fit of the residuals to the normal distribution. To avoid the bias that might be caused by using records representing different levels of effort, we weighted records in our analysis according to the number of trips covered by each. Because the records were weighted in the analysis, compressing the data did not change the degrees of freedom of the analysis. The number of trips covered by each record varied from one to over 100 and averaged about 10. A large number of records with only one trip occurred in the data set, due to port-sampling visits in which only one boat was interviewed on a given day. Compressing the data reduced the total amount of variation in the data set because some of the individual variation among fishing units was eliminated. Not all of this type of variation was eliminated, however, since we still had a considerable number of records for only one trip. The amount of variation in the dependent variable that was explained by the model increased from the original 3.7% to approximately 22% when we applied it to the compressed data set, and the distribution of residuals more nearly approximated a normal distibution (Fig. 1B).

Once we had made the initial improvement in the distribution of the residuals, we tested the effect on this distribution of the multiplier (M) used in the log transform of the dependent variable (see equations 1 and 2). If zero values of the dependent variable occur in a data set, the addition of a constant to the value is necessary before making the log transformation, because the log of zero is not defined. Applying a multiplier to the variable before adding one is essentially the same as changing the constant from one.

Recreational fishing success is frequently presented in terms of 100 hrs of trolling time. We tested M = 100, 200, 300, 400 and 500. Since six hours was the most common duration of trolling during each trip, using these multipliers was analagous to changing the constant from one to: 0.06 (M = 100), 0.03 (M = 200), 0.02 (M = 300), 0.015 (M = 400), and 0.012 (M = 500). We selected the M that minimized the sum of the absolute values of the coefficients of skewness (g_1) and kurtosis (g_2), as suggested by Berry (1987) for improving the fit of the data to a normal distribution. A minimum was reached at M = 300, when $g_1 = ...0.015$ and $g_2 = 0.162$ (Table 3). This is equivalent to adding a constant of 0.02 to the data after multiplying by six.

Although histograms such as that shown in Figure 1B suggested that the residuals from the final models were normally distributed, they did not satisfy the Kolmogorov-Smirnoff criteria of normality ($P<0.001$); therefore, we conducted a detailed analysis of the residuals from the blue marlin regression to determine whether their fit to a normal distribution could be improved by eliminating groups of data. Residuals were grouped according to sample type, area, or month; and the distibution of weighted residuals within each group was examined (Tables 4, 5, and 6). Residuals were then grouped, first by the number of trips represented by the record (Table 7) or by the number hooked per record (Table 8).

Certain groups displaying obviously abberant distributions relative to the normal distribution expected for the complete set of residuals were excluded from the data set, one group at a time, and a separate regression analysis was performed on the remaining residuals. The following eliminations were made: (1) type 1 (port samples); (2) area 1 (New York to Beaufort, N.C.); (3) records representing less than 10 trips; (4) records representing less than 20 trips; and (5) records in which no blue marlin were hooked (the zero records).

As indicated in Table 9, none of these eliminations improved the fit of the residuals to the

Table 3. Statistics from analysis of the effect on residual distribution of changing the multiplier in the dependent variable (weighted number of records = 94,294).

Mult	Equiv. Const.	Coef. of Kurtosis	Coef. of Skewness	Sum of 1 & 2	K-S Z	R^2	F-stat	Mean SS
100	**0.06**	**0.889**	0.415	1.304	9.71	0.2137	502	0.4134
200	0.03	0.307	0.127	0.434	10.85	0.2180	516	0.6762
300	0.02	0.162	−0.015	0.177	15.39	0.2203	522	0.8698
400	0.015	0.111	−0.105	0.216	18.79	0.2218	527	1.0259
500	0.012	0.092	−0.169	0.261	21.42	0.2228	530	1.1582

Note: weighted number of records = 94,294.

Table 4. Distribution of weighted records within standardized residual intervals, by sample type, from regression of blue marlin HPUE on dummy variables. (Values are number of weighted records.)

Limits of Interval in Standard Deviation Units		Sample Type	
Lower	Upper	1	2
−9.99	−3.00	60	20
−3.00	−2.67	12	0
−2.67	−2.33	0	216
−2.33	−2.00	237	1,646
−2.00	−1.67	800	1,726
−1.67	−1.33	5,798	250
−1.33	−1.00	3,482	3,791
−1.00	−0.67	1,014	4,454
−0.67	−0.33	255	6,452
−0.33	0.00	595	12,903
0.00	0.33	1,233	13,528
0.33	0.67	1,758	11,828
0.67	1.00	2,139	6,547
1.00	1.33	2,616	3,719
1.33	1.67	1,922	1,318
1.67	2.00	1,469	429
2.00	2.33	903	107
2.33	2.67	481	54
2.67	3.00	275	33
3.00	9.99	212	12

normal distribution; in fact, the opposite was true. Therefore, the complete data base seemed preferable to any of these alternatives, and this is what we used to calcualte our standardized values. Lack of normality in the distribution of residuals has no effect on regression models and their predictions but may affect calculated confidence limits on the predictions (Kenkel 1984).

In addition to dummy variables representing alternative states of our parameters and their interactions, we also tested the effects of two environmental variables — sea state (average wave-crest height) and cloud cover — on the percent of variation in fishing success that could be explained by the model. These variables were treated as continuous variables in this test. Both sea state and cloud cover were collected at the same time that catch and effort data were collected, and were included on the data records. Wind data, also included on the records, was not tested in the model because it was highly correlated with sea state. Sea state and cloud cover were poorly correlated with each other.

Modeling was conducted on a Burroughs 6800 computer. The GLMs were developed using the NEW REGRESSION procedure in the BACKWARD DELETION mode of Statistical

Table 5. Distribution of weighted records within standardized residual intervals, by sample area, from regression of blue marlin HPUE on dummy variables. (Values are number of weighted records.)

Limits of Interval in Standard Deviation Units		Area					
Lower	Upper	1	2	3	4	5	6
−9.99	−3.00	0	0	0	0	80	0
−3.00	−2.67	0	0	0	0	12	0
−2.67	−2.33	0	43	0	105	0	68
−2.33	−2.00	432	25	0	469	0	957
−2.00	−1.67	16	23	9	1,005	40	1,433
−1.67	−1.33	0	95	0	128	67	5,758
−1.33	−1.00	3,886	103	232	390	400	2,262
−1.00	−0.67	1,719	228	64	1,175	484	1,798
−0.67	−0.33	683	351	24	1,897	878	2,874
−0.33	0.00	1,063	357	830	3,230	2,337	5,681
0.00	0.33	1,493	241	555	3,215	2,164	7,093
0.33	0.67	2,053	524	507	3,576	897	6,029
0.67	1.00	1,577	269	162	1,775	586	4,317
1.00	1.33	1,565	232	0	1,174	307	3,057
1.33	1.67	834	42	23	422	121	1,798
1.67	2.00	385	12	0	188	97	1,216
2.00	2.33	227	0	0	27	30	726
2.33	2.67	105	0	0	0	28	402
2.67	3.00	38	0	0	2	2	266
3.00	9.99	44	0	0	0	3	177

Table 6. Distribution of weighted records within standardized residual intervals, by months, from regression of blue marlin HPUE on dummy variables. (Values are number of weighted records.)

Limits of Interval in Standard Deviation Units		Month							
Lower	Upper	3	4	5	6	7	8	9	10
−9.99	−3.00	0	0	0	3	8	44	9	16
−3.00	−2.67	0	0	0	12	0	0	0	0
−2.67	−2.33	0	0	43	68	105	0	0	0
−2.33	−2.00	0	126	234	629	563	134	159	38
−2.00	−1.67	352	343	292	870	296	232	92	49
−1.67	−1.33	0	79	833	605	1,594	1,080	1,104	753
−1.33	−1.00	73	222	461	189	1,981	2,839	1,119	389
−1.00	−0.67	396	367	469	1,317	1,868	801	202	48
−0.67	−0.33	450	351	609	2,061	1,218	1,136	616	266
−0.33	0.00	516	1,199	1,390	2,898	2,530	1,685	1,948	1,332
0.00	0.33	487	859	1,172	3,675	3,683	2,252	1,760	873
0.33	0.67	668	1,107	1,564	3,052	3,051	2,029	1,266	849
0.67	1.00	219	614	1,041	1,595	2,177	1,374	1,086	580
1.00	1.33	258	302	779	1,003	1,759	1,148	842	244
1.33	1.67	166	120	189	648	730	765	419	203
1.67	2.00	81	39	157	300	502	509	179	131
2.00	2.33	13	29	93	172	241	313	99	50
2.33	2.67	0	19	47	77	171	141	53	27
2.67	3.00	2	9	46	44	61	60	47	39
3.00	9.99	7	11	35	22	74	41	23	11

Table 7. Distribution of weighted records within standardized residual intervals, by number of trips in record, from regression of blue marlin HPUE on dummy variables. (Values are number of weighted records.)

Limits of Interval in Standard Deviation Units		Number of Trips							
Lower	Upper	1	1-9	10-19	20-29	30-39	40-49	50-59	> = 60
−9.99	−3.00	18	32	10	20	0	0	0	0
−3.00	−2.67	5	7	0	0	0	0	0	0
−2.67	−2.33	2	29	104	43	38	0	0	0
−2.33	−2.00	41	592	684	374	138	0	54	0
−2.00	−1.67	217	951	832	358	168	0	0	0
−1.67	−1.33	1,283	3,974	513	97	30	41	110	0
−1.33	−1.00	447	2,414	1,463	931	539	434	506	539
−1.00	−0.67	77	535	848	1,158	736	809	323	982
−0.67	−0.33	5	105	1,114	1,206	1,392	1,189	390	1,306
−0.33	0.00	4	271	1,453	1,948	2,335	1,963	1,069	4,455
0.00	0.33	4	578	1,982	2,606	2,690	1,679	1,642	3,530
0.33	0.67	4	933	2,534	2,619	2,685	2,122	530	2,159
0.67	1.00	17	1,297	2,111	1,383	1,396	785	265	1,432
1.00	1.33	8	1,481	1,797	1,048	769	576	326	330
1.33	1.67	18	1,460	1,032	363	134	128	105	0
1.67	2.00	29	1,051	542	89	104	83	0	0
2.00	2.33	96	675	153	86	0	0	0	0
2.33	2.67	141	343	25	26	0	0	0	0
2.67	3.00	125	183	0	0	0	0	0	0
3.00	9.99	131	77	16	0	0	0	0	0

Table 8. Distribution of weighted records within standardized residual intervals, by number of blue marlin hooked, from regression of blue marlin HPUE on dummy variables. (Values are number of weighted records.)

Limits of Interval in Standard Deviation Units		Number Hooked							
Lower	Upper	0	1	2	3	4	5	6	>=7
−9.99	−3.00	80	0	0	0	0	0	0	0
−3.00	−2.67	12	0	0	0	0	0	0	0
−2.67	−2.33	216	0	0	0	0	0	0	0
−2.33	−2.00	1,883	0	0	0	0	0	0	0
−2.00	−1.67	2,486	10	30	0	0	0	0	0
−1.67	−1.33	5,790	186	19	53	0	0	0	0
−1.33	−1.00	5,538	827	556	20	61	43	0	228
−1.00	−0.67	1,232	1,369	1,113	613	420	180	171	370
−0.67	−0.33	76	1,292	1,289	973	906	178	460	1,533
−0.33	0.00	57	1,156	1,463	1,425	941	1,124	1,003	6,329
0.00	0.33	34	1,394	942	1,070	1,070	741	1,017	8,493
0.33	0.67	0	1,459	966	961	920	1,065	688	7,527
0.67	1.00	0	1,077	949	301	637	502	406	4,814
1.00	1.33	0	872	827	473	313	565	299	2,986
1.33	1.67	0	548	539	490	308	200	123	1,032
1.67	2.00	0	409	267	226	217	185	61	533
2.00	2.33	0	248	171	155	86	63	76	211
2.33	2.67	0	178	78	69	50	53	17	90
2.67	3.00	0	121	82	37	24	13	30	1
3.00	9.99	0	88	52	28	19	7	5	25

Table 9. Statistics from analysis of the effect on residual distribution of excluding subsets of data for which the distribution of residuals was highly non-normal.

Group Excluded	Weighted Number Records	Coef. of Kurtosis	Coef. of Skewness	Sum of Abs. Val. 1 & 2	K-S Z	R^2	F-stat	Mean SS
None	94,294	0.162	−0.015	0.177	15.39	0.2203	522	0.8698
<10 trips	74,634	0.653	−0.582	1.235	17.11	0.2554	544	0.5467
<20 trips	57,421	0.973	−0.556	1.529	10.62	0.2914	536	0.4001
# hooked = 0	76,890	0.760	0.246	1.006	6.58	0.2543	535	0.3516
Type 1	69,033	0.859	−0.579	1.438	17.51	0.2651	566	0.5466
Area 1	78,174	0.375	−0.079	0.454	19.37	0.1836	399	0.8475

Package for the Social Sciences (SPSS, Hull and Nie 1981).

Results

Table 10 indicates the adjusted R^2 values and other statistics of various alternative models for each of the four dependent variables. Generally speaking, the models for white marlin explained about twice as much of the variation in their dependent variables as did the models for blue marlin. Although sea state and cloud cover were indicated to be highly significant ($P<0.0001$) independent variables in blue marlin models, the models that included these variables explained little more of the variation in fishing success than models without them. For instance, the model with sea state explained only 0.2% more of the variation in blue marlin hooked-per-unit effort than the model without this variable. The model with both sea state and cloud cover explained only 0.5% more of the variation in blue marlin hooked-per-unit effort than models without these two variables. Although sea state was a highly significant ($P<0.0001$) variable when added to the white marlin models, cloud cover was not.

The standardized values of HPUE and CPUE resulting from the model are plotted by year in Figures 2 and 3. Indices are reported as base numbers rather than logs; retransformation was

Table 10. Statistics of the four basic models and alternative models containing environmental variables.

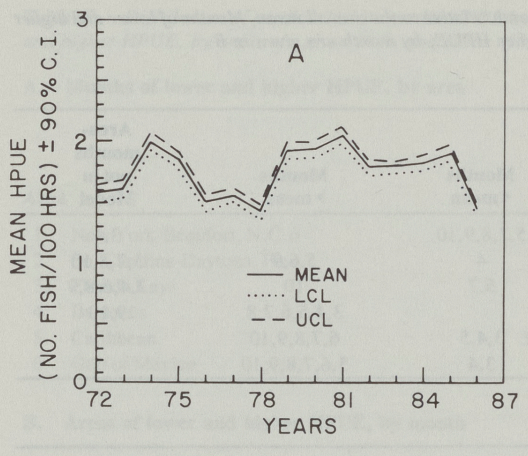
Group Excluded	Weighted Number Records	Coef. of Kurtosis	Coef. of Skewness	Sum of Abs. Val. 1 & 2	Adj. K-S Z	R^2	F-stat	Mean SS
Blue Marlin Hooked								
Dummies only	94,294	0.162	−0.015	0.177	15.39	0.2199	522	0.8698
Dummies & sea		0.169	−0.010	0.179	14.96	0.2219	518	0.8675
Dummies, sea, and sky		0.185	−0.005	0.190	15.31	0.2246	513	0.8650
Blue Marlin Caught								
Dummies only		0.503	0.511	1.014	21.28	0.2255	539	0.8097
White Marlin Hooked								
Dummies only	94,547	0.360	−0.157	0.517	14.76	0.4342	1,423	1.1593
Dummies & sea		0.363	−0.158	0.521	15.28	0.4354	1,402	1.1573
White Marlin Caught								
Dummies only	94,547	0.440	0.109	0.549	11.80	0.4061	1,269	1.1354

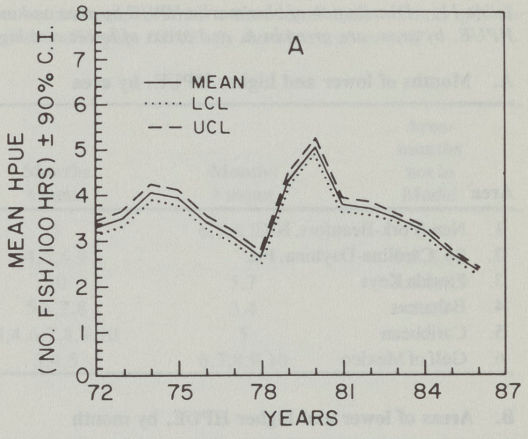
accomplished by taking the exponent of the sum of the regression coefficient and the constant, then subtracting one, and then dividing by three. Division was by three rather than 300 so that the index could be reported in terms of 100 hrs of trolling. The pattern of variation in HPUE and CPUE was similar within both species. A feature common to three of the plots — white marlin HPUE and CPUE and blue marlin HPUE — is a minimum in 1978; blue marlin CPUE is lower in 1976 than in 1978. White marlin HPUE and CPUE reach their maxima in 1980, whereas blue marlin HPUE and CPUE reach their maxima in 1981. A persistent decline after 1980 is evident in white marlin HPUE and CPUE; whereas a decline from 1981 to 1982 was followed by years of stability in blue marlin HPUE and a slight increase in blue marlin CPUE, followed by a decline from 1985 to 1986. Estimated 90% confidence limits around the values are shown but may not be accurate because our residuals were not quite normally distributed.

Predictions of HPUE based on area-month interactions and holding-"year"-effects constant were used to examine seasonality within areas and to compare HPUE in the various areas within months. In Table 11A, the months in which blue marlin HPUE was *lower* than an overall mean, estimated from all the area-month interactions, are listed by area in the *first* column; months in which it was *higher* than the mean are listed in the *second* column. Area-months excluded from the program because of lack of data (empty cells) or for certain other reasons are listed in the final column. In Table 11B, the areas in which blue marlin HPUE was lower than the overall mean are listed by month in the first column. Areas in which blue marlin HPUE was higher than the overall mean are listed in the second column. Areas excluded from the program are listed by month in the final column. The same information is given for white marlin HPUE in Table 12.

The period of higher-than-average blue marlin HPUE is limited to one month in the area from New York to Beaufort. Early summer and fall (May, June, and September) are the months of greater than average HPUE in the area from South Carolina to Daytona. October HPUE in the Florida Keys is higher than the average; October is the only month when blue marlin tournaments are scheduled in the Keys. Higher-than-average blue marlin HPUE occurs from March through August in the Bahamas, June through October in the Caribbean, and May through October in the Gulf of Mexico. Clearly, the Caribbean, the Bahamas, and the Gulf of Mexico are the principal areas of the blue marlin fishery in the western north Atlantic. Our modeling results indicate that HPUE is higher than average in these three areas during most months sampled.

Model predictions suggest that the seasonality and centers of interest of the white marlin fishery are somewhat different from those of the blue marlin (Table 12A). The northeast, which includes New England, is an area of higher than





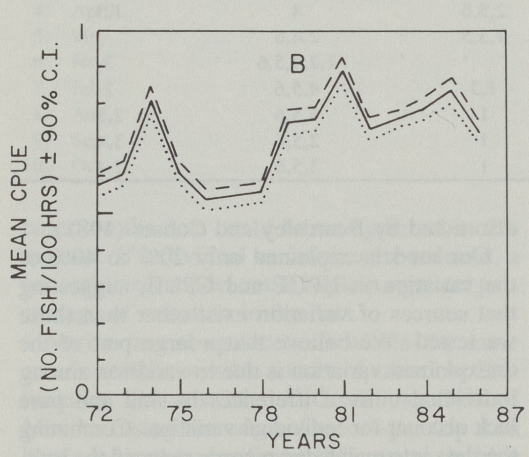


Figure 2. Standardized number of blue marlin hooked (A) and caught (B) per 100 hrs of fishing, by year, based on data from all six areas. Estimated 90% confidence limits are included.

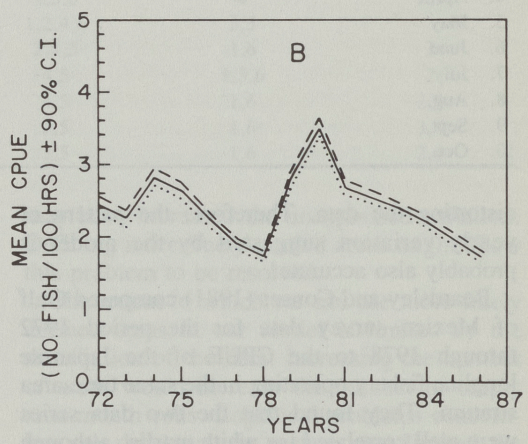


Figure 3. Standardized number of white marlin hooked (A) and caught (B) per 100 hrs of fishing, by year, based on data from all six areas. Estimated 90% confidence limits are included.

average HPUE from June through October. White marlin HPUE is below average in the area from South Carolina to Daytona in all months sampled. Above average HPUE is found in May and July in the Florida Keys and in March and April in the Bahamas. May is the month of above average white marlin HPUE in the Caribbean. June through October are months of above average white marlin HPUE in the Gulf of Mexico. The northeast, including New England, and the Gulf of Mexico are indicated as the only two areas of consistently high white marlin HPUE for several months (Table 12).

Discussion

Modeling results indicate seasonal and areal differences in fishing success for blue marlin and white marlin and separate areal-seasonal patterns for the two species. Some aspects of the seasonal and areal patterns indicated by the model are reasonable to those familiar with the fishery and are similar to those described by Prince et al (1989) in an independent examination of the same data. This agreement between the model's perception of seasonal and areal variation in fishing success and what is known about the fishery suggests that the model is not

Table 11. Distribution of blue marlin HPUE by area and month relative to the overall mean. Months of lower and higher HPUE, by area, are given in A, and areas of lower and higher HPUE, by month are given in B.

A. Months of lower and higher HPUE, by area

Area	Months < mean	Months > mean	Area-months not in Model
1. New York-Beaufort, N.C.	5,7,8,9,10	6	3,4
2. So. Carolina-Daytona, Fla.	4	5,6,9	3,7,8,10
3. Florida Keys	5,7	10	3,4,6,8,9
4. Bahamas		3,4,5,6,7,8	9,10
5. Caribbean	3,4,5	6,7,8,9,10	
6. Gulf of Mexico	3,4	5,6,7,8,9,10	

B. Areas of lower and higher HPUE, by month

Month	Areas < mean	Areas > mean	Area-months not in Model
3. March	5,6	4	1,2,3
4. April	2,5,6	4	1,3
5. May	1,3,5	2,4,6	
6. June		1,2,4,5,6	3
7. July	1,3	4,5,6	2
8. Aug.	1	4,5,6	2,3
9. Sept.	1	2,5,6	3,4
10. Oct.	1	3,5,6	2,4

distorting the data. Therefore, the pattern of yearly variation suggested by the model is probably also accurate.

Beardsley and Conser (1981) compared Gulf of Mexico survey data for the period 1972 through 1978 to the CPUE of the Japanese longline fishery operating in the same time-area stratum. They found that the two data series were well correlated for white marlin, although not for blue marlin. They concluded, because the two independent sources of data for white marlin displayed the same trend, that the trend reflected a similar time-area specific availability of the population to fishing. This type of question is difficult to resolve, particularly for far-ranging, relatively rare, non-schooling species such as billfishes. Nevertheless, Beardsley and Conser's (1981) results provide support for the use of NMFS recreational billfish survey data from the western north Atlantic in developing abundance indices.

Our standardized values of HPUE and CPUE suggest that white marlin abundance declined from 1975 through 1978, increased from 1979 through 1980, and decreased from 1981 through 1986. A decrease from 1976 through 1978 was also noted by Beardsley and Conser (1981).

Our models explained only 20% to 40% of the variation in HPUE and CPUE, suggesting that sources of variation exist other than those we tested. We believe that a large part of the unexplained variation is due to variation among individual units. Differences in skill and pure luck account for individual variation. Combining the data into event-day records reduced the individual variation but did not eliminate it entirely because 2,672 records in our compressed blue marlin data set (approximately 10% of total records) represented individual trips; apparently, only one trip was sampled on some days at some locations. A total of 16,988 records represented fewer than 10 trips but more than one trip.

A tournament-day makes a useful sampling unit, because individual variation is almost eliminated. The individual variation in non-tournament records could be reduced if sampling strategy were revised to maximize the number of individual fishing units sampled in a given day, even if fewer days were covered. In future coverage, it might be possible to improve the number of intercepts per day by covering ports on weekends rather than on weekdays. Analyses

Table 12. Distribution of predicted white marlin HPUE by area and month relative to the overall mean. Months of lower and higher HPUE, by area, are given in A, and areas of lower and higher HPUE, by month are given in B.

A. Months of lower and higher HPUE, by area

Area	Months < mean	Months > mean	Area-months not in Model
1. New York-Beaufort, N.C.	5	6,7,8,9,10	3,4
2. So. Carolina-Daytona, Fla.	4,5,6,9		3,7,8,10
3. Florida Keys	10	5,7	3,4,6,8,9
4. Bahamas	5,6,7,8	3,4	9,10
5. Caribbean	3,4,6,7,8,9,10	5	
6. Gulf of Mexico	3,4,5	6,7,8,9,10	

B. Areas of lower and higher HPUE, by month

Month	Areas < mean	Areas > mean	Area-months not in Model
3. March	5,6	4	1,2,3
4. April	2,5,6	4	1,3
5. May	1,2,4,6	3,5	
6. June	2,4,5	1,6	3
7. July	4,5	1,3,6	2
8. Aug.	4,5	1,6	2,3
9. Sept.	2,5	1,6	3,4
10. Oct.	3,5	1,6	2,4

based on the data could be strengthened in this manner. If individual variation were reduced, a general linear model could explain a greater percentage of variation in the data.

Variation among locations within the same area is another possible source of variation. Preliminary analysis of data from the Gulf of Mexico (using the original record-per-trip data base) indicated significant differences in blue marlin HPUE among locations. For instance, over the 15-yr period, HPUE at Galveston was significantly higher than anywhere else in the Gulf ($P<0.05$). Some of the variation in the data might be explained by separating the data into more finely-graded areas. Our preliminary analysis suggested, although differences among locations were significant, that the percent of variation in blue marlin HPUE explainable by locational differences was fairly small.

Just as we did, Beardsley and Conser (1981) found significant differences in blue marlin (HPUE) between non-tournament and tournament sampling. They also noted that the differences between the two varied among locations within the Gulf of Mexico. This change within what we considered in our model as one area may have increased the unexplained variation. Defining more finely-graded areas might allow this problem to be resolved.

The extent to which we can use more finely defined areas in our model is limited by the distribution of the data. Increasing the number of areas would increase the number of empty area-month cells. Logistical problems concerning our data analysis system also limited the extent to which areas could be subdivided. The size of the matrices that must be manipulated in regression analysis increases as the square of the number of variables. As we define the GLM, each two-way interaction is a variable; thus, as the number of variants of any one factor is increased, the matrices can quickly become unmanageably large.

Long-term and short-term effects of variable oceanographic and meteorologic factors may be sources of variation in the data. Spiller et al (1988) found that substantial improvements could be made in harvest sampling efficiency by cancelling sampling during inclement weather. We tested two variables that might affect either the efficiency of fishing units or the propensity of marlin to strike bait. Both vari-

ables were highly significant in the blue marlin equation and one was highly significant in the white marlin equation, but neither explained much of the data's variation — possibly because the dummy variables for area-month interactions explained most of the spatial-temporal variation in the data that was due to sea state and cloud cover. The addition of these variables potentially could reduce variation only within areas and months or, possibly, among months of different years.

Conclusions

The following conclusions can be drawn from this analysis:

1. Standardized annual values of HPUE and CPUE suggest that the fishing success for white marlin may have declined from 1981 through 1986. No long-term trend was seen in standardized values of blue marlin HPUE and CPUE.
2. The seasonal and areal variations predicted by the models for blue marlin and white marlin are consistent with what is known about the distribution of these two species and the fisheries for them, suggesting that relative values between years, as well as between months and between areas, accurately reflect differences in fishing success.
3. The pattern of annual variation in white marlin fishing success indicated by this analysis agrees with the pattern in the first eight years of data (Beardsley and Conser 1981).
4. Only about 20% of blue marlin and 40% of white marlin fishing success were explained by the models, which raises the question of how the models might be improved, either by, (a) reducing the variation in the data, or (b) adding other factors to explain additional variation.
5. Part of the unexplained variation undoubtedly is due to differences in anglers, captains, equipment, and fishing sites. We greatly reduced this source of variation when we combined the data into a record for each fishing day-location instead of a record for each fishing trip. This general category of variability would be reduced still further if more samples per day were taken at each sampling location. A low number of samples is more common in non-tournament sampling than in tournament sampling and might be improved by sampling ports on weekends, rather than weekdays, when more units are fishing.

Summary

We standardized recreational fishing success for blue marlin and white marlin in the western north Atlantic during the years 1972 through 1986 by fitting a general linear model to data acquired from tournament and non-tournament anglers. In this analysis, fishing success was expressed in terms of number of fish hooked or boated per unit of fishing (HPUE and CPUE).

Compressing the data from a record-per-trip to a record-per-day basis improved the fit of the residuals to a normal distribution and increased the percent of variation in fishing success that could be explained by the model. For example, the R^2 for number of blue marlin hooked per unit of fishing time was increased from 4% to 22% by expressing the data in terms of number of fish hooked or caught per unit effort per day. The R^2 for white marlin HPUE or CPUE was nearly twice that for blue marlin HPUE or CPUE.

The influencing factors considered in the analysis were sample type (tournament or non-tournament), area, month, and year. Both main effects and certain two-way interactions were examined. A downward trend in fishing success for white marlin after 1980 was indicated after standardization. No apparent trend was evident in standardized fishing success for blue marlin. Standarized fishing success may indicate change in abundance over time, particularly in this case, in which standardized values were based on fishing information from much of the range of each species in the western north Atlantic.

Acknowledgements

Mark Farber and Stephen Turner of the Southeast Fisheries Center's Miami Laboratory provided advice on the analysis. Farber furnished the useful relationship presented in equation 3. Alan Rosenthal calculated the confidence limits and prepared the original versions of Figures 2 and 3.

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Isolation of Biomarker Proteins from Blue Marlin, White Marlin, and Sailfish from the Western Atlantic Ocean: A Means of Identifying Billfish Carcasses

James X. Hartmann and Raymond E. Waldner

Available data suggest that the stocks of blue marlin *(Makaira nigricans)* and white marlin *(Tetrapturus albidus)* are currently fully exploited or are overexploited in the Atlantic Ocean (Farber and Conser 1983, Conser, 1985). Data on the Atlantic stocks of certain other billfishes, such as sailfish *(Istiophorus albicans)*, are difficult to interpret, in part due to the lumping together of data from different species (Conser) 1980, Limouzy and Cayre 1981). Conser (1985) states that, ". . . the outlook for the future status of the billfish stocks may depend greatly on an ability to determine the status of stocks with greater accuracy and precision than is now possible." A current problem involving the assessment of billfish stocks is that billfishes caught by longline vessels may be butchered on site, and the dockside identification of the frozen carcasses is difficult if not impossible using normally available means. Thus, accurate catch statistics for the various billfish species cannot be obtained at present. The purpose of this study was to determine whether blue marlin, white marlin, and sailfish of the western north Atlantic could be identified by examination of the banding patterns of their muscle proteins following electrophoretic separation, using polyacrylamide gel isoelectric focusing (PGIEF), and to identify and characterize species-specific (biomarker) proteins for each of these species. Isoelectric focusing was chosen as the electrophoretic method due to its high resolution, speed, and reproducibility (Svensson 1967). Isoelectric focusing of muscle proteins in a polyacrylamide gel has been previously established as a means for obtaining a "fingerprint pattern" specific to a species of fish (Lundstrom 1980, 1981).

Materials and Methods

Muscle tissues from four blue marlin, two white marlin, and six sailfish caught off southeast Florida and the Bahamas were used for this study. Muscle samples were received either fresh or frozen and maintained at −70°C until needed. Samples of pure white muscle were thawed at room temperature and proteins were extracted with the use of a ground glass homogenizer.

Five different protein extraction solutions were compared to determine which yielded the greatest number of identifiable protein bands following PGIEF. To this end, all five solutions were tested on muscle from a single fish, and were applied simultaneously in separate lanes on the same gel. The protein extraction solutions included:

1. 0.02% NaCl in distilled water;
2. 60 ml of 0.02% NaCl, 0.001 g of phenylmethylsulfonyl fluoride, 2.5 ml of 20% NP 40, and 0.012 g of sodium azide;
3. solution #2, plus 8M urea;
4. 10% dimethylsulfoxide in 0.02% NaCl; and
5. distilled water.

For each sample, 0.2 g of muscle tissue was homogenized in 1 ml of a test solution. The ground glass insert of the homogenizer was turned 50 times in a 180° arc, and was lifted every 10 turns.

The fluids thus obtained were decanted into

1.5 ml screw-top centrifuge vials. Each sample was then centrifuged for 30 min in a Savant Speed Vac Concentrator Model SVC-200H (Savant Instruments, Inc., Farmingdale, NY) at 1725 rpm (650xg), after which the supernatant fluid was drawn off with a pipette and further diluted with distilled water. PGIEF and subsequent silver staining were carried out simultaneously for all samples on a Pharmacia pH 5-8 IEF gel in a Pharmacia PhastSystem electrophoretic unit (Pharmacia, Piscataway, NJ), following the procedures outlined in the PhastSystem Owners Manual (Anonymous 1987). After staining, more bands were apparent from the sample homogenized in distilled water than those prepared using the other extraction solutions. Thus, all billfish samples were homogenized in distilled water.

The extraction of proteins from billfish muscle tissues followed the procedure outlined above, except that 0.6 g of muscle from each fish was homogenized in 3 ml of distilled water. After collecting the supernatant fluids, a two-fold dilution series was prepared from each sample in a 96 well microplate. Each dilution was then mixed with 200 microliters of Bio-Rad Protein Assay Solution (Bio-Rad, Richmond, CA.), as described by Bradford (1976). A series of blank wells and standards were added to the microplate as described in the Bio-Tek Automated Microplate Reader Model 309 Owner's Manual (Anonymous, 1986), and the relative optical density of each well in the microplate was read in a Bio-Tek Microplate Autoreader model EL309 (Bio-Tek Instruments, Winooski, VT), at a wavelength of 600 nm. The dilutions were then applied to pH 5-8 Pharmacia PhastSystem IEF gels and underwent PGIEF and silver staining following the procedures outlined in the PhastSystem Owners Manual (Anonymous 1987).

Protein extracts having a relative optical density of 0.500 to 0.600 were found to be optimal for PGIEF and silver staining using the Pharmacia PhastSystem. Subsequent testing showed that this concentration could be approximated by diluting the supernatant solutions 1:16 with distilled water, unless the muscle sample that a supernatant fluid was prepared from contained a large amount of water.

Results

The three billfish species examined in this study could be readily distinguished by their PGIEF muscle protein banding patterns, although the majority of muscle proteins appear to be conserved among all billfishes sampled. Sailfish have one or, in some individuals, two very darkly stained bands located 14.2 and 14.9 mm from the cathodic end of the 36.2 mm Pharmacia pH 5-8 IEF gels (Fig. 1, bands a and b, respectively). Although the other two billfish species also exhibited bands at this approximate location, the proteins from sailfish muscle consistently stained much darker when the same protein concentration was used from all species. The fact that all six sailfish exhibited band a while only two exhibited band b indicates intraspecific genetic variation. An additional band, 13.3 mm from the cathode (Fig. 1, band c), can be seen in three of the six sailfish.

Sailfish exhibit an unique band 11.3 mm from the cathode (Fig. 1, band d). White marlin display a band slightly closer to the cathode (11.1 mm) (Fig. 1, band e), indicating a higher pI. This band appears to be peculiar to white marlin, but there is an indication of a very lightly stained protein in this area in sailfish. Thus, this protein may prove to be shared by sailfish and white marlin.

Blue marlin can be distinguished from sailfish and white marlin by the presence of protein bands 15.8 and 10.5 mm from the cathode (Fig. 2, bands a and b, respectively). The gels shown in Figures 1 and 2 are representative of over 10 electrophoretic separations at pH 5-8.

Discussion

Considerable similarity exists in the muscle protein banding patterns of blue marlin, white marlin, and sailfish from the western north Atlantic. Even so, these species can be differentiated by their muscle electrophoretic patterns. Intraspecific variation was observed between some sailfish (Fig. 1, bands b and c), but the overall banding pattern was still distinct for a given species. It could be argued that the intraspecific variation resulted from degradation of muscle samples and that proteolytic cleavage gave rise to the additional band b in Figure 1. Neither heating samples of muscle tissues at 33°C for 2.5 hr nor maintaining samples at 22°C for 2.5 hr, however, produced changes in the banding patterns or produced band b.

The observed variations could be due to factors such as genetic differences between or within stocks, or gender. If such variations prove

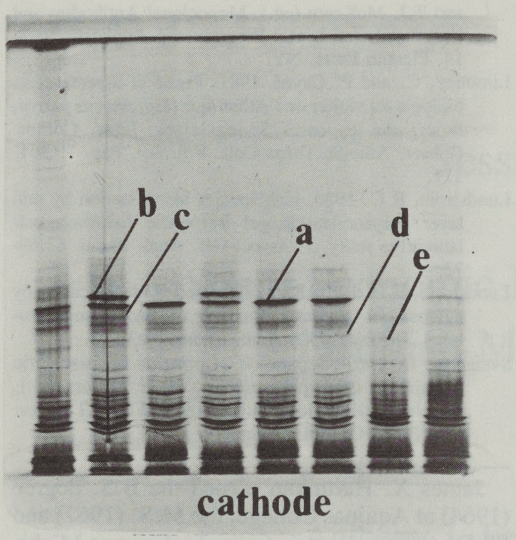

Figure 1. Silver stained Pharmacia pH 5-8 IEF gel showing muscle protein banding patterns of sailfish and white marlin lanes 1-6 and 7-8 respectively. a = darkly stained band in all sailfish; b = darkly stained band in 2 of 6 sailfish; c&d = sailfish biomarker proteins; e = white marlin biomarker protein.

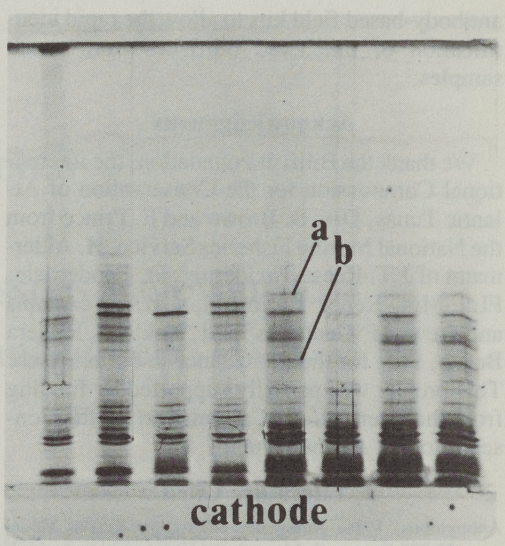

Figure 2. Silver stained Pharmacia pH 5-8 IEF gel showing muscle protein banding patterns of sailfish and blue marlin lanes 1-4 and 5-8 respectively. a&b = blue marlin biomarker proteins.

to be stock specific, they could provide a means to identify stocks. All sailfish muscle samples used in this study were from mature fish taken off the southeast coast of Florida, but the point of origin of these fish remains undetermined. Intraspecific variations indicate a need to examine several individuals of a species in order to characterize that species electrophoretically. As only two white marlin were utilized in this study, the results for this species should be regarded as tentative.

The species specific proteins observed in at least two of the three billfish species (Fig. 1, bands d and e; Fig. 2, bands a and b) provide an additional means of distinguishing between these species. These biomarker proteins were observed in all individuals of a given species used in this study; however, further studies are necessary to determine if variations in these proteins exist. It could be argued that the observed species specific proteins resulted from proteolytic cleavage of the billfish muscle proteins. The same samples utilized in the foregoing isoelectric focusing study were run but the muscle proteins were separated by molecular weights. The protein banding pattern was identical for all three species and individuals within a species (unpublished observations). If protein degradation accounted for the observed species specific biomarkers, this fact would have been evident as differences in the molecular weights of the muscle proteins. It is concluded that the biomarker proteins have electrophoretic mobilities peculiar to a given species and were selected during evolution as advantageous mutations in either enzymatic or structural muscle proteins.

Biomarker proteins can be used to elicit the production of monoclonal and/or polyclonal antibodies (Goding 1986). Antibodies can, in turn, be incorporated into simple, portable field kits to identify species biochemically from tissue samples. Antibodies are currently utilized in diagnostic testing for a number of physiological and pathological conditions involving antigenic recognition (Kennett et al 1984).

Summary

Blue marlin, white marlin, and sailfish from the western north Atlantic display species specific protein banding patterns when their muscle tissues are subjected to polyacrylamide gel isoelectric focusing. Intraspecific variations in muscle proteins were especially evident in sailfish and may indicate genetic differences within or between stocks, or differences in gender. Biomarker proteins were noted in blue marlin and sailfish, and possibly in white marlin. Biomarker proteins can be used to produce

antibody-based field kits to allow the rapid identification of butchered billfishes from tissue samples.

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Session 3

Socio-Economic Issues Relevant to Billfish Management

Anthony J. Fedler, Chairman

Profiles of Recreational Billfishermen: Implications for Management

John R. Maiolo

Saltwater (marine) recreational fishing is a very large component of the total leisure context in the United States. According to Gordon (1981), such fishing in 1980 consisted of 20 million anglers; generating an estimated six billion dollars in direct expenditures for the nation's economy. Thompson (1984) estimated the expenditures to be 7.5 billion dollars for the same year. He also gauged an increase to nine billion dollars in 1982, and the number of anglers to be 21 million in 1983.[1] Associated with this growth has been a spate of studies documenting and analyzing its nature and impacts (e.g., CMA 1977, Ditton and Fedler 1983, Johnson et al 1986). Many of these studies have been generated by the requirements of the Magnuson Fishery Conservation and Management Act (MFCMA) and/or regional and state management initiatives.

As a leisure activity, recreational billfishing may stand alone. For many sport fishermen, catching billfishes (blue marlin, *Makaira nigricans;* white marlin, *Tetrapturus albidus;* and sailfish, *Istiophorus platypterus,* especially) is the most glamorous and thrilling of all the types of recreational fishing. It is glamorous from the standpoint of the vessels and gear, entertainment, skill, risk, and even specialized clothing. It may be, indeed, an activity which deserves the much utilized social scientific label, "subculture." All of the elements are present — specialized technologies, values, beliefs, myths, language, norms (customs), and costumes (DeFluer et al 1981). It is also very expensive, involving thousands of specialized boats and millions of dollars spent annually on gear, gasoline, tournament expenses, food, housing, repairs, and clothing. More than 20,000 vessels annually catch upwards of 80,000 billfish within the U.S. EEZ, alone (NMFS 1979), and it has been estimated that it cost $350 per boat per day, on average, to fish for billfish in 1982 (CPUE was estimated to be 0.27 billfish per boat per day; SAFMC 1982). For one multispecies fishing tournament, it was estimated that nearly $432,000 was spent only for the offshore division (mainly billfishing), and this figure excludes incidental boat necessities (Ditton and Loomis 1985). Also, there are over 800 billfish tournaments in the United States and nearby waters each year.

Because of the numbers and types of people involved, along with the volume of expenditures, it is understandable that there is a great deal of management policy interest in regard to billfishes. If we are to take seriously the mission of this second international symposium, i.e., planning, research, and management in the 90s and beyond, some very pointed questions must be asked, and sensitive questions examined. What do we want the fishery to look like? Who are, who will be, and who should be the participants? Who should share in the costs and benefits of protecting the fishery? Does it matter how many fish are available, if it doesn't matter

[1]One must be careful in accepting such estimates uncritically. There isn't always agreement among the researchers computing them. There is concensus among fisheries experts, however, that sport fishing across the U.S. has flourished under the domestic economic policies of the U.S, wrought by the Reagan administration, i.e., disproportionately beneficial to higher income groups. The geographical area which is the exception, of course, is the Gulf of Mexico region, which has undergone severe economic hardship due to the falling price of crude oil.

to the fishermen who catch them in competitive tournaments? Or, is it important that the nation preserve it's stocks at certain levels, and for what reasons? Does it matter which size the fish are that are caught? Note that these are not questions which can be answered with biological assessment data. They can be addressed only with social scientific information, and I doubt whether many would argue that they must be answered before effective management, whatever the objectives, can occur.

In the Spring of 1986, under the auspices of the South Atlantic Fishery Management Council (Charleston S.C.), East Carolina University social scientists began a study of recreational billfishing in the United States and nearby coastal waters. The study was designed as a first step (pilot study) in the examination of the factors which influence participation in recreational billfishing, generally, and in tournament billfishing, specifically. The results were geared toward the developing Fishery Management Plan for billfishes (SAFMC 1987). It should not go unnoticed that such a plan has been under development for over a decade, and it wasn't until the mid-eighties when social scientific research was undertaken by social scientists. The South Atlantic Fishery Management Council and its staff deserve a great deal of credit for pressing for the research, and developing the funding support so that it could be undertaken.

In the design of the study, it became clear very early that the most important policy question which needed to be addressed was the nature of the social factors influencing participation in the sport, and how that participation is sustained over time in such an expensive and time consuming activity. Management personnel with whom we had been in contact had been operating on the hypothesis that catch rate was the key factor influencing participation rates. Historically, with such a notion, management initiatives have been focused almost exclusively on the quantity of fish available, i.e., taking steps to maintain a given number of fish in order to enhance catch rates, which was presumed to help sustain the sport at the appropriate level perceived by management (see, for example, SAFMC 1982, 1987). We took the position that the real or perceived condition of the fish stock was but one of a number of variables influencing participation. If social influences were found to be part of the participation equation, managers would be faced with a different set of problems, requiring different foci for developing management solutions. This point needs more clarification, because the controversies surrounding the management objectives are complicated, especially to the uninitiated.

Some have argued that the billfish stocks are on the decline and future participation by sport fishermen will suffer. Others have argued that billfishes are so highly migratory that estimates of their population sizes and/or their declines are unreliable. It seems, however, that both sides agree that fishing effort has increased dramatically during the past decade (SAFMC 1987). Further, despite disagreement as to the condition of the stocks, both camps have come to agree that some form of regulation is necessary. They are now focusing on the sizes of the fish landed and killed, instead of the numbers destroyed (SAFMC 1982, 1987). The most recent management proposal would require the release of blue marlin under 90.72 Kg (200 lbs), white marlin under 22.68 Kg (50 lbs), and sailfish under 13.61 Kg (30 lbs). The assumption is that released fish are available for reproduction and growth to a more "desirable" size; it is presumed, too, that participation rates are thereby protected, if not enhanced (See Meehan, Walker and Associates 1988 for an example of Tournament Rules and designed to respond to this assumption).

It is difficult to find solid biological evidence to support such a regulatory model, and most knowledgeable resource scientists and managers seem to be hard pressed to argue from such a standpoint. Further, as management groups come to grips with the biological issues in the fishery, the contention here is that they must also come to grips with the sociological issues. It seems sensible to assume that knowing how and why anglers participate and, in some respects, how that participation may operate independently of the stock condition, would be crucial in any management regime. This assertion is not meant to understate the need to protect the stocks biologically, for if there were few or no fish there would be no fishermen pursuing them at some point down the line. The decisions on how the stock is to be protected, however, would need to be different if the participation rates were exclusively affected by stock condition and catch rates, rather than by catch rates and stock condition in combination with social influences. Given that the main purpose of recent management efforts is to protect the recre-

ational side of the fishery (SAFMC 1987), the design of the study was directed to the issue of social factors influencing participation. This paper reports on the results and their implications for management policy.

In order to understand better the nature of recreational billfishing, how it operates, how the practitioners view themselves and their sport, and the relationship of fishing success to fishing satisfaction and continuing participation in the fishery, the research team decided that billfish tournaments would be a fertile ground for gathering the necessary data (this decision was based also on time and financial constraints). With over 800 billfishing tournaments occurring each year in the United States and nearby waters, we found an extraordinary array of formats. We were able to group them by area, focus, size, and prestige in order to select eight for study and obtain maximum representatives within given budget constraints. From a list compiled by the National Marine Fisheries Service, we chose three from the east coast of the U.S.; three from states bordering the Gulf of Mexico, one each from the western, central, eastern sections; one located in Puerto Rico; and one in the Bahamas (part of the Bahamas Championship). This selection, we felt, was as representative as possible in terms of region, tournament size, species targeted (blue marlin, white marlin, sailfish, the combination of two, or all three), the configuration of trophies and prize money, and time of year.

Our goal at each tournament was to select 20 anglers representing about 14 vessels, with an appropriate distribution of people in regard to sex, age, experience, and level of fishing activity. In some cases, only one or two marinas were involved in the tournaments, and a random statistically-based sample was utilized. In three cases, the distance between marina locations, and other factors which created time problems, forced a selection on an availability basis.

We feel comfortable that both the tournament and respondent selections are adequately representative of tournament participation. The opportunistic nature of the respondent sample in three cases, however, precludes claiming statistical representativeness with respect to the total universe of tournament billfishermen. Also, unfortunately, we cannot make a claim either of representativeness of the entire fishery.

Our efforts produced a total of 140 usable interviews, 20 fewer than our target of 160. Each respondent was administered an interview schedule consisting of both structured and unstructured questions, which had been pretested on a small sample of anglers prior to the initiation of full-scale field work. The interviews lasted an average of 45 minutes.

We experienced few refusals during the entire survey; most respondents were eager to assist in the study. Tournament directors uniformly endorsed our presence by circulating printed announcements during tournament registration periods. In each case, we had been in constant contact with the directors for about 30 days in advance of the tournaments. They also assisted us in making travel and lodging arrangements; in some cases, our bed and board were provided free of charge.

Findings

Demographics of the Fishermen and Their Boats

The sample was overwhelmingly white in racial make-up. Only one respondent classified himself as black but this figure may have differed if more interviews had been done in Puerto Rico because of heavier participation from the Dominican Republic, the Bahamas, and other Caribbean nations having large Afro-Caribbean populations. Classifying those participants may have been problematic, however, since one cannot meaningfully classify a person into a category which is not recognized in his or her own culture.

The respondents were predominantely male. Only two out of the 140 were female, both of whom are recognized as top-flight anglers. This number may not be representative since women do not frequent the docks or after-fishing gathering places as often as men. These two areas were used most often as interview sites. Some fishermen pointed out that their wives often accompanied them to tournaments, and fished with them, but did not frequently participate as official tournament anglers. We could not, however, document this contention.

Ages ranged from 13 to 73 years, with the greatest frequencies occurring between 46 and 50, the period of highest earnings productivity. The age distribution does exemplify the continuity of the sport from one generation to the next.

Our sample was dominated with well educated people, with the average number of years of formal schooling being 16, e.g., a college degree. Further, the sample was dominated by an

occupational class best described as "business/entrepreneur," certainly no surprise. The dominant groupings included real estate developer, insurance and banking executives, investment firm executives, or similar businesses (Table 1).

Table 1. Respondent occupations.

Title or Category	Frequency	Percent of Sanple
Business Owners	63	46
Corp. Executives	16	11
Other Prof./Business	49	35
Retired	12	8
Totals	140	100

The boats used by the respondents in our sample were predominantly in the 30-60 foot range (87%). About half (48%) were owned by the respondents and most of those (80%) were solely owned. Only two boats were chartered.

Almost half of the boats were made by one of two manufacturers, with the remainder of them manufactured by over 30 other companies. Most of these were custom built.

Approximately half of the boats had professional crews or mates, and nearly three quarters of those vessels had captains who were full time throughout the year. Mates were mostly part-time seasonal employees.

Fishing Experience and Fishing History

This topic is explored in great detail in an earlier report (Orbach et al 1986). The issue is briefly examined here only to provide a backdrop for the next sections which deal with the matter of continuity of effort over time.

Because billfishing tends to be a specialization of recreational fishing, and tournaments a further specialization within billfishing, one would predict simply that the sample's respondents have fished recreationally long before they entered a tournament. This was, in fact, found to be the case. The mean time of recreational fishing was found to be 27 years; for billfishing 10. The range for tournament billfishing was found to be one year to 50 years.

Interest in billfishing developed through associations with others who were active in the sport, for about half of the sample (friends, relatives, business associates). About a fifth saw the sport as a natural progression of moving from one type of recreational fishing to the next, culminating in billfishing.

The most experienced fishermen, in terms of number of years fished, were found in tournaments which did not emphasize cash prizes, but were considered to be the most prestigious. These fishermen placed more emphasis on the ambiance of the tournaments, including the location, their prestige, and social relationships which accompany them. These anglers also enter about three fewer tournaments per year than anglers who enter those which contain great amounts of prize money through calcuttas. Yet, this class of fishermen exhibited higher percentages of first and second prizes than their counterparts who fish the so-called "money" tournaments (Orbach et al 1986).

For about a fifth of the sample, money offered in tournaments (regular prize money and parimutuel betting through calcuttas) affected which tournaments they entered. About 16% choose fishing companions on the basis of prize money potential, and about one in every twelve select a vessel on which to participate on the basis of potential winnings (Orbach et al 1986).

Tournament officials and fishermen are reluctant to discuss calcuttas. They are seen as separate from prize money and/or trophies, which are based upon points. The "mainstream" of billfish tournaments focus on points per fish, with a minimum number of points awarded regardless of the size of the fish, for example, 200 points for a blue marlin, which may vary depending on whether the fish is boated or released. Otherwise, the points awarded are usually one point per pound. Calcuttas, however, complicate the mix of kills and releases. One may be faced with a 175-pound blue marlin, worth 175 points if killed versus 200 or more if released for the tournament award competition, but a daily or overall calcutta win only if the fish is brought to the dock.

There are many aspects of the parimutuel betting system we could not pursue because of the sensitivity of the issue. Anglers are reluctant to discuss the topic, but we were able to uncover the fact, impressionistically, that the recreational community is split on the question. A large number of anglers want tournaments formatted on some kind of point system, the argument being based on conservation grounds. Others wish to keep things as they are with the possible exception of some kind of a limit (we found no one opposed to the increasingly popular minimum limit of 200 lbs for blue marlin). That posture is suggested by the finding that 14 respondents (10%) indicated that they entered tournaments specifically for financial

reasons, that is, to make money. Some of our respondents spoke to the emerging class of anglers who move through a regular annual circuit of fishing tournaments based on where the best chances of financial success are located.

It is important to see how this circumstance translates into perceptions of fishing success. It is not a question of catching certain amounts of fish or large sizes. It means catching whatever it takes to win, even if it is only one fish, no matter the size. We found that two-thirds of the respondents did not intend to change their annual format, even when they reported that the previous year's fishing was not good. This response pattern is better understood with the calcutta concept in mind. A significant number of billfishermen define success, and pattern their fishing years, in terms of winnings rather than in terms of a specific number of fish, that is, "whatever it takes to win."

Fishing Success and Styles of Participation

One could reasonably hypothesize that fishing success affects one's willingness to sustain participation in the billfish fishery. After all, catching fish is what it's supposed to be all about! This hypothesis was the working straw-man hypothesis from which we operated. Clearly, too, this hypothesis is the notion from which managers had been operating up to the point of our study and, as such, were focusing on policies which would affect fishing success, mainly of a biological nature.

We asked the respondents two key questions in addressing this issue: How did they rate their previous year's fishing success (we had already asked about how many fish were caught, what size, species, and so on)? Then, we asked how the previous year's success had affected the current year's fishing patterns. The results are rather startling (Table 2). Nearly two-thirds of the 116 respondents answering the question reported that the previous year's fishing was not good. Their responses to the bad year ranged from increasing fishing effort, changing gear and technology or areas, or, in one case, changing tournaments. Overall, 28% of the people who had exprienced a poor year made changes in styles of participation but, 72% did not! It is also noteworthy that, among the third having a "good" previous year, the percentage patterns are not very different. To be sure, one year's data are not sufficient to warrant the conclusion that fishing success has no impact, but they do give important leads, and suggest that we push farther into the data. There are two aspects which should be considered as to how such responses of "success" are interpreted.

The first point has to do with the angler's *perception* of a good or bad year. When he or she reports a bad year, and then claims to have done nothing to change, is it possible that the angler determined that nothing could be done to affect success? To put it another way, if an angler believes the bad year was due to weather, a phenonmenon clearly beyond the respondent's control, why would a shift in effort or technology improve the chances for success? A similar line of reasoning could apply to response in the "good year — no change" category.

Another point is that the question we asked about catches of billfishes during the previous year did not address factors which affect how an angler labels catches leading to the *interpretation* of a good or bad year. We do not know how many hookups were made, nor how many billfish were seen but not caught[2]. Also, of the three to four anglers fishing on board, even if the respondents did not catch a fish, did any of the others? Falk et al (1983) reported that group catch levels affect satisfaction within the context of specific fishing trips. If any of these factors are positive, the angler's perception of overall success increases, if not for himself, then for billfishing in general.

We did ask a series of questions in a very general way, however, to allow the respondents, themselves, to tell us the factors which would either force them to cut back on billfishing, on tournament billfishing, or to cut out those activities altogether (Table 3). Relatively few respondents consistently indicated that poor fishing would affect their activities (including the 0 in the first category). Some respondents persisted in a stance of reporting that nothing short of death could make them reduce or quit fishing. Financial and work-related problems revealed the highest percentages in four out of the six categories.

Discussion

We have presented evidence to indicate that fishing success, as traditionally defined in terms of catches (size, quantity, species) does not seem

[2]Specific tournament and casual billfishing effort data were gathered for a five-year period through a battery of questions by which the respondents were required to recall activity. In some cases, respondents provided log books to us.

Table 2. Effects of perceptions of previous year's fishing success on current year fishing activities (Row percentages in parentheses).[1]

Previous Year Fishing Good	Current Year's Activities: Increased Effort	Changed Technology	Changed Fishing Areas	Changed Tournaments	Reduced Effort	No Change	Totals
No	7 (9.3)	6 (8.0)	3 (4.0)	1 (1.3)	4 (5.3)	54 (72.0)	75 (99.9)
Yes	4 (9.8)	4 (9.8)	2 (4.9)	2 (4.9)	2 (4.9)	27 (65.9)	41 (100.2)
							Total 116

[1]These are *first* responses only. Multiple responses were possible. Also, these distributions are based on 116 usable responses.

Table 3. Respondents' self-defined reasons for reducing or eliminating fishing activities[1] *(Row percentages).*

	Self-Defined Reasons: Health/Personal Problems	Financial/ Work Related	Poor[2] Fishing	Nothing[3]
Reduce Recreational Fishing Generally	25%	39%	0	16%
Reduce Billfishing Outside of Tournaments	23%	39%	8%	16%
Reduce Tournament Billfishing	17%	47%	12%	2%
Stop Recreational Fishing Generally	35%	23%	10	24%
Stop Billfishing Outside of Tournaments	29%	27%	9	16%
Stop Tournament Billfishing	17%	33%	10%	10%

[1]First reasons given only. Multiple reasons could be given. Rows will not total 100% since all responses are not presented.

[2]For some, this literally meant *no* fish at all.

[3]These respondents could not conceive of anything to prompt reduction or quitting except death (when the interviewer promoted them with such a possibility).

to impact participation in the recreational billfish fishery in a way we might intuitively expect. It must be made very clear, however, that the argument here is that numbers and sizes of fish are not suggested as irrelevant. Johnson et al (1986) have illustrated the importance of catch rates in research on nearshore recreational fishing. Data from a sample of 140 tournament fishermen, based on fishing effort and success from five years of recall moreover, can be viewed only as a first step. Poor success over time (as matched with expectations) might produce different results in a more expected direction. It can be argued, nevertheless, that factors other than fishing success in the traditional sense need to be recognized as crucial variables in maintaining participation levels.

Elsewhere, we have dealt with variables other than catch rates in social-psychological, and subcultural terms (Maiolo and Kitner 1986, Kitner and Maiolo 1988). In social-psychological terms, we have argued that our data are not inconsistent with those of Fedler (1984), who focuses on the motives for fishing and reports a "relatively low priority" placed by marine recreational fishermen ". . . on catching fish as an outcome" from the fishing experience (p. 81). When discussing *satisfaction,* however, he notes that the number and kinds of fish caught are important in determining satisfaction, when a number of factors are considered simultaneously. This seemingly contradictory set of statements is clarified by the conclusion that, ". . . the importance of the number of fish caught

seems to be a subjective evaluation . . . since neither differences in the number of fish caught nor the groups in which they fished . . . had any relation to overall satisfaction . . . (p. 81). In a similar vein, J. Johnson (pers. comm.) recently commented on the role of motivation and satisfaction as they relate to fishing choices over time. He hypothesized that motivation is probably influenced by long term fishing successes, while satisfaction is influenced by more discreet periods of time, such as a specific fishing trip. He then argued that the motivation to fish can remain stable so long as *average* catch rates, over time, do not drop below some threshold. The exact level of such a threshold may vary among individual fishermen, and its determination would certainly be a fruitful line of inquiry in the billfish fishery.

At the sociocultural level, the issues relate to the internalization of socio-cultural elements into recreational fishing, and the social supports, operating *independently* of catching fish in terms of quantity and size. Kitner and Maiolo (forthcoming) have suggested that the sport of billfishing manifests boundaries, with mechanisms channeling entry and maintenance, and provide data to support such a contention. Entry is effected through a regularized means by which people with similar life styles "connect" with friends, family, and business associates. The subculture operates to link personal preferences, e.g., the sport, with group activities, such as team fishing, competition and prizes, dock and clubhouse socials, and vividly so through tournaments.

Maintenance of the activity is accomplished through the process of learning how to feel when a hookup occurs; participating in tournament activities; understanding the rarity of landing a billfish, which separates the angler from the rest of the fishing world; and overcoming what others might see as unpleasant aspects of the activity (risk, demanding hours, seasickness). These elements, taken together, form a context which takes on a life of its own, and in a way to mitigate impacts of variations in success, i.e., numbers and sizes of fish caught, winning tournaments, etc.

Summary and Conclusions

Proposed management measures for regulating recreational billfishing have been based primarily upon biological analyses which, in turn, focus on numbers and sizes of species available. Research on the "careers" of billfishermen has uncovered social-psychological and sociological factors which seem to operate to motivate and maintain the effort that such fishermen manifest in recreational fishing in general, and tournament fishing, in particular. Notwithstanding the caveats associated with sample size and representativeness, the evidence gathered indicates that fising effort in a variety of contexts is maintained at certain thresholds regardless of perceived stock conditions. This may be true in regard to regulatory measures as well.

This examination of recreational billfishing would seem to have some important policy implications. Even in cases where sport fishermen actively pursue prize money at the level of hundreds of thousands of dollars, catch rates play a minimal role at best ("it only takes one big fish every couple of years to pay for all of my expenses," we were told by several of our respondents). Knowing that "low" catch rates will not appreciably affect participation (if such a finding can be confirmed with further research and knowing how social processes operate to initiate and sustain fishing activity) gives the manager a broader range of options. Knowing further that "size" is important mostly in comparative terms (i.e., tournament competition) allows the policymaker the opportunity to consider a very wide range of options, indeed.

Insofar as commercial activities in *other* fisheries probably have a great impact on billfish stocks (SAFMC 1987), such as billfish bycatch from tuna longlining and fishing for swordfish *(Xiphias gladius),* how those other fisheries are managed may be tied into our findings, as well. For example, a great deal of time and effort has gone into developing policies directed toward constraining foreign tuna longlining and domestic commercial swordfishing. In both cases, quotas, seasonal closures, and area closure options are broadened with the knowledge gained by this study, particularly if the data are confirmed through further research. That is, such quotas and closures may not need to be as restrictive as presently imagined.

Should managers and recreational billfishermen, then, press for size limits or quotas? If the management schemes are directed toward protecting or enhancing participation, our preliminary evidence would indicate that such policies may have litte effect. The first thing that needs to be done is to test the results on a larger popu-

lation, and over time. It they hold up, the manager's efforts might be spent more effectively in developing policies which are grounded in rationales other than participation.

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Policy and Management Frameworks for Highly Migratory Species Under the Magnuson Fishery Conservation and Management Act: The Case of Billfishes

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The United States has formally claimed management jurisdiction since 1976 over all highly migratory species of fishes other than tunas, including billfish, within 200 miles of her coast under the mandate of the Magnuson Fishery Conservation and Management Act of 1976 (MFCMA). Many of the individual states have had various regulations concerning billfishes for several decades (PFMC 1981), and the U.S. had participated in a number of international organizations concerned with billfishes prior to 1976 (Greenough and Joseph 1986). The MFCMA presented, for the first time, however, a comprehensive domestic framework within which billfish management might be addressed.

The development of billfish management regimes under the MFCMA has been more problematic than those for other fisheries for a variety of reasons: Most species of billfishes found in U.S. waters are highly migratory; billfishes occupy ecological niches along with other, related species, notably tunas; billfish use in the U.S. is primarily recreational while in many of the other countries, through whose jurisdictions the billfishes migrate, and on the high seas, they are harvested for commercial purposes; billfish life histories and population characteristics and dynamics are poorly-known.

This paper will first set out some of the unique characteristics of billfishes and billfish fisheries in the U.S. Second, it will recount the development of the U.S. domestic billfish management regimes under the MFCMA since 1976. Finally, the present domestic management regimes under the MFCMA will be set into the context of international management of billfishes and other highly migratory species.

Billfishes and Billfish Fisheries

Billfishes are members of closely related families that include blue marlin *(Makaira nigricans),* white marlin *(Tetrapturus albidus),* swordfish *(Xiphias gladius),* sailfish *(Istiophorus platypterus),* and spearfish *(T. angustirostris).* They are closely associated in their ecological niches with a number of other species — tunas, pelagic sharks, and other large pelagics (wahoo, *Acanthocybium solanderi;* dolphin, *Coryphaena hippurus).* All of these species except the highly migratory tunas are under U.S. jurisdiction via the MFCMA, yet the billfishes are the only set of species under the MFCMA for which no biological conservation measure imposed unilaterally by the U.S. within her Exclusive Economic Zone, EEZ, could have any substantial impact on the fish stocks, themselves. That is, the billfishes are so highly migratory, and such a small percentage of the stocks occur at any point in time within the U.S. EEZ (with the exception of sailfish and, along some dimensions, swordfish), that no U.S. regulation, alone, however stringent, could have a substantial impact on the conservation of these species (WPFMC 1986, SAFMC 1988).

Billfishes are thus different from other migratory species such as salmon, for which indi-

vidual country domestic management can have significant effects even though the resource is migratory and passes through a number of national jurisdictions during its life cycle. This circumstance has two implications: (1) international management is a necessary condition for biological conservation of the billfishes (Joseph and Greenough 1979); and (2) any rationale for management of billfishes under the MFCMA must be made principally on social, cultural, and economic grounds — that is, it is more an allocation than a conservation question (Orbach 1985, Maiolo, 1988).

The use of billfishes and associated species in the U.S. EEZ is principally recreational, with the exception of swordfish and certain of the associated species (dolphin, sharks, tunas) for which there are developing commercial fisheries within the U.S. EEZ. Even for those species for which there is some commercial fishery, there is a developing recreational fishery as well. The recreational use of these fishes in the U.S. is more pronounced than in any other country, and is a subcultural feature of the general movement towards coastal and marine leisure and tourism in the U.S. (Miller and Ditton 1986).

Finally, the relationship between billfishes — in particular blue marlin and white marlin — and tunas is one which has dominated the policy-making framework for billfishes in the U.S. under the MFCMA. Their feeding and migratory patterns are somewhat different from one another, but these species are found in such close general proximity and share sufficiently similar patterns to make them accessible to the same kinds of fishing gear in most of the same locations. Thus, the exclusion of tunas from the MFCMA has raised the question of whether regulations to restrict the taking of billfishes with tuna-directed fishing gear constituted a reasonable or unreasonable restriction on the ability of foreign nations in particular to fish for tunas in the U.S. EEZ (Drewry 1979).

The Development of Domestic U.S. Management Regimes for Billfishes

A number of states such as California have had regulations concerning certain of the species of billfishes for decades (PFMC 1981). Beginning in the 1950s, the Inter-American Tropical Tuna Commission (IATTC) and, in the late 1960s, the International Commission for the Conservation of Atlantic Tunas (ICCAT), directed attention to the billfish resource, principally in terms of data collection and research. It was not until the late 1970s, under the then-new MFCMA, that any focused national effort on billfish management under U.S. jurisdiction and in U.S. waters was undertaken.

Under the MFCMA, the responsibility for developing Fishery Management Plans (FMPs) is assigned to eight Regional Fishery Management Councils. These FMPs can be developed by a single council for the areas and fisheries under their jurisdiction, or by more than one council together for their combined jurisdictions. The authority for reviewing these FMPs, according to the National Standards listed in the MFCMA and, in the event the FMP submitted by the council or councils is approved, for implementing the regulations pursuant to the FMP, is vested in the U.S. Department of Commerce (DOC). This approval and implementation authority is further delegated from the Secretary of Commerce, through the undersecretary for oceans and atmosphere (as Administrator of the National Oceanic and Atmospheric Administration), to the Director of the National Marine Fisheries Service. The Director, in turn, relies heavily on the advice of his four Regional Directors (Northwest — Seattle, Southwest/Pacific — Los Angeles, Southeast — St. Petersburg, Northeast — Gloucester) through whom the FMPs are officially submitted to DOC for review.

The councils, then, are quasi-federal agencies having the responsibility to prepare FMPs but, lacking authority to implement them, and the DOC/NOAA/NMFS is the public trust agency having the authority to approve and implement the FMPs. The councils provide the regional socio-political and initial scientific input, and the DOC provides final scientific and public trust review. The regulations pursuant to the FMP are valid in the U.S. EEZ outside of the 3-mile territorial sea which, in the U.S., is under the management jurisdication of the states, unless special circumstances dictate their application within the 3-mile zone as well. [See Bubier and Rieser (1984) for a discussion of preemption of and supercession over state fishery regulations by the federal government under the MFCMA].

In the case of the billfishes, however, another provision of the MFCMA came into play. Realizing that it would take some time for the regional council system to develop its capabilities, the Congress included in the MFCMA provision for Preliminary Fishery

Management Plans (PMPs) to be prepared by the Secretary of Commerce (in reality, by NMFS) in cases where management was required but the councils had not yet had time to develop a full FMP. Several such PMPs were produced in the first few years of the MFCMA and, by law, they were only permitted to regulate fishing by foreign vessels in what was then the U.S. Fishery Conservation Zone (FCZ). (President Reagan's Executive Order upgrading the FCZ to an Exclusive Economic Zone did not occur until 1983.) When an FMP was developed by a council for any fishery governed by a PMP, the PMP would be superceded.

Billfish Management Under Preliminary Management Plan

A principal impetus for the MFCMA was to "kick the foreigners out" (Smith 1982), and the PMPs developed for billfishes were a good example of how this was attempted. The development of these PMPs was also an example of many of the questions and issues for which precedents were set as the implementation of the MFCMA unfolded (see Cicin-Sain and Orbach 1986 for an analysis of some of these issues).

First, a decision had to be made concerning the proper unit of analysis and management. One of the MFCMA National Standards dictates that stocks should be considered throughout their ranges, and that inter-related stocks should be considered together, as a "unit". Initial consideration was given by NMFS to writing a single PMP for billfishes within the U.S. jurisdiction in both the Atlantic, including the Gulf of Mexico and Caribbean (hereafter referred to collectively as 'the Atlantic') and in the Pacific oceans. This approach was ultimately rejected in favor of separate PMPs for the Atlantic and Pacific, due to the different situations of both the fisheries and the socio-political context of billfish use in the two regions.

The second question was one about which of the associated large pelagic species to include in the PMPs. There was initial consideration, at least in the Atlantic, of a "large pelagics" PMP but, in both the Atlantic and Pacific, the approach finally adopted was that of a billfishes and oceanic/pelagic sharks PMP. This decision was made in part because regulatory authority under a PMP was limited to foreign fishermen and, as a practical matter in the case of billfishes, to foreign longline fishermen fishing principally for tunas but harvesting billfishes as bycatches.

The PMP scenario unfolded differently in the Atlantic and the Pacific oceans. The Atlantic Billfish PMP was approved by the Secretary earlier (1978) than the Pacific Billfish PMP (1980), and was revised before the Pacific PMP even took effect. Part of the reason for this revision was that the conflict between foreign and domestic fishermen was much more in evidence in the Atlantic, where foreign longline fishing came into conflict with other fixed-gear fisheries as well as with the recreational billfish fishermen, and where the domestic swordfish fishery was much more developed than in the Pacific. In addition, the Atlantic, Gulf of Mexico, and Caribbean councils were more in agreement on the general need for if not the exact configuration of a PMP than were the Pacific and Western Pacific councils, a factor which also came into play in the later development of billfish FMPs, as we shall see following.

The eventual result of both Atlantic and Pacific PMPs was that foreign longliners were restricted from fishing within 100 miles of the U.S. mainland (seasonally, in the Atlantic) and the main Hawaiian islands. They were also required to "release" (dead or alive) all billfishes brought to the vessel (the so-called "non-retention" policy), and to register, pay fees, and take aboard U.S. observers whenever they fished within the U.S. EEZ (see the PMPs — DOC 1978, 1980 — for complete sets of the regulations and conditions).

Thus, by 1980, there existed a rudimentary billfish management framework under the MFCMA, but one which affected only foreign fishermen. This framework was, of course, the beginning of the allocation scheme, but a beginning which distinguished only between domestic and foreign users of the resource and which had no arguable conservation objective for the billfish stocks as a whole.

Billfish Management Under Fishery Management Plans

Activity was already under way, before the first billfish PMP was implemented, to develop FMPs for billfishes in both the Pacific and the Atlantic regions. This development occurred differently in the two regions. Both regions involved more than one council — in the Pacific, the Pacific (west coast contiguous states of the U.S. mainland) and the Western Pacific (Hawaii and the U.S. Pacific Commonwealth territories

and possessions) Fishery Management Councils; in the Atlantic, the New England, Mid-Atlantic, South Atlantic, Gulf of Mexico, and Caribbean Fishery Management Councils (hereafter referred to as the east coast councils).

The Pacific. In the Pacific, even though two different councils and two very different coastal fishery situations were involved, the interaction in the development of the FMPs was fairly smooth. At first, the Pacific Council felt that they should have a separate FMP for the Pacific coast region, and they proceeded to develop such an FMP (PFMC 1981). Ultimately, however, this FMP was put on hold — never formally submitted to DOC — and the Pacific Council in essence threw in with the Western Pacific in their FMP. This action was taken largely because the billfish question was not as pressing on the Pacific coast as it was in Hawaii, due to three factors. First, billfishing was not as important and highly visible an activity as it was in Hawaii. Second, the foreign longliner off the Pacific coast fished closer to Hawaii. Third, the state of California had passed several regulations which were deemed to have gone a long way toward addressing the problems and issues in waters off that state, where virtually all of the billfishing activity on the Pacific coast occurred (PFMC 1981).

The Western Pacific Fishery Management Council (WPFMC), then, proceeded as the lead council for a Pacific billfish FMP. A complete FMP was formally submitted to DOC in August of 1981, but was disapproved by the Secretary under the provisions of the MFCMA in January of 1982. The reasons for this disapproval are instructive in terms of the public trust attitude of the DOC at the time (WPFMC 1986:

1. The species in the management unit included only species of billfishes and did not include other non-tuna species taken in the fisheries for pelagic species;
2. It was not clear that the benefits of managing the fisheries for billfishes would exceed the costs;
3. The area closures for foreign longline fishing proposed in the initial plan appeared to the NMFS to be larger than necessary in order to protect domestic fishing interests, and did not appear to be fully justified by the data available in the billfish FMP; and
4. The need for the FMP was not strongly established given that the NMFS' Preliminary Management Plan (PMP) was, in effect, denying foreign longline fishing from occurring in the FCZ.

In response to this disapproval, the WPFMC submitted and had approved in 1986 a revised FMP. Quoting from the FMP:

> "This revised FMP addresses these concerns [see above] by expanding the management unit to include dolphin fish . . ., wahoo . . . and oceanic sharks; by adding more recent data on the domestic fisheries which have become available to better demonstrate the growth and importance of domestic fisheries and the benefits of the FMP's management measures; by strengthening data collection to assure the availability of an adequate data base to evaluate the effectiveness of the FMP in the future; and by providing for a re-evaluation of the need to adjust the measures of this plan after five years." (WPFMC 1986:2-3.)

This approved FMP prohibited foreign longline fishing within 150 miles of the main Hawaiian islands; within 100 miles of the Northwest Hawaiian islands, within 150 miles of Guam; within an approximately 15,000 square-mile area around American Samoa and Swain Island; and within 12 miles of each U.S. Pacific Island possession. It prohibited foreign drift-gillnetters from fishing anywhere in the EEZ of the Western Pacific region, but allowed domestic fishermen to use this gear under special permit. Finally, the FMP required licensing and mandatory data reporting for all fishery participants and, for foreign fishermen, the filing of "effort plans" two months prior to entering the U.S. EEZ for fishing purposes. The Pacific billfish FMP did NOT contain ANY restrictions on catch or retention of billfishes or tunas.

With respect to the Pacific coast, the PMP remained in effect. Thus, the PMP governed foreign fishing off the Pacific coast while state regulations addressed domestic fishing, and the FMP covered both domestic and foreign fishing in the U.S. 'island Pacific'.

The Atlantic, Gulf of Mexico, and Caribbean. The situation on the east coast was very different from that in the Pacific. On the east coast, all five councils from New England to the Caribbean were involved with billfishes, but each with different use patterns and perspectives in their respective areas (SAFMC 1982). It was decided early on that any billfish FMP should be done by all five councils together, the largest

number involved with any FMP under the MFCMA. Further, there were actually two different FMPs developed for billfish species: a swordfish FMP and a billfish FMP that did not include swordfish.

Space is lacking here to detail the hsitory of the swordfish FMP except to make the following summary points (see Greenough and Joseph 1986 for a brief discussion of the history of the swordfish FMP). First, like the billfish FMP, the swordfish FMP involved all five of the east coast councils. Second, when the swordfish FMP was submitted to DOC in 1985 it was only partially approved, in such a way in the judgement of many as to render the FMP of little use and effect. Finally, many of the issues explored hereafter with respect to the billfish FMP were colored by decisions made and perceptions and impressions formed in the development of the swordfish FMP. In fact, several suggestions were made to the councils (Orbach 1985) that they consider combining the swordfish and billfish FMPs, possibly into a large pelagics FMP. The species were clearly related, the objectives of the two FMPs were very similar, and the two separate FMPs proposed principal regulations on exactly the same group of fishermen: domestic longliners and gillnetters. These suggestions were rejected for two reasons: first, the swordfish FMP was already well under way; — second, the recreational billfish constituency on the east coast simply wanted a billfish FMP apart from the swordfish FMP, which addressed a largely commercial fishery.

As with the Pacific billfish FMP, work on the Atlantic billfish FMP had begun in the late 1970s. A draft of the FMP was approved in January 1982 by the South Atlantic Fishery Management Council (SAFMC), the lead council on the FMP. It would be 1988, however, before all five east coast councils approved a billfish FMP for submission to the DOC.

The draft approved by the SAFMC in 1982 had several major provisions, and covered blue marlin, white marlin, sailfish, and spearfish. First, only "traditional recreational fishing gear (ie., rod and reel)" would be permitted in a directed fishery for billfishes, with the exception of the Caribbean where traditional handlines would be permitted in a small scale food-fish fishery. Second, all billfishes, taken by foreign longliners must be released, "in a manner which will ensure maximum probability of survival" (SAFMC 1982:5). Third, the area closures and other provisions related to foreign fishing specified in the Atlantic PMP would be continued, as long as they were not in conflict with any of the provisions of the FMP. Fourth, only one billfish per boat per trip would be allowed to be retained by domestic longliners, who were otherwise to be subject to the same "non-retention" policy as foreigners. Finally, data reporting would be complete and mandatory for foreign fishermen but on a sample basis for domestic fishermen, with no licensing or fees involved for the latter.

It must be emphasized that this 1982 draft of the FMP did not represent a consensus of the five councils. There is a great deal of material in the 1982 draft that presents the different proposals of various councils on such features as limits to domestic recreational catch or possession and phasing down or out of foreign billfish bycatch (SAFMC 1982).

After six more years of discussion, an Atlantic Billfishes FMP was approved by all five east coast councils and was submitted to the DOC for review in 1988. Most of the provisions remained the same as in the 1982 draft: only rod and reel in a directed fishery, with the Caribbean exception; "non-retention" by foreign longliners, and continuance of the other provisions of the PMP; sampling of the catches of domestic fishermen, but with no permits or fees. In addition, a number of provisions were added: (1) a "no sale" provision for all billfishes; (2) a complete non-retention provision for all domestic commercial fishermen; (3) minimum size limits for the U.S. recreational fishery for blue marlin (200 lbs), white marlin (50 lbs) and sailfish (30 lbs); and (4) mandatory catch-and-effort reporting from all U.S. billfish tournaments.*

Atlantic and Pacific: The Different Approaches to Billfish Management

There are significant differences between the Atlantic and Pacific billfish FMPs. First, the Pacific FMP includes associated pelagic species, a feature introduced through the initial disapproval of that FMP. The Atlantic FMP may have a similar experience, although the existence of a swordfish FMP in the Atlantic may affect this issue.

Second, the Pacific FMP allows both foreign and domestic commercial and recreational

**Editor's Note:* The FMP for Atlantic billfishes was approved by the Secretary of Commerce effective October 18, 1988.

fishermen to retain the billfishes they catch, and allows a "directed fishery" by all fishery constituents. In fact, this was one of the major factors that the Pacific FMP put forward in arguing why the FMP was needed over and above what was already being done through the PMP in the Pacific — that the FMP would reduce wastage and encourage full utilization. The WPFMC rejected the argument that the foreign bycatch affected the availability of billfishes to the recreational fishery, given the area closures in the FMP. The east coast councils vigorously embraced this argument in their "non-retention" policy for both domestic and foreign fishermen, even in the face of their own area closures.

Third, the no-sale provision of the Atlantic FMP highlights one of the major cultural differences between the Atlantic and the Pacific. In the Pacific, especially in countries such as Japan and, by association, within the Asian population in the Pacific islands, billfishes are considered to be as much food fish as recreational objects. Exactly the opposite perception prevails on the east coast of the U.S., where coastal leisure and tourism overwhelms any minor tradition of food-fish utilization for billfishes.

The International Management Context

In the U.S., the question of management of highly migratory species has been overwhelmingly dominated by the tuna issue (Joseph and Greenough 1979, Orbach 1980, Hudgins 1988). Briefly, the U.S. has an historical high-seas tuna fishery that has fished traditionally in what are now the 200-mile zones of other countries, notably on the west coast of Central America and South America, the west coast of Africa and in the south and western Pacific. When the MFCMA was passed, the U.S. high-seas tuna industry obtained a provision in that law excluding highly-migratory species — defined specifically as tunas — from U.S. management jurisdiction. To quote Greenough and Joseph (1986:124), "This position on tunas, together with the fact that the U.S. does claim jurisdiction over billfishes which, like tunas, are highly migratory and are taken in longline operations concurrently with tunas, has led to increasing confrontations with respect to management problems, both domestically and internationally."

The problem is that, while the U.S. high-seas tuna fleet's position may have given them a bargaining chip at the time — in the 1950s through the 1970s — the costs and benefits of that "chip", the tuna exclusion, have changed considerably since that time. Virtually all other coastal nations except the U.S. are now claiming jurisdiction over tunas. The use of marine resources has become a very contentious issue, especially in small island or developing nations, where the ratio of marine to terrestrial economic resources is high. It is now arguable, therefore, that the U.S. tuna exclusion is working against the U.S. tuna interests in their attempt to gain reasonable access to the fishing grounds adjacent to those nations. It is also probably working against the U.S. fishery management establishment in its attempt to achieve coordinated international management of highly migratory species. This circumstance, in conjunction with the inability of the U.S. to regulate tunas and associated species within its own EEZ due to the tuna exclusion, constitute the "problems" referred to earlier by Greenough and Joseph (1986).

From the perspective of U.S. law and policy, the question of whether the U.S. can regulate billfish bycatches by tuna fishermen, either foreign and domestic, has been largely settled (Drewry 1979). Similarly, the question of whether the U.S. can regulate its citizen fishermen outside of the U.S. FCZ, where many billfish and tunas are taken, has also been settled (in the affirmative). The problems that remain, however, are two-fold: (1) how do we manage the growing domestic fishery for tunas and billfishes within the U.S. EEZ, given that authority for the management of tunas does not exist; and (2) given that international management is necessary for any conservation objectives to be achieved, in addition to allocation, how do we go about constructing a composite international/national management framework with which to accomplish this multi-objective management?

In answer to the first question, if the FMP is substantially approved as submitted, there will be two very different management approaches to apparently similar fish populations on the Atlantic and Pacific coasts of the U.S. Tunas, an increasingly popular species for exactly the same recreational and commercial gears that now take billfishes, will still be beyond the pale of the MFCMA due to the highly migratory species (i.e., tunas) exclusion, throwing into the domestic FMP arena many of the same problems that have plagued the foreign PMP arena. If the Atlantic Billfish FMP were to be substantially

dispproved, the east coast councils would have to consider some of the same points that the WPFMC did in its rewrite of its Pacific Billfish FMP. In addition, there would most probably be pressure to move towards consideration of an amalgamated large pelagics FMP.

These largely domestic management questions are directly relevant to the second problem — that of the composite international and national management framework for billfish management. This question for billfishes is structurally similar to the question for tunas: if major decisions concerning conservation or allocation are to be made through international agreements and organizations, what is the role of the Regional Fishery Management Councils? Should the structure be similar to that developed for the north Pacific halibut *(Hippolgossus stenolepis),* where the International Pacific Halibut Commission makes the major conservation decisions and the allocation of the resource among domestic users is delegated to the Regional Fishery Management Councils (USC 16 S.773c)? Or should the councils have a greater role in the initial conservation decisions, which inevitably are textured by the user needs and preferences, especially for species such as billfishes where so little concrete information exists about the stocks, themselves? What is the function of the Department of State, which has the principal role in foreign allocations within the U.S. EEZ under the MFCMA and of the U.S. Congress in making treaties?

The answer to this second question is largely dependent on the outcome of the present discussion concerning potential amendments to the MFCMA to include tunas under that Act. If such an amendment is adopted in the near future, the discussion might move toward models such as the halibut situation. If such an amendment is not made, the billfish discussion will probably remain ambiguous for some time to come.

Summary

Several things stand out concerning the history of billfish management in the U.S. First, it is only in the last decade that attempts have been made to develop any comprehensive integrated domestic and international framework for billfish management, with little progress thus far. U.S. participation in international organizations was a step; the PMPs were a step; the FMPs were a step; amendments to the MFCMA may be a step. Many of these steps were taken, however, by different actors in different arenas for different purposes.

Second, the question of billfish management in the U.S. is mainly an economic, cultural, and (ultimately) political question. It is a matter more of allocation than of conservation. In many ways this approach, certainly justifiable under the MFCMA, makes the development of the management framework more nebulous, more contentious, more in need of social scientific data and information that are as lacking as are data on the billfish stocks, themselves. How can rational allocation decisions be made without documented knowledge of the configuration and characteristics of the resource constituents, and of the costs and benefits of various management alternatives?

Third, the economic, cultural, and political context of billfish management varies considerably among the several regions where billfish fisheries exist: the south and western Pacific; the U.S. west coast; New England and the Mid-Atlantic; the south Atlantic and Gulf of Mexico; and the Caribbean. As is reflected in the history of the development and ultimate configuration of the billfish PMPs and FMPs, each of these regions has its own traditional billfish use characteristics and preferences, which vary widely among the regions. Thus, no matter how considered a framework we develop nationally for billfish management, the management approaches within that framework will differ considerably.

Finally, billfishes cannot be considered alone. They are part of a large ecosystem complex that, most notably, includes tunas, as well as a number of other large pelagic species. What is critical for management is not simply the fact that these species occur together in the marine environment, but that the recreational and commercial users of those resources are developing more complete and common uses for these species as a complex.

Ultimately, concern in the U.S. for billfishes is based on the nation's collective cultural perception of the ocean environment and the creatures that live in it. Billfishes are beautiful, powerful, and uncommon. Law is simply formalized cultural preference; thus, marine mammals, endangered species, billfishes, and other animals in the marine environment are singled out for special protection or consideration. The challenge in billfish management is to meld the cultural preferences not only of a diverse group

of U.S. citizens, also of the citizens of other countries, into a consensual agreement on the conservation and use of these singular species.

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Fleet Characteristics and Boat-Owner Expenditures Associated with Virginia's Recreational Marlin-Tuna Fishery

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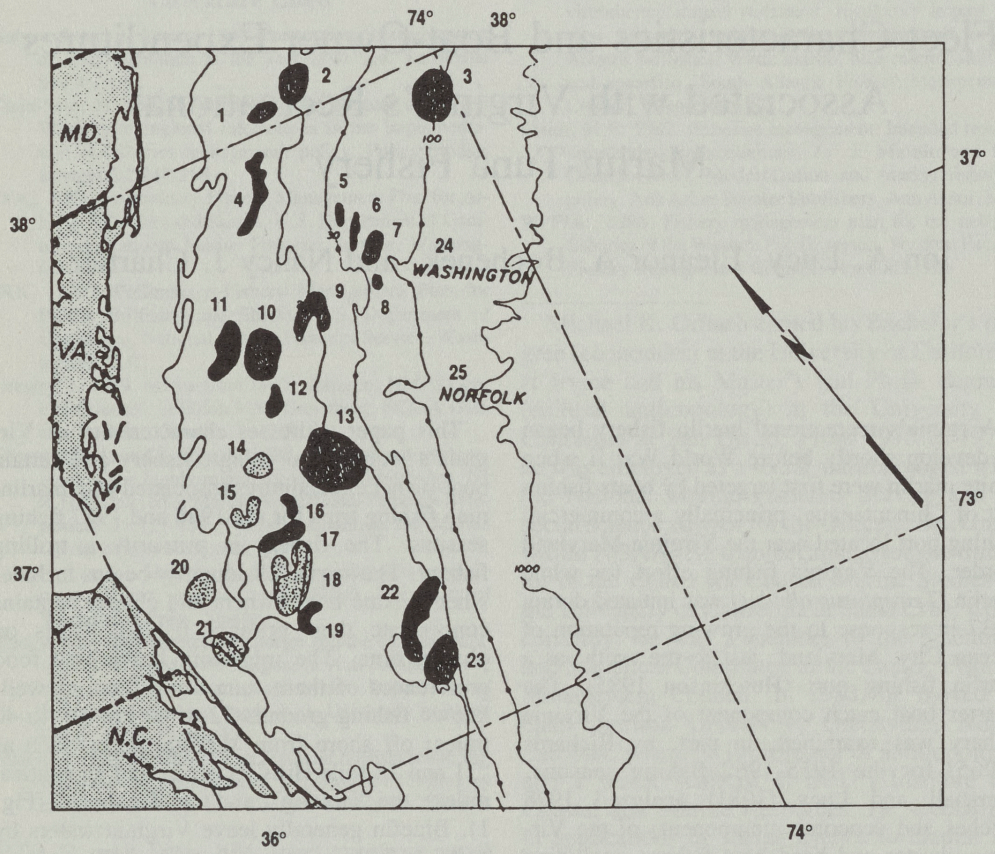
Virginia's recreational marlin fishery began to develop shortly before World War II when white marlin were first targeted by boats fishing out of Chincoteague, principally a commercial fishing port located near the Virginia-Maryland border. The Virginia fishing effort for white marlin *(Tetrapturus albidus)* was initiated during 1937 in response to the growing reputation of Ocean City, Maryland, just to the north, as a marlin fishing port (Hutchinson 1985). The charter boat catch component of the Virginia fishery was examined, in part, by Richards (1965) for the 1955-1962 fishing seasons. Marshall and Lucy (1981) analyzed 1978 catches and economic components of the Virginia charter and head boat fishery, including those boats which fished offshore for marlin and tuna.

The large pelagics survey of the National Marine Fisheries Service expanded its port sampling program in 1980 to include several Virginia ports. The dockside survey provided catch and effort data for charter and private boats primarily targeting bluefin tuna *(Thunnus thynnus)* and billfish (Birdsong 1980, 1981, 1982; Lopez et al. 1984). A regional study of the recreational pelagic fishery was completed in 1983 for the mid-Atlantic states of New York through Virginia (Figley 1984, Figley and Prim 1984). Studies of Virginia's marlin and tuna fishery have continued since 1983 utilizing dockside, telephone, and mail survey techniques developed in the 1983 regional study (Bochenek 1989, Bochenek and Lucy 1988, Lucy et al 1988, Bochenek et al 1989).

This paper addresses characteristics of Virginia's recreational pelagic fishery and certain boat-owner expenditures associated with marlin-tuna fishing trips for the 1986 and 1987 fishing seasons. The fishery is primarily a trolling fishery. The season customarily begins in June, when private boat owners and charter captains concentrate their primary fishing efforts on bluefin tuna. The migratory habits and food preferences of these tuna bring them to well-known fishing grounds 32 to 64 km (20 to 40 miles) off shore from Virginia ports, such as "21 and 26 Mile Hills" (i.e., 21 and 26 nautical miles), the "Hotdog", and the "Fishhook" (Fig. 1). Bluefin generally leave Virginia waters by early August, migrating farther north. In June, part of the fleet also fishes farther off shore along the edge of the continental shelf, seeking the season's first white marlin and yellowfin tuna *(Thunnus albacares)*.

By July, the majority of the fleet shifts its effort to the more distant fishing grounds in pursuit of yellowfin tuna, white marlin, and the occasional blue marlin *(Makaira nigricans)*. Bigeye tuna *(Thunnus obesus)* and sailfish *(Istiophorus platypterus)*, while relatively rare catches, are also highly prized by the Virginia fleet. The fleet travels as far as 128 km (80 miles) off shore in search of these species, fishing waters ranging from 37 m (120 ft) to more than 1,829 m (6,000 ft) in depth. Some of the most popular marlin-tuna grounds during both mid and late season are known as "Cigar", the "Fingers", "20 Fathom Fingers", and Norfolk Canyon, a submarine canyon cutting the shelf



Tuna and Billfish Grounds Off Virginia

1. Jackspot
2. The Fingers
3. Poor Man's Canyon
4. Lumps
5. First Lump
6. Second Lump
7. Rockpile
8. 29 Fathom Lumps
9. 20 Fathom Fingers
10. 21 Mile Hill
11. No Name
12. 26 Mile Hill(Hambone)
13. The Fingers
14. Triangle Wrecks
15. Fishhook
16. Hot Dog
17. Southeast Lumps
18. Horseshoe
19. Boomerang
20. V Buoy
21. 4A Buoy
22. Cigar
23. Honey Hole
24. Washington Canyon
25. Norfolk Canyon

Figure 1. Chart of marlin-tuna fishing grounds targeted by Virginia fleet.

edge (Fig. 1). The fishery continues into September, or even October, if weather conditions remain favorable.

Methods

A questionnaire was mailed to boat-owning fishermen at the end of the 1986 and 1987 fishing seasons to obtain the majority of data presented in this paper. The mailings were made to private boat owners and charter boat captains identified through ongoing telephone and dockside sampling efforts as making a minimum of three trips per season from Virginia ports in pursuit of marlin or tuna. Three to four weeks following the initial mailing, postcards were sent to fishermen reminding them to return the questionnaire. Since all responses to the survey were anonymous, no follow-up survey of non-responding fishermen was attempted. Few questionnaires were returned by the postal service as undeliverable in either year. Catch and effort data were also collected on the fishery during each season utilizing dockside and telephone interview techniques (Bochenek 1989, Bochenek et al 1989).

The mail survey requested information from boat captains and owners concerning seasonal fishing patterns of their respective boats and expenditures associated with fishing trips targeting marlin-tuna. Boat owners were also asked to name ten boats (or captains) from their home port which had fished two or three times during the season for marlin or tuna. Boat names from returned surveys, already identified through dockside and telephone interviews as active in the fishery, were considered "known" or "marked", while previously unidentified boats were considered "unmarked". Using this information, estimates of the total fleet size for the Virginia fishery were calculated, using both the Lincoln-Peterson Index and the Mark and Recapture Method (Giles 1971, Figley 1984). These values were then averaged to provide an overall size estimate of the marlin-tuna fleet. Sampling methodologies utilizing dockside and telephone interview techniques, and resulting data analysis techniques are detailed in Bochenek and Lucy (1988), Bochenek (1989), and Lucy et al (1988).

Results and Discussion

Fleet Characteristics

Questionnaires were mailed to 450 boat owners/captains in 1986 and 593 owners/captains in 1987, producing response rates of 42% and 32%, respectively. A delay in mailing of the questionnaires until early spring of 1988 likely contributed to the lower response rate for 1987. From responses to the question requesting ten names of boats (or captains) active in the marlin-tuna fishery, it was estimated that researchers had identified 51% of the active fleet members during telephone and dockside interviews in 1986 and 58% of the fleet in 1987. The estimated size of the marlin-tuna fishery fleet in 1986 was 886 boats and 1,021 boats in 1987, with the fleet containing 65 and 68 charter boats during each year, respectively (Table 1). Approximately 85% of the charter boats chartered full-time, while 15% of such boats carried charter customers infrequently. The apparent growth in fleet size over the two-year period was more likely the result of researchers' better identifying boats active in the fishery in 1987 rather than an actual major expansion occurring in the fleet itself.

The results of the mail survey indicated that home port distribution of the fleet (the port from which a boat fished most often) remained relatively constant between 1986 and 1987. Approximately 52% of the fleet fished primarily from Rudee Inlet in Virginia Beach, during 1987, compared to 50% of the fleet in 1986. Approximately two-thirds of the marlin-tuna charter fleet operated out of Rudee Inlet, with the majority of the remaining charter boats concentrated at the town of Wachapreague on Virginia's Eastern Shore. Wachapreague accounted for 17% of the total fleet's effort in 1987 (15% in 1986), while Lynnhaven Inlet in Virginia Beach was the point of origin for approximately 13% of the fleet's 1987 trips (15% in 1986). North Carolina ports (primarly Oregon Inlet and Hatteras Inlet in equal proportion) served as the principal ports of departure for 8 to 9% of the Virginia fleet over the two-year period. For the 1987 fishing season, 43% of Virginia's offshore captains stipulated that either Oregon Inlet or Hatteras Inlet was their second most frequently used "home port", indicating the regional character of the Virginia fishery.

Average vessel length in the fleet remained constant at 8.5 m (28 ft.) during 1986-1987 (Table 1). Detailed information was obtained in 1987 on size differences between private and charter boats, with the latter averaging 11.3 m (37 ft.) compared to 7.9 m (26 ft.) for privately operated boats. Comparing the length distribution of the overall marlin-tuna fleet in 1987 to

Table 1. Characteristics of Virginia's recreational marlin-tuna fleet; mean values include ranges in parentheses.

	1986	1987
Estimated Fleet Size	886	1021
Number/% Charter Vessels	65/7.3%	68/6.6%
M/T Trip Charter Fee	$510	$588
	($200-$850)	($400-$750)
Boat Length (meters)	8.5 TF[a]	8.5 TF[a]
(1m = 3.28 Ft.)	(5.5-16.8)	(5.2-14.6)
	—[b]	7.9 PB
	(—)	(5.2-14.6)
	—	11.3 CF
	(—)	(7.0-14.0)
Gas/Diesel Powered	78% G/22% D	79% G/21%D
Total Horsepower	—	327
		(90-970)
Year Boat Built	1979	1980
	(1939-1986)	(1956-1987)
Year Boat Purchased	1982	1983
	(1961-1986)	(1961-1987)
Boat Purchase Price	$57,800	$50,000
	($5,000-$750,000)	($1600-$550,000)

[a]TF — Total fleet (private and charter boats); PB — Private Boat Fleet; CF — Charter Fleet.
[b]Data not available.

the size distribution of boats whose owners-captains responded to the mail survey for the 1987 season indicated that the survey repsonse was representative of the fleet (Fig. 2). Boats longer than 15.5 m (51 ft.), comprising less than 3% of the fleet, were not represented in the survey response. Other characteristics of the fleet, including types of engines used, ages of vessels, and average vessel purchase price, are presented in Table 1.

Fishing Patterns

Through 1986 dockside and telephone interviews with boat owners and captains, data were collected on 892 and 212 fishing trips, respectively; in 1987 similar sampling efforts collected data on 706 and 308 fishing trips, respectively (Lucy et al 1988). The length of a typical marlin-tuna fishing trip in both 1986 and 1987 generally ranged from 10 to 12 hours, of which 6.2 hours was the average time spent trolling baits. The average number of anglers carried per trip (4.0 in 1986; 4.1 in 1987) and the average number of lines fished per trip (5.8 in 1986; 6.0 in 1987) varied little between years (Table 2).

The Virginia fleet made more trips per boat for marlin-tuna in 1987 than in the previous year, averaging 13 trips per boat in 1987 out of Virginia ports (Table 2). Charter vessels increased their rate of fishing trips per boat (27 trips) approximately 35% during the 1987 season over the average rate of 20 trips per boat in 1986. Virginia boats averaged two to three marlin-tuna trips per season out of North Carolina ports while only an occasional trip was made out of Ocean City, Maryland, the ocean inlet closest to Virginia's northern border. The overall fleet averaged 31 saltwater trips per boat out of Virginia and other ports during 1987, with approximately 48% of the fleet's effort devoted to marlin-tuna trips. Participants in the 1986 fishery estimated a similar proportion of fishing effort (52%) devoted to marlin-tuna trips. Estimates of the fleet's total seasonal fishing effort out of Virginia ports, derived from weekly or biweekly random telephone interviews of boat owners and captains active in the fishery (Figley 1984, Bochenek and Lucy 1988), indicated that 6,903 and 8,247 marlin-tuna trips were made by the fleet during 1986 and 1987, respectively (Table 2).

A more detailed pattern of the fleet's fishing pattern during 1987 is presented in Table 3. Requesting fishermen to distinguish trips made specifically for bluefin tuna from the more general category of marlin-tuna trips indicated that bluefin were targeted on approximately one-third of the 15 "marlin-tuna" trips averaged per boat by the fleet out of Virginia and North Carolina ports combined (Tables 2 and 3). Com-

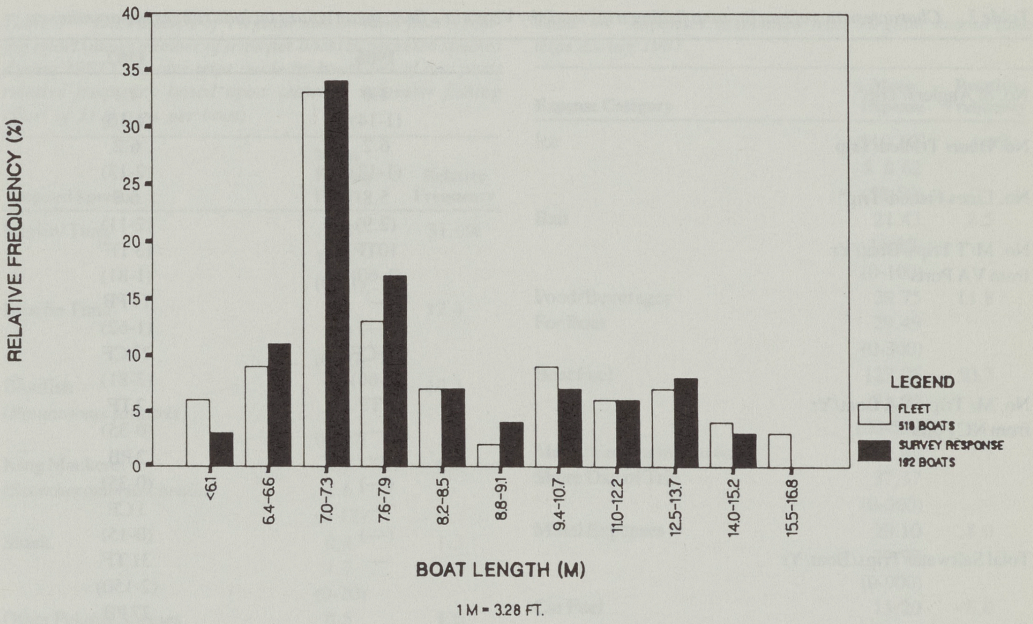


Figure 2. Length distributions of boats active in the 1987 marlin-tuna fleet versus those operated by owners and captains responding to the 1987 mail survey.

bining the relative frequencies of "bluefin" trips and general "marlin-tuna" trips accounted for 48% of the fleet's total effort.

Expenditure Patterns

Less emphasis was placed upon gathering comprehensive expense data associated with a typical marlin-tuna trip in 1986 than during 1987. Fishermen were requested in 1986 to provide a breakdown of estimated trip expenses in only four basic expenditure categories. Based upon 185 survey responses, boat owners and captains had the following mean expenses per trip in 1986 (standard deviations in parenthesis): Ice/Bait — $32 ($27); Food/Beverages — $26 ($20); Boat Fuel — $119 ($76); and Meals/Entertainment — $28 ($46).

A more detailed listing of expenditure categories was utilized on the mail questionnaire in 1987, resulting in more comprehensive information on total expenses associated with a typical fishing trip (Table 4). Because expenditure categories were somewhat different each season, no statistical comparisons were made between years. After combining ice and bait expenses for 1987, visual inspection of the data indicated that similar levels of spending occurred in the first five expense categories listed in Table 4 for 1986 and 1987. Based upon the 1987 data, these spending categories accounted for approximately 83% of marlin-tuna trip expenses. Other significant types of expenditures on which data were obtained in 1987 were motel expenses and car fuel costs, averaging slightly over $20 and $15 per fishing trip, respectively (Table 4).

Mean 1987 fishing trip expenditures ($244 per trip) for boat owners and captains in Virginia's fleet (Table 5) were similar in magnitude but less than those of boat owners in New Jersey's fishery. Brown and Ofiera (1987), studying New Jersey's 1986 offshore big-game fishery, estimated that boat-owner and captain expenses averaged approximately $267 per trip, discounting $19 per trip spent for lost or damaged fishing gear. Almost half (48%) of the New Jersey fleet's seasonal fishing effort consisted of trips targeting marlin, yellowfin tuna, and bigeye tuna, similar to Virginia's fishery. Using the Consumer Price Index to convert the 1986 mean expenditure value to 1987 dollars (WEFA 1988), New Jersey boat owners, on the average, would have spent $277 per marlin-tuna trip in 1987. Therefore, the Virginia fleet's 1987 data appear to provide a reasonable estimate of mean total trip expenditures.

Table 2. Characteristics of marlin-tuna fishing trips made by Virginia's fleet; mean values include ranges in parentheses.

	1986	1987
No. of Anglers/Trip[a]	4.0	4.1
	(1-14)	(1-10)
No. Hours Trolled/Trip	6.2	6.2
	(1-12)	(2-13)
No. Lines Fished/Trip[a]	5.8	6.0
	(2.9)	(2-11)
No. M/T Trips/Boat/Yr	10TF	13 TF[b]
from VA Ports	(1-60)	(1-81)
	—[c]	11 PB
	(—)	(1-62)
	20 CF	27 CF
	(1-60)	(3-81)
No. M/ Trips/VA Boat/Yr	3 TF	2 TF
from NC Ports	(—)	(0-35)
	—	2 PB
	(—)	(0-35)
	—	1 CF
	(—)	(0-15)
Total Saltwater Trips/Boat/Yr	—	31 TF
		(2-150)
		27 PB
		(2-150)
		57 CF
		(15-150)
Proportion of Year's Trips Boat M/T Fished	52% TF	48% TF
Total No. M/T trips made by Fleet from VA Ports[d]	6930	8247

[a]Derived by combining data from dockside and telephone interviews.

[b]TF — Total Fleet (private and charter boats); PB — Private Boat Fleet; CF — Charter Fleet; mean values rounded off to nearest whole fishing trip.

[c]Data not available.

[d]Derived by applying Figley's (1984) technique to fishing effort data collected throuugh telephone interviews.

Boat owners were also asked to approximate annual expenses associated with owning and operating their boats (Table 5). More comprehensive information was requested for 1987 than for 1986. Annual boat preparation and maintenance expenses dominated annual boat-related expenditures in both years, averaging over $2,000 per boat owner each year. Nine percent of vessel owners indicated having to make "major" repairs on their boats and 10 percent re-powered their boats during 1987. Boat insurance costs averaged $770 in 1987 while slip rental and storage fees accounted for annual expenditures of $590 per boat owner. Expenditures by boat owners participating in the 1987 marlin-tuna fishery averaged approximately $3,400 for maintaining, storing, and insuring their boats (Table 5).

Projected annual expenses for boat-related cost items and fishing-related expenditures totaled approximately $5.4 million in 1986, excluding charter fee revenues accrued by the fleet (summing categories in Table 5). Projected annual fleet expenditures were approximately $7.2 million in 1987 (excluding charter fee revenues), primarily the result of including the fishing gear category in expenditure estimates and of the larger fleet size calculated for the year (Table 6).

The economic contribution of Virginia's marlin-tuna fishery, while primarily benefiting the Commonwealth of Virginia, is also shared with the state of North Carolina and other states where members of the fleet may occasionally fish. The 1987 mail survey requested that boat owners estimate the proportion of their various boat- and fishing-related expenditures made in Virginia in contrast to those made outside the Commonwealth's boundaries. Average responses for various expenditure categories indicated that

Table 3. Distribution of Virginia marlin-tuna fleet's fishing effort (mean number of trips per boat) by targeted species during 1987 (includes trips made by boats out of any port; relative frequency based upon seasonal saltwater fishing effort of 31.0 trips per boat).

Targeted Species	Mean Fishing Effort	Relative Frequency
Marlin/Tuna	9.6[a]	31.0%
	11.4	
	(0-81)	
Bluefin Tuna	5.4	17.4
	7.7	
	(0-60)	
Bluefish	3.2	10.3
(Pomatomus saltatrix)	4.7	
	(0-40)	
King Mackerel	2.0	6.5
(Scomberomorus cavalla)	2.6	
	(0-12)	
Shark	0.4	1.3
	1.7	
	(0-20)	
Other Pelagic Species	0.5	1.6
	1.7	
	(0-10)	
Wreck/Artificial Reef Species	3.8	12.3
	6.4	
	(0-50)	
Other Non-Pelagic Species	6.1[b]	19.7
(inshore trips for summer flounder, etc.)	(—)	

[a]Mean, standard deviation and range; based upon 187 responses.

[b]Value estimated by subtracting total of means of all other catagories from 31.0 fishing trips per boat for season.

Table 4. Expenses associated with Virginia marlin-tuna trips during 1987.

Expense Category	Mean Expense	Relative Frequency
Ice	$10.10[a]	4.0%
	$ 8.62	
	($0-50)	
Bait	21.43	8.5
	16.85	
	(0-100)	
Food/Beverages	29.75	11.8
For Boat	29.49	
	(0-300)	
Boat Fuel	127.95	50.7
	71.55	
	(20-550)	
Meals/Entertainment on	19.41	7.7
Shore Day of Trip	37.37	
	(0-300)	
Motel Expenses	20.10	8.0
	79.97	
	(0-900)	
Car Fuel	15.20	6.0
	18.34	
	(0-100)	
Parking	1.37	0.5
	5.64	
	(0-50)	
Clothes	4.05	1.6
	16.17	
	(0-100)	
Other Transportation	2.88	1.1
(tolls, etc.)	11.72	
	(0-100)	

[a]Mean, standard deviation and range; based upon 174 responses.

boat owners and captains in Virginia's marlin-tuna fishery made approximately 84% to 93% of their boat- and fishing-related expenditures inside Virginia (Table 6). Boat owners indicated that 84% to 87% of slip rental, storage, and boat insurance expenditures occurred within Virginia, together with 91% of annual boat preparation and maintenance expenditures. Concerning fishing-associated expenses (gear, fishing trip costs, and tournament fees), 89% to 93% of the estimated expenditures occurred within Virginia. The percentage of fishing-related expenditures apportioned to Virginia by participants in the fishery is similar to the fleet's home port distribution (89% of the fleet fished most often out of Virginia home ports in 1987).

Applying the categorical estimates of proportional spending within Virginia to the projected total expenditures made in 1987 by boat owners in the fleet defined appropriate levels of internal spending (Table 6). Combining all expenditure categories indicated that approximately $6.4 million of $7.2 million in total expenditures was spent during 1987 within Virginia by marlin-tuna fleet members. Estimated charter fees for marlin-tuna trips from Virginia ports exceeded $1.0 million during 1987. Therefore, total direct expenditures within Virginia associated with the fishery were $7.5 million, approximately 90% of the fleet's overall total expenditures of $8.3 million (Table 6).

Conclusion

Virginia supports a significant and diverse marlin-tuna fishery which, through continuing studies, has been estimated to include over one thousand vessels. Focusing the majority of its fishing effort on white marlin and yellowfin

Table 5. Mean annual vessel expenses, including ranges, and projected total expenses for Virginia's marlin-tuna fleet (projected expenses, unless otherwise indicated, based upon a fleet size of 886 vessels in 1986 and 1021 vessels in 1987).

Expense Category	1986	1987
Initial boat Preparation	$2,770	$2,060
and Maintenance[a]	$0-75,000	$0-35,000
	$2,453,330	$2,103,260
Slip Rental/Storage	650[b]	590
	—	0-4,000
	575,900	602,390
Boat Insurance	804[b]	770
	—	0-6,000
	712,344	786,170
Launching Fees	—[c]	50[d]
	—	0-2,300
	—	51,050
Total Fishing Gear	—[c]	1,387[d]
	—	0-9,998
	—	1,416,127
Mean M/T Trip Expenses	205[e]	244[f]
	22-1150	48-709
	1,415,115	2,012,268
Total M/T Tourn. Fees	222	211
	0-5000	0-4000
	196,692	215,431
M/T Trip Charter Fees[g]	510	588
	200-850	400-750
	663,000[h]	1,079,568[h]

[a]Includes hauling, bottom painting, and engine overhaul.
[b]Information not requested in 1986; average of 1985 and 1987 mean expenses.
[c]Data not available.
[d]Includes rods, reels, tackle, gaffs and fighting belts.
[e]Contributing expenses include boat fuel, ice, bait, food-beverages during trip, and meals ashore day of trip; total expense based upon 6903 M/T trips.
[f]Contributing expenses include those above plus motel expense, car fuel, parking, clothing, tolls; total expense based upon 8247 M/T trips.
[g]Not an expense to boat owner/captain; represents charter fishing party expenditure.
[h]Projected total expense based upon 1300 (1986) and 1836 (1987) charter trips.

tuna, the fleet also devotes considerable effort to other types of fishing, notably trips for bluefish, wreck fishing species, and non-pelagic inshore species. The nature of the fishery, especially distances to the offshore fishing grounds, dictates that significant expenses are associated with the activity. Through dockside and telephone interviews, as well as a mail survey of boat owners and captains active in the fishery, we have characterized the fishery and derived estimated boat-owner expenditures associated with marlin-tuna fishing trips made from Virginia ports. In addition, expenditures associated with owning, maintaining, and operating a boat in the fishery have been established. The development of this type of information for multiple fishing seasons should prove helpful to fishery managers and government officials as they assess the importance of fish stocks and boating access facilities associated with maintaining a viable recreational pelagic fishery.

Table 6. Projected total marlin-tuna fleet expenditures for all fishing areas (total expense) and within Virginia during 1987; expenditures associated with vessel ownership and fishing activity distinguished from charter fee revenues accrued to fleet during fishing season.

Expense Category	Total Expense[a]	% Spent in VA	Amount Spent in VA
Initial Boat Preparation and Maintenance	$2,103,260	90.8%	$1,909,760
Slip Rental/Storage	602,390	84.3	507,815
Boat Insurance	786,170	86.6	680,823
Launching Fees	51,050	92.3	47,119
Fishing Gear	1,416,127	91.4	1,294,340
M/T Trip Expenses	2,012,268	88.9	1,788,906
M/T Tournament Fees	215,431	93.1[b]	200,566
SUBTOTAL	$7,186,696	—	$6,429,329
M/T Charter Fees	1,079,568	96.4[c]	1,040,704
TOTAL	$8,266,264		$7,470,033

[a]From Table 5.
[b]In 1987 Virginia-based boats made an estimated 1195 M/T tournament trips of which 1113 (93.1%) were out of Virginia ports.
[c]In 1987, Virginia-based charter boats made an estimated 1904 charter trips of which 1836 (96.4%) were from Virginia ports.

Summary

Virginia's recreational marlin-tuna fishery was examined over the 1986 and 1987 fishing seasons. Data were collected characterizing vessels in the fishery, the fleet's fishing patterns, and expenditures associated with boat ownership and fishing activity. A combination of sampling strategies were employed to gather data from boat owners and captains active in the fishery, including mail surveys, telephone interviews, and dockside interviews.

The Virginia marlin-tuna fleet consisted of an estimated 886 vessels in 1986, of which 65 were charter boats. For 1987, the fleet was estimated at 1,021 vessels, of which 68 were charter boats. Approximately 50% of the fleet fished primarily out of Rudee Inlet in Virginia Beach with Lynnhaven Inlet and the town of Wachapreague accounting for almost equal shares of another 30% of the fleet's fishing effort.

Overall, the fleet's vessels averaged 8.5 m (28 ft.) in length, with charter boats being larger

(11.3 m/37 ft.) than privately operated boats (7.9 m/26 ft.). Fishing effort was estimated at 13 trips per boat out of Virginia ports in 1987 compared to 10 trips per boat during 1986. The fleet averaged two to three trips per boat each year out of Oregon or Hatteras inlets in North Carolina. Total fishing effort for the fleet, determined from random telephone interviews of boat owners and captains throughout the season, was estimated to be 6,903 (1986) and 8,247 (1987) trips for marlin-tuna. Marlin-tuna fishing accounted for approximately 48% of the fleet's overall saltwater fishing activity during 1987. Such trips averaged approximately four anglers per trip and provided 6.2 hours of actual fishing time.

Marlin-tuna fishing trip expenses for boat owners and captains were estimated to be $205 per trip during 1986, with more comprehensive estimates in 1987 indicating $244 spent per trip. Adjusting for inflation, these per trip expenses were similar in magnitude to those estimated for the 1986 New Jersey marlin-tuna fishery. Boat owner expenses associated with owning and operating a boat in the fishery (maintenance, insurance, and storage costs) averaged $3,400 in 1987. Annual fishing gear expenses in 1987 averaged almost $1,400 per owner. Projecting average annual expenses for these categories, as well as fishing trip expenditures for the entire fleet, indicated that boat owners spent an estimated $7.2 million on marlin-tuna fishing activity.

Focusing on expenditures by the fleet only within Virginia, fleet owners and captains estimated making 84% to 93% of their marlin-tuna fishing related expenditures in Virginia, depending upon the expenditure category. Spending by the 1987 fleet within Virginia therefore accounted for approximately $6.4 million.

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A Social And Economic Research Agenda In Support Of Billfish Conservation

Anthony J. Fedler and Robert B. Ditton

Over the years government has devoted relatively little money to billfish research efforts. This situation is not likely to change in the near future without more effective private sector effort. Billfish anglers have often been dismissed as an elite group incapable of taking action by themselves in behalf of billfish stocks. This kind of thinking needs to change.

In this paper we summarize what little is known about billfish anglers, and examine some of the limitations of recently collected data. We identify some needs for strategic information that can be used by private interests as leverage to generate greater governmental support of billfish conservation efforts (i.e., research, management, and education).

It would have been easy for us to have suggested an exhaustive list of research studies to improve our overall understanding of billfish anglers and their activity. Or we could have written a paper around the social and economic research needs identified previously by Human Sciences Research, Inc. (1979) for the National Marine Fisheries Service (NMFS). We could also have used this opportunity to outline a major research role for the government. We suspect that those efforts would make little difference, however, based on the limited extent that government has previously supported social science studies of billfish anglers.

Instead, we have taken what we feel is a more realistic approach, one that critically examines existing available data for billfish anglers and identifies those social and economic data essential for arguing for billfish conservation. We take a limited approach and direct our remarks to non-governmental interests for several reasons.

First, the billfish angling constituency is relatively small in comparison to other angler groups. The billfish fishery has been classified as a "rare event" fishery for sampling purposes; not only are fewer fish caught compared to other species but fewer anglers seek them, as well. In these economic times, managers often equate the size of the constituency group with the priority given management of a particular species. For this reason, we do not see federal fisheries managers doing much more for billfish conservation than they are currently doing or might be required to do, for example, under the proposed Fishery Management Plan for Atlantic Billfishes (FMPAB).

Second, the need for extensive social science research on billfish does not appear to be driven by any major allocation issue. There is not the same magnitude of allocation problems between recreational and commercial interests in the billfish fishery as is found elsewhere in other fisheries. Understanding benefits of billfish as a recreational rather than a commercial fishery did not require much sophisticated social and economic analysis. If the FMPAB is approved by the Secretary of Commerce, for example, government would probably see little need for continuing social science and economic study of billfish anglers in support of management and research efforts.

Third, the need for social and economic understanding in fisheries is still not fully understood and appreciated. This circumstance is partially due to traditional thinking in fisheries management (Voiland and Duttweiler 1984) and the relatively recent emergence of a new paradigm of fisheries management, mandated under the Magnuson Fisheries Conservation and

Management Act, which requires that optimum yield be determined based on social, economic, as well as biological considerations. Also, it is difficult to have much appreciation for the social sciences when biologists have limited funds with which to understand the animal and its migratory and reproductive patterns. We don't like it but we would not expect funds to be expended for social science research when there are pressing biological research needs.

Finally, we recognize that the collection of social science information specific to billfish anglers would be difficult and expensive. Unlike other studies at the population level (i.e., licensed anglers, and boat anglers), the lack of an identifiable universe of billfish anglers makes it almost impossible to sample billfish anglers efficiently.

What Is Known?

There is little social and economic information specific to billfishing to comment upon. Beyond the matter of quantity, there is the matter of quality; problems surround currently available data and their use. First, there is a general lack of sufficient sample size for each state to provide adequate information for a regional or national perspective on the number of billfish anglers, their characteristics, and behaviors. This fact has promoted the over-generalization of results from limited data sets (e.g., Figley 1984, Brown and Ofiera 1987). Second, many billfish anglers catch other species in conjunction with billfish, thus raising questions about the calculation and monitoring of catch per unit of effort (CPUE) for billfish. Third, the catch of multiple species on a billfish trip also has implications for the apportionment of expenditures and economic impacts to various fisheries. Finally, localized studies of billfish tournaments generate only a partial picture of billfish angling activity.

Much of what is currently known about billfish angling on the Atlantic coast has been derived from work by the National Marine Fisheries Service (NMFS) over several years and by Figley (1984). Data presented in the FMPAB indicates that 2,347 blue marlin *(Makaira nigricans)* and 7,761 white marlin *(Tetrapturus albidus)* were caught in the Atlantic Ocean, Caribbean Sea, and Gulf of Mexico during 1984 (SAFMC 1988). About 36% of the blue marlin and 58% of the white marlin were released. Results of the NMFS billfish survey indicate that nearly 291,000 boat-days were devoted to the pursuit of billfish in 1977. Anglers spent an average of $350 per day in their quests. Figley (1984) estimated that mid-Atlantic anglers spent over 21,000 boat-days fishing for marlin and tunas during 1983. Expenditures associated with these trips were in excess of $40 million.

Catching a billfish is an uncommon event even for those anglers who actively pursue them. Approximately 10 to 30 days were needed to catch a blue marlin, 10 to 20 days for a white marlin, and 5 to 6 days for a sailfish *(Istiophorus platypterus)*. These catch rates probably vary greatly by state and time of year.

To develop some additional information concerning the number of anglers, effort expended for, catch, and harvest of billfishes in the Atlantic Ocean and Gulf of Mexico, we examined the NMFS Marine Recreational Fisheries Statistics Survey (MRFSS) data for 1987 and selected out those anglers in the intercept survey who indicated they were seeking billfish. This procedure resulted in a sample of 555 individuals who indicated they were targeting marlin or sailfish on their trips. Results were skewed toward two states, North Carolina and Florida, where intercept sample frequency was high (Table 1). The incidence of encountering a billfish angler in the remaining states was extremely long as reflected in the sample numbers. These low incidence levels make unreliable any estimates of the total number of billfish anglers or their success rates. As a result, we will focus on the two states where sample sizes were adequate to make estimates with some degree of confidence.

Based on the 1987 MRFSS intercept data, about equal percentages of the salt water anglers in North Carolina and Florida sought billfish. Based on the total numbers of marine anglers in each state, however, Florida billfish anglers outnumbered their counterparts in North Carolina by a 6 to 1 margin. The data in Table 1 are characteristic of the data from most billfish work to date in that it has been difficult on a regional or national basis to intercept billfish anglers. Localized studies, such as Figley's (1984), are more useful for determining angler numbers, trip characteristics, and angler behaviors.

Examination of the effort, catch, and harvest data for anglers pursuing billfishes, albeit limited, results in some interesting information.

Table 1. Number and percent of billfish anglers in selected Atlantic and Gulf states, 1987.

State[1]	Total No. of Intercepts	No. of Billfish Anglers	% Seeking Billfish	% of Anglers Catching Billfish	Estimated No. of Billfish Anglers	Estimated No. of Saltwater Anglers
North Carolina	7,778	192	2.5	21.4	25,000	1,018,000
Florida	12,600	337	2.7	14.8	154,000	5,699,000
New York	2,292	3	—	—	—	894,000
Delaware	1,078	2	—	—	—	180,000
Maryland	1,431	5	—	—	—	932,000
Virginia	2,162	4	—	—	—	612,000
South Carolina	2,255	9	—	—	—	363,00
Mississippi	1,425	2	—	—	—	278,000
Louisiana	2,501	1	—	—	—	676,000

Source: NMFS Marine Recreational Fisheries Statistics Survey, unpublished data for 1987.
[1]No anglers targeting billfish were intercepted in: Maine, New Hampshire, Massachusetts, Connecticut, New Jersey, Georgia, and Alabama. Texas does not participate in the MRFSS survey.

First, the catch rate for all billfishes combined was identical for North Carolina and Florida at 0.025 fish per hour (Table 2), or one billfish caught per 40 hours (5 days) of fishing. Off North Carolina, the blue marlin catch rate was 0.0036, or one fish for every 278 hours (35 days) of angling. White marlin were caught at a rate of 0.022, or one fish for every 46 hours (6 days). The collateral catch of dolphin *(Coryphaena hippurus)* and various tunas averaged about 0.20 fish per hour, or one fish per 5 hours of angling.

Sailfish catch rates in Florida waters averaged one fish per 58 hours of angling, whereas it took 222 hours (28 days) and 285 hours (36 days) of angling, respectively, to catch one blue marlin or white marlin. These are yearly averages varying by season when fish may be more abundant. A high percentage of the fish caught on billfish trips in Florida waters were dolphin and various tunas, as would be expected. The catch rate for these fish by anglers targeting on billfishes was 0.395 fish per hour, or 1 fish for every 2.5 hours of fishing.

Upon examining the data more closely, in terms of the types of fish caught by anglers seeking billfishes, we discovered that many anglers also caught fish that are not traditionally caught by trolling. A number of anglers reported catching snappers *(Lutjanus* spp.), groupers *(Epinephelus* spp.), and other species that are usually caught by bottom fishing or drift fishing. This circumstance suggests that some billfish anglers may not devote their entire trip to trolling; it also raises some questions. First, what percentage of "billfish" anglers fish solely for billfishes on their trips? An answer to this question is important if CPUE is used as an indicator of species abundance. Unless the percentage of fishing effort for billfishes on a particular trip is consistent among anglers during a season or year, across years, changes in the percentage of effort expended for billfishes will have a significant effect on CPUE.

The second question raised by other species being caught during a billfishing trip is: What are the conditions that cause anglers to switch target species and fishing methods during a trip? Understanding angler behavior as it relates to changes in target species and fishing methods during a trip can add insight into fluctuations in CPUE and add qualitative information for assessing changes in the fishery.

Additional questions raised are: What proportion of anglers seeking billfishes are committed billfish anglers; and, what proportion are more opportunistic anglers who would like to catch a marlin or sailfish but at least want to "catch something" during their trips? This information

Table 2. Summary of catch statistics for billfishes and other species for anglers seeking billfishes in North carolina and Florida during 1987.

Type of Fish	Catch Per Hour North Carolina	Florida
Sailfish	NA	0.017
Blue Marlin	0.004	0.005
White Marlin	0.022	0.004
All Others	0.198	0.392

Source: NMFS Marine Recreational Fisheries Statistics Survey, upublished data for 1987.

has implications for understanding the composition of the billfish constituency, the size of the billfish angling population, and the core of dedicated enthusiasts who are most likely to become involved in behalf of billfish conservation activities.

The fact that some anglers do not spend their entire fishing trips in pursuit of billfishes also has implications for valuing the billfish industry in terms of expenditures and economic impacts. For example, NMFS data reported in the FMPAB shows that an average of $350 per boat-day was spent for billfishing (SAFMC 1988). If a percentage of a billfish trip is for species unrelated to billfish (e.g., snapper or grouper) then it can be argued that some of the trip costs should be allocated away from the billfish fishery. This concern needs to be addressed because the economic production of the recreational fishery has been an essential argument used in allocating the billfishery among user groups.

Finally, a limited number of billfish tournament angler studies provide a partial view of the overall population of billfish anglers and their activity (Potts 1984, Ditton and Loomis 1985, Falk 1985, Ditton and Arneson 1966, Orbach et al 1986, Ditton and Loomis 1988). We do not know the extent to which the results in these studies can be generalized to billfish anglers as a group. For example, do motivations, participation patterns, and trip costs for tournament anglers differ from those of billfish anglers in general? If relationships can be established between tournament billfish anglers and the general population of billfish anglers, then we may have more confidence in using tournament anglers as a proxy group. Furthermore, this development could create the opportunity for more efficiently monitoring changes in the billfishery, thus eliminating the need for expensive surveys at the population level.

Discussion

Constituency groups need to explore ways to be more effective if they are to coax government to exercise fully its responsibilities for management of common property fisheries resources. Instead of relying on ethical and biological arguments, those who represent billfish anglers in political decision-making need to recognize the imperative of using well-grounded constituent and economic arguments. Biological points made by anglers can be (and often are) dismissed by management agencies as naive, anecdotal, uninformed, and not based on data. Legislators often do not understand biological arguments, as well.

Numerous examples exist, however, where social and economic data have been used effectively to support resource allocation decisions, enhanced research funding, and conservation efforts. For example, the size and distribution of the angler constituency, and its economic production vis-a-vis the commercial fishery, played an important role in the passage of legislation which prohibited the commercial harvest and sale of red drum *(Sciaenops ocellatus)* and spotted seatrout *(Cynoscion nebulosus)* caught in Texas waters. When legislators were unconvinced by stock assessment data, they were moved to action by an economic impact statement prepared by staff of the Texas Parks and Wildlife Department that showed how valuable these species are to the state as game fishes (Christian 1986).

Also, the Sport Fishing Institute (SFI), Washington, D.C., has developed an extension program to provide information on angler expenditures and their economic impacts directly to decision-makers and those who seek to influence decision-makers. The SFI recently used social and economic information in testimony before the Florida Marine Fisheries Commission in support of game fish status for red drum. Based on the limited social and economic information contained in the proposed Atlantic Billfish Management Plan, these types of arguments remain to be made effectively in behalf of billfish conservation.

The number of billfish anglers in the United States may be small relative to other fisheries, but their overall expenditures and economic impacts may be disproportionately higher due to greater expenditures per angler per day. This point was demonstrated by Graefe and Ditton (1986) in their comparative study of expenditures and economic impacts by bay and offshore anglers in Texas. They compared a large number of bay anglers who spent a small amount daily with a much smaller number of offshore anglers who spent twice as much as per angler per day. Offshore anglers also tended to make a greater proportion of their expenditures in coastal communities than did nearshore anglers. Those working in behalf of billfish conservation need to emphasize the disproportionately higher rate of expenditure per billfish angler per day, as

compared with other angler groups, and their respective overall economic impact in local and regional economies. They also need to emphasize that these benefits can be lost without adequate conservation measures. Decision-makers can understand these kinds of arguments and their political implications.

The billfish fishery includes much more than anglers and fish. Billfishes are an attraction for anglers and are the resource base for a significant support industry. Billfish anglers spend money across a wide variety of sectors as evidenced, for example, by the total expenditures of anglers who fished in the offshore heavy tackle division of the 1984 Deep Sea Roundup, in Port Aransas, Texas. Of the $155,000 spent by the 186 anglers in this group, 36% was for boat fuel and oil; 18% for restaurants and meals; 16% for lodging; 8% for charter boat and other expenses; 6% for snacks, beer, and beverages; 5% for fishing tackle and equipment; 4% for bait; 3% for auto fuel; 2% for launch fees and boat slip rentals; and 2% for ice (Ditton and Arneson 1986). All of these business interests have an economic stake in billfish conservation, whether they know it or not.

Information on billfish angler expenditures, and their distribution by economic sector, needs to be disseminated throughout the industry in an effort to expand constituency support for billfish conservation. If domestic and foreign commercial fishing interests are allowed to deplete the stocks of billfishes to the point where anglers no longer feel they have a reasonable opportunity to catch them, these expenditures could be severely curtailed or lost. The impact of this loss on the providers of goods and services, and on local communities dependent on angler expenditures, should be abundantly clear.

Private groups like the International Game Fish Association, The Billfish Foundation, the National Coalition for Marine Conservaton, the Pacific Game Fish Research Foundation, and the Coastal Conservation Associaton, among others, need to have and use better social and economic information in order to influence others of importance in behalf of billfish conservation. Specifically, they need to know: (1) the estimated number and regional distribution of billfish anglers in the United States and their frequency of billfish angling, (2) their level of expenditures, (3) their overall impact on local and state tourism economies, and (4) their "market share" of the sport fishing industry. These kinds of information are well understood by government decision-makers. Unfortunately, there is not much available at this point in time, and governmental officials are unlikely to support these kinds of data collection because they know they will be used against them by private groups lobbying in behalf of more comprehensive billfish research and management. If this information is to become available for use in the public policy arena, it will probably have to be supported by a consortium of private groups.

In this paper, we have identified what we think we know about billfish anglers, some reasons why we know so little, in our opinion what we need to know about this angler group, and how this should be accomplished. To the extent that private groups achieve a strategic understanding of the billfish angler constituency, they will have a greater chance of securing additional public funds in support of billfish research and conservation. We see greater social and economic understanding as the prerequisite first step to funding and implementation of a billfish research agenda developed cooperatively by public and private interests.

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Session 4

Age and Growth Studies

Eric D. Prince, Chairman

Comparisons of Four Hardparts for Estimating Ages of Pacific Blue Marlin

(Summary Paper*)

Kevin T. Hill and Gregor M. Cailliet

The majority of age information available for Pacific blue marlin *(Makaira nigricans)* has been based on the use of otoliths (Radtke 1981, Wilson 1984), with little consideration being given to other skeletal structures. Cursory examination of anal spine cross sections by Wilson (1984) revealed growth patterns assumed to be annuli, but problems were encountered interpreting early growth due to destruction by a vascularized matrix at the spine core. The present study was undertaken to assess qualitatively and quantitatively the usefulness of sagittae (otoliths), vertebrae, and dorsal and anal fin spines for estimation of ages of Pacific blue marlin.

Methods

Various combinations of the four structures were collected from a total of 211 male (19.1 to 170.3 kg) and 105 female (20.9 to 747.9 kg) blue marlin in Kona, Hawaii (Table 1). Sagittae were mounted and coated for scanning electron microscopy (Radtke 1983) with age assignments being based on quantification of ridges along the anterior rostrum edge on the ventral plane of growth as well as ridges along the ventral surface of the medio-ventral and medial planes of growth (Prince et al 1986). Vertebrae were boiled, then sectioned longitudinally, the cartilaginous face of the centrum was peeled away, and the two centrum halves were soaked in 70% isopropanol. Numerous increments were evident on vertebrae after drying, total numbers of which were estimated by extrapolation techniques (Hill 1986).

Dorsal (#6) and anal (#2) fin spines were thin-sectioned according to the methods of Prince et al (1984) and Hill (1986) and examined under a compound stereoscope. Spine growth bands were counted and their radii measured in all samples (Fig. 1). Unpaired t-tests revealed significant differences in dorsal and anal spine-band radius growth between sexes from the sixth band outward; therefore, males and females were treated separately (Fig. 2). The destruction of early growth bands by a vascularized matrix in larger spine sections necessitated the application of descriptive band radius statistics from smaller fish whose bands were not destroyed. Corrected age estimates were assigned to larger spine samples by comparing the radii of their first four visible bands to the means and 95% confidence limits of the compiled data (Fig. 2). Corresponding ages were assigned when the radii of at least three of four first visible bands fit well within the 95% confidence limits of the compiled data. The use of this method for correcting age estimates was based upon the assumption that there was a predictable number of growth bands per millimeter radius in the core matrix region.

In order to test the relative reproducibility of age estimates for fin spines and sagittae, a subsample of 20 of each hardpart was aged three times each by two readers. The average percent error (APE) method of Beamish and Fournier (1981) was applied to uncorrected age estimates.

*A considerably more detailed report to be published in Fishery Bulletin, U.S., Vol. 87, No. 4.

Table 1. Summary of numbers and size ranges of Pacific Makaira nigricans from which skeletal hardparts and measurements were collected. F = Female, M = Male, LJFL = lower jaw-fork length, AR = anal spine radius, DR = dorsal spine radius, SW = sagittae weight, CD = centrum cone depth.

		LJFL (cm)			Weight (kg)			Hardpart Size	
Hardpart	**N**	**Min.**	**Max.**	**Mean**	**Min.**	**Max.**	**Mean**	**Min.**	**Max.**
Anal Spines								*AR (mm):*	
M	150	114.8	263.1	205.3	19.1	170.3	75.0	3.98	10.10
F	49	163.8	363.4	260.4	35.2	555.2	180.8	5.66	18.11
Dorsal Spines								*DR (mm):*	
M	66	177.0	263.1	208.7	46.3	170.3	78.5	7.65	12.46
F	30	163.8	445.8	275.7	35.2	748.0	227.4	6.58	21.00
Otoliths								*SW (mg):*	
M	54	169.5	251.5	206.4	38.6	138.8	75.9	0.415	4.985
F	45	163.8	445.8	265.9	35.2	748.0	197.4	0.800	10.400
Vertebrae								*CD (mm):*	
M	122	169.5	251.5	206.3	38.6	138.8	74.8	17.45	40.48
F	77	147.0	337.7	261.1	20.9	447.7	176.5	18.30	45.99
Total									
M	211	114.8	263.1	205.1	19.1	170.3	74.2		
F	105	147.0	445.8	264.9	20.9	747.9	190.9		

Two basic assumptions of the ageing theory are that the chosen structure grows in proportion to the growth of the animal, and that the observed increments increase in number with the growth of the hardpart and the animal. Lower jaw-fork length (LJFL) and fish round weight (W) were modeled with hardpart size (sagittal weight, vertebral cone depth, and spine radius), separated by sex.

Results And Discussion

Linear equations best described the relationships between LJFL and vertebral cone depth, and anal and dorsal spine radius (AR & DR, resp.), while exponential equations best fit the LJFL — sagittal weight relationship. Coefficients of determination ranged from $r^2 = 0.19$ for male vertebral cone depth to $r^2 = 0.72$ for LJFL v. female anal spine radius, where $AR = -2.5879 + 0.0528$ (LJFL). Comparisons of W to cone depth and spine radius were best described by logarithimic equations, and the relationship between W and sagittal weight was linear. Coefficients of determination ranged from $r^2 = 0.30$ for male cone depth to $r^2 = 0.87$ for female dorsal spine radius, where $DR = 2.3157 * W^{0.3499}$.

Modeled comparisons between hardpart growth and growth increment counts were best described by logarithmic equations for sagittal ridges and corrected anal and dorsal spine band counts (DC). Vertebral increments increased linearly with the growth of the centrum cone. Coefficients of determination ranged from $r^2 = 0.39$ for male dorsal spines to $r^2 = 0.83$ for female dorsal spines, where $DC = 0.5380 * DR^{1.2227}$. Therefore, growth of each of the four structures is related to some extent to the growth in length and weight of the fish, and the number of growth increments increased with hardpart growth. Dorsal and anal fin spine growth was more closely related to somatic growth and estimated age than were otolith and vertebrae growth; therefore, spine structures will perhaps be more suitable for purposes of back-calculation in future studies.

Growth patterns observed in spines sections and sagittae were similar to those previously described for Pacific blue marlin (Radtke 1983, Wilson 1984), and analogous to those of other billfish species (Hedgepeth & Jolley 1983, Prince et al 1984, Prince et al 1986). Corrected dorsal spine age estimates ranged from 6 to 12 for males and from 5 to 22 for females. Similarly, corrected anal spine counts ranged from 3 to 18 for males and from 5 to 27 for females. Sagittae ridge counts ranged from 5 to 16 for males and from 4 to 24 for females. Wilson (1984) reported similar ranges of estimated ages of Pacific blue marlin using both internal and external sagittae morphologies. Vertebrae contained minute increments ranging in number from 250 to 800

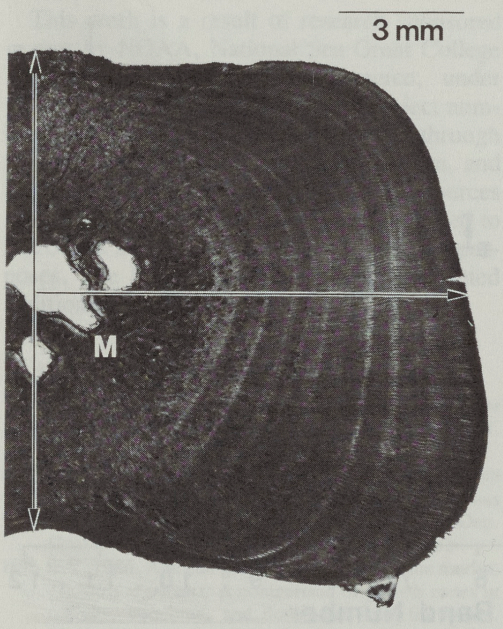

Figure 1. Thin transverse cross section of the 2nd anal spine from a 138.3-kg female Pacific blue marlin *(M. nigricans)* as viewed by a binocular dissecting microscope at 63 × magnification with transmitted light. Vertical line indicates the mid-sagittal plane of the spine with the midpoint representing the spine focus. Horizontal line represents the counting path. Concentric growth-band radii were measured along the horizontal line from the spine focus to the outside edge of each translucent zone. M = core matrix.

extrapolated counts, too numerous to be considered analogous to growth patterns in the other structures.

Wilson et al (1983) defined verification as the "confirmation of a numerical interpretation", a term usually used in reference to the precision of estimated age. Comparisons of age estimates from corresponding fin spines and sagittae provided partial verification of growth patterns quantified in each structure (i.e., these structures appear to be reacting to the same environmental stimuli). Vertebral increments were not included in the comparisons. There were significant positive linear relationships between sagittae ridge counts and corrected spine band counts. Correlation coefficients (r) ranged from $r = 0.84$ for sagittae counts v. anal spine counts to $r = 0.95$ for dorsal v. anal spine counts. Slopes of the regressions did not significantly differ from parity. In addition, Wilcoxon signed-ranks tests revealed no statistical difference between counts of corresponding hardparts. This circumstance lends further support for the hypothesis that all three structures are depositing increments in relation to similar stimuli. Prince et al (1984) reported similar results when corresponding otoliths and dorsal spines of Atlantic blue marlin and white marlin were compared.

APE values ranged from 4.88% error for anal spines to 9.68% for sagittal counts (Table 2). Reader 1 had more precise age estimates for each hardpart. Anal spine counts had the lowest error for both readers. In addition, comparisons of mean age estimates between readers revealed higher variability of sagittal counts compared to dorsal and anal fin spines (Fig. 3). There was a greater percentage of age estimates within ± 1 and ± 2 years for anal and dorsal spines than for sagittae, and the greatest difference between readers was eight for sagittae. Higher variability of sagittae age estimates may be related to problems in interpretations of ridges in regions of acute calcium overburdening, overlapping ridges, or multiple ridges within a larger ridge.

Table 2. Average percent error (APE) values calculated from triplicate uncorrected readings of 20 randomly selected anal fin spines, dorsal fin spines, and sagittae.

Hardpart	Average Percent Error Reader 1	Reader 2
Anal Fin Spines	4.88%	8.79%
Dorsal Fin Spines	5.50%	9.18%
Sagittae	8.15%	9.68%

In summary, sagittae and dorsal and anal fin spines all contain structures useful for age estimation of this species. We assumed that the observed growth patterns were formed with annual periodicity, but this supposition has yet to be validated. Anal and dorsal fin spines are simpler to collect and process than sagittae and, based on reader comparison results, they are easier to interpret when estimating age. Problems of early growth band destruction in larger spine samples can be partially overcome once a sufficient number of smaller samples have been collected and their band radius statistics applied. Sagittae, more difficult to collect and interpret, still hold promise to provide detailed information on early growth from internal features such as "daily" increments (Prince et al this volume). Vertebrae did not appear to be useful for age estimation because of the nature of regular incrementation.

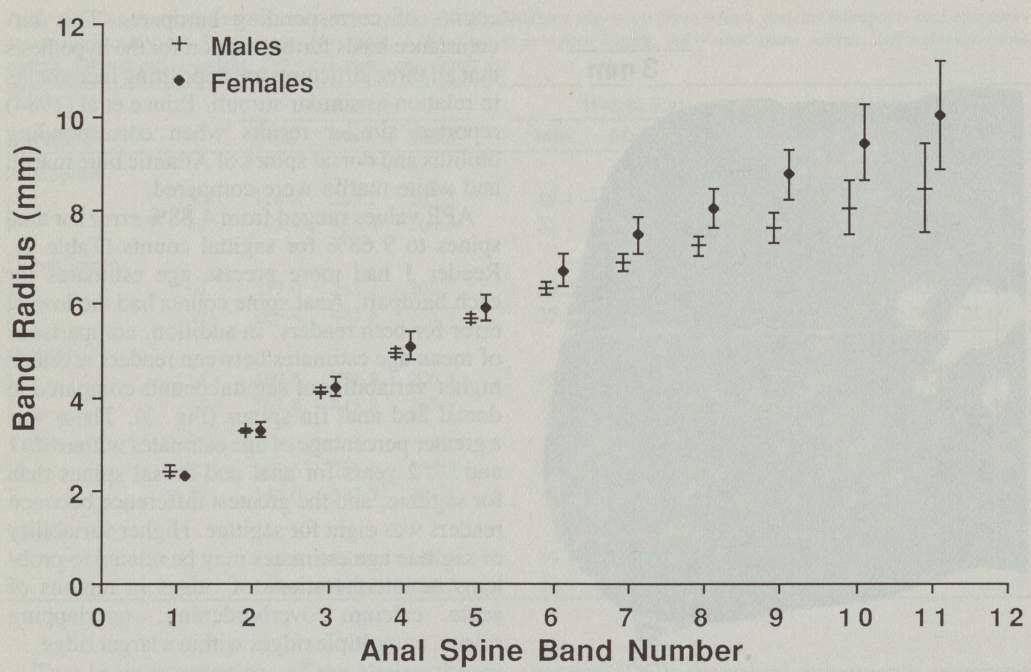

Figure 2. Mean (±95% confidence limits) anal spine band measurements for male and female Pacific blue marlin *(M. nigricans)*. Data are from specimens which had at least the first or second band present. All other specimens were assigned inner rings and final age estimates are based upon these data.

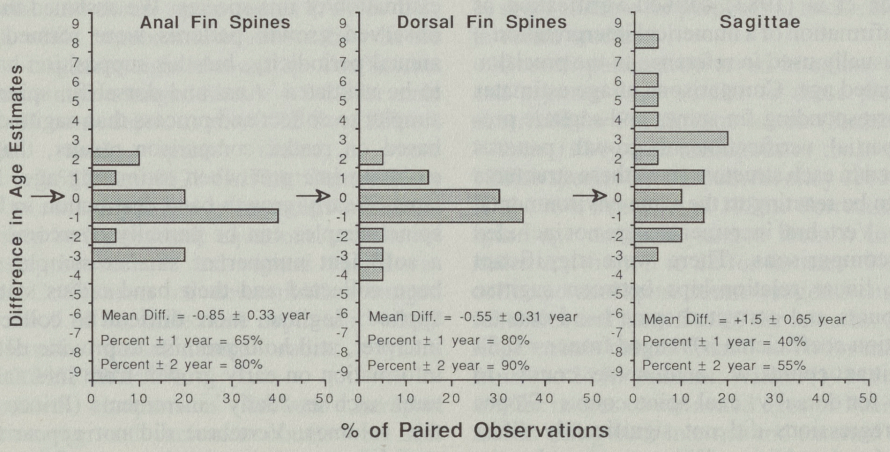

Figure 3. Comparison of differences of mean age estimates between readers (1 minus 2) for anal spines, dorsal spines, and sagittae.

Acknowledgements

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Gregor M. Cailliet received the Ph.D. degree (biology) at the University of California-Santa Barbara in 1972. His disseration was on the feeding habits and distributon of two deep-sea fishes off Santa Barbara, California. He became a faculty member at Moss Landing Marine Laboratories, California State University, in 1972, continuing to the present. His research interests center on aspects of the life histories of marine fishes, including studies of deep-sea, pelagic, estuarine, and demersal fishes, most recently having concentrated on elasmobranchs and sturgeon, and on bony fishes such as blue marlin, sablefish, and rockfish. He is especially interested in age determination and verification techniques, which usually involve evaluating growth zones in calcified structures.

The Potential Of Using Allometric Growth Characters For Resolving Routine Size And Age Estimations Of Billfishes

Nelson M. Ehrhardt

Determination of the age composition of fish in the landings is vital to many stock assessment techniques because it provides a time scale for size measurements necessary to estimate mortality rates. Traditionally, age composition of landings is estimated by converting statistically meaningful length samples to age frequencies with the aid either of a growth function or an age-length obtained from the same landings. This seemingly simple process represents a stumbling block in billfish stock assessment because billfish species are distributed over wide geographic ranges and are captured as target and non-target species in a variety of seasonal commercial and sport fisheries. As a result, collection of length samples of fish in the landings, as well as samples for age determination, have been temporally isolated and geographically fragmented.

Difficulties in ageing billfishes, such as the lack of validated ageing methodology, and problems in interpreting the meaning of zonations, further complicate generation of age-length keys. Dorsal spines are usually vascularized in older fish, thereby obscuring zonations associated with early growth history (Prince et al 1986). Otoliths have external and internal rhythmic depositions that could represent age information (Radtke and Dean 1981, Radtke et al 1982, Radtke and Hurly 1983), but they are very small and difficult to detect. Age determinations can be obtained from otoliths only by observing growth discontinuities with scanning electron (SEM) and light microscopy. The complexity and expense of these methods significantly impairs the use of billfish otoliths for routine age determinations of fish in the landings. Moreover, only headless and finless fish carcasses are landed from the commercial longline fisheries, thereby preventing the collection of hard parts for ageing billfishes.

Because of the difficulties encountered in routine ageing of billfishes, age stucture of fish in the landings has often been estimated by using a general growth equation estimated for the species involved. For example, age structure of swordfish *(Xiphias gladius)* landings from the Atlantic Ocean are obtained by converting size distributions to age by means of a sex-combined growth equation (Miyake and Rey 1989). The difficulty is that no apparent growth in length is observed among animals older than age 5. Consequently, many age classes may be identified within a narrow length range. As with to swordfish, growth of Atlantic sailfish *(Istiophorus platypterus)* (Fig. 1) shows a significant overlap of length-at-age distributions for ages older than 3 years (Hedgepeth and Jolley 1983). When the cited conditions prevail, several biases are introduced when converting length-frequency to age-frequency data using a fitted growth relationship. These biases are discussed by Powers (1983) and Bartoo and Parker (1983).

The purpose of this paper is to develop a procedure for routine collection of size (shape) information from billfish landings and to estimate the age composition of billfishes in the landings from an allometric discrimination of age groups. The procedure is demonstrated with

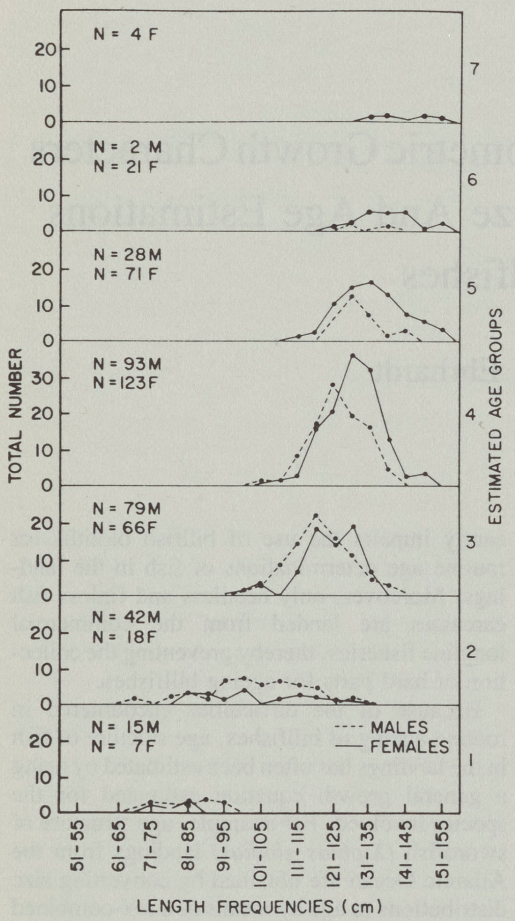

Figure 1. Distribution of length at age of sailfish *Istiphorus platypterus*. (From Hedgepeth and Jolley 1983).

Atlantic sailfish, where age was estimated from dorsal spines, but it may be applied to any fish species showing allometric growth.

Materials and Methods

From February 1 to April 10, 1988, a total of 25 male and 23 female sailfish that were caught in the recreational fishery off the Florida Keys were sampled for morphometric measurements and biological data. Each fish was sexed and a video record of the left side of each specimen was obtained with a standard home video camera at a distance of 6 m, directly above the fish. Also, a photo of each fish was obtained for data back-up purposes. The first six anterior dorsal spines were obtained from each fish following the procedures of Prince and Lee (1982).

A truss network (Strauss and Bookstein 1982) of 12 morphometric measurements (Fig. 2, bottom) was obtained from digitized video images, using commercial optical image processing software for personal computers. Relative measurements were converted to real scale by means of a 76.2 × 76.2-mm (3 × 3-inch) optic size identifier attached to each fish at the time of video recording. All measurements were approximated to the nearest 0.5 mm.

Prince et al (1986) suggest that sections from the 5th dorsal spine are the best choice for ageing Atlantic sailfish when otoliths are not available for that purpose. Therefore, the first six dorsal spines were collected to insure correct identification of spines in the laboratory and spine number 5 was cleansed of tissue and labeled with a collection number. Two sections about 0.45 mm thick were obtained from each spine using a Buehler ISOMET saw equipped with a diamond wafer blade. All sections were cut at a standard position, which was at a distance equivalent to 1/3 of the spine's basal size measured vertically from an imaginary basal plane (Fig. 2, top). All spine sections were stored in labeled vials with isopropyl alcohol.

Spine sections were submerged in water and examined for age determination under transmitted light using a compound stereoscope at 12 × magnification. Two independent age determinations were made on each section and those cases for which age could not be resolved were discarded from the analyses. Age data were stored with corresponding records of morphometric measurements.

Fish growth investigations have usually been based on a comparison of anterior-posterior length measurements to age. Billfish apparently grow very slowly, however, after the age of first maturity (Prince et al 1986); subsequently, they become deeper-bodied. This condition apparently explains the early asymptotic character of growth in length observed among most billfish species. Under these circumstances, a truss network of measurements (Fig. 2) may better explain the true growth pattern of billfish than the simple lower jaw-fork length measurement because the former provides a more even coverage of fish body form.

In the truss network, covariance observed between pairs of homologous dimensions taken over size (age) is due, in large part, to their joint dependence on growth. Allometric growth of homologous body dimensions were then

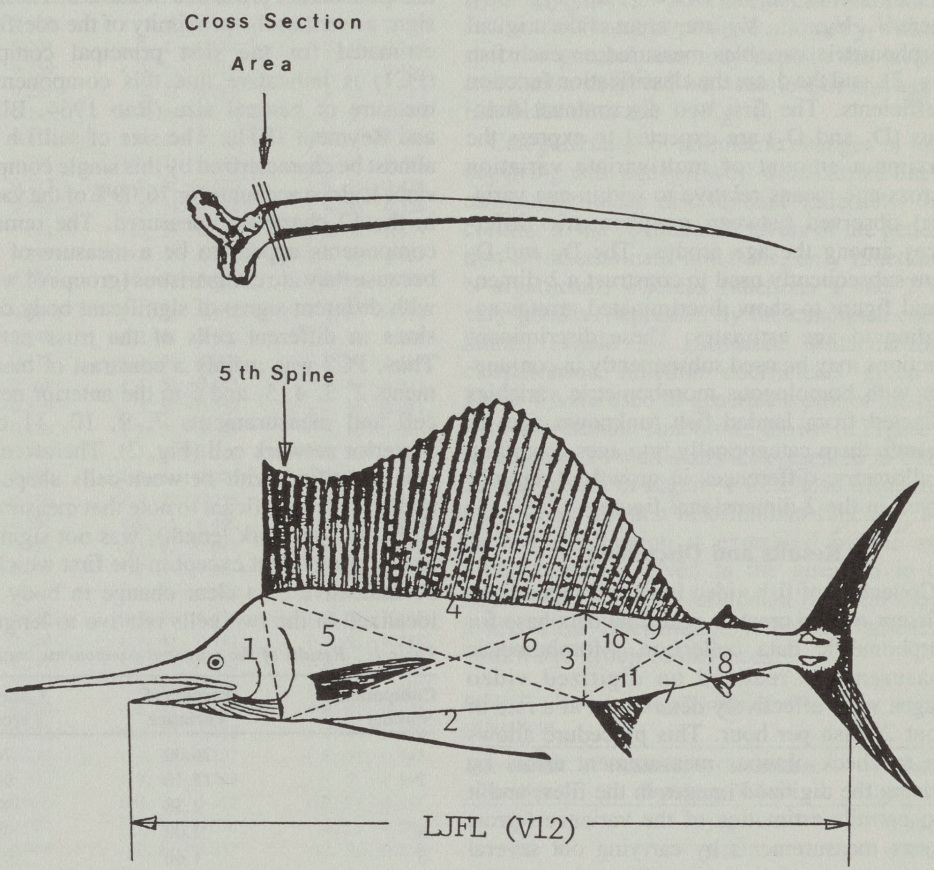

Figure 2. Morphometric measurements (V) taken in the truss network (numbers indicate variable V) and location of spine sections obtained for ageing.

analyzed by the statistically powerful multivariate techniques of principal component analysis and linear discriminant functions. These statistical procedures are discussed in detail by Rao (1952) and Pimentel (1979). It can be shown (Jolicoeur 1963, Bookstein et al 1985) that allometry is indicated by unequal weights of the logarithmically transformed dimension variables on the first principal component. Therefore coefficients for the first principal component were estimated from the covariance matrix of the 12 log transformed morphometric measurements defined in the truss network (Fig. 2). Hence, each of the coefficients represents the allometry of one variable with respect to the general size expressed by the first component. In the analyses, coefficients were normalized to mean square 1 such that, if all dimension variables covaried equally with size, all the coefficients would be normalized to 1 indicating isometry (Bookstein et al 1985). Coefficients larger or less than 1 indicate positive and negative allometry, respectively.

If homologous morphometric dimensions indicate allometric growth, then it may be possible to discriminate individual fish by age according to allometry. However, principal components analysis is not a modelling technique but a very useful statistical tool for transforming data into new measures that maximize variance (categorical analyses). Hence, in order to discriminate morphometric data of fish of unknown age into age groups, age discriminant functions were estimated from morphometric data and correspond-

ing estimated ages based on dorsal spines. Discriminant functions are of the form

$$D_i = d_{i1}V_1 + d_{i2}V_2 + \ldots + d_{i12}V_{12} \quad (1)$$

where $V_1, V_2, \ldots, V_{12}$ are values of the original morphometric variables measured on each fish (Fig. 2), and the d_i are the classification function coefficients. The first two discriminant functions (D_1 and D_2) are expected to express the maximum amount of multivariate variation (across-age means relative to within-age variation) observed between morphometric differences among the age groups. The D_1 and D_2 were subsequently used to construct a 2-dimensional figure to show discriminated groups according to age estimates. These discriminant functions may be used subsequently in conjunction with homologous morphometric variables collected from landed fish (unknown age) to separate them categorically into ages according to allometric differences in growth at age observed in the 2-dimensional figure.

Results and Discussion

Collection of fish video images resulted in an efficient way to create a real-time data base for morphometric data collection. Morphometric measurements realized on digitized video images were effectively determined at a rate of about 20 fish per hour. This procedure allows one to check obvious measurement errors by revising the digitized images in the files, and it also permits estimation of the variance (error) of size measurements by carrying out several measurements of the same dimension on the digitized images. The results indicate that landings' fish size could be expeditiously and routinely registered on video tapes and morphometric dimensions could be measured subsequently in the laboratory.

Age determinations from spine sections were possible in 31 of the 48 fish sampled, or in 64.6% of the cases. Multiple growth bands and excessive spine vascularization were the two most significant impediments to determining age among the 17 rejected spine sections.

A 2-way analysis of variance on measurements for males and females and age indicated no significant differences in morphology based on sex ($P>0.05$); therefore, data were pooled regardless of sex.

The character of body shape development is reflected in the results of principal components analysis. About 91.2% of the variance of categorical morphometric dimensions was explained along the axis of the first two principal components (Table 1). Weights of principal components are presented in Table 2. The similar sign, as well as the proximity of the coefficients estimated for the first principal component (PC1) is indicative that this component is a measure of general size (Rao 1964, Blackith and Reyment 1971). The size of sailfish could almost be characterized by this single component since it alone accounts for 76.09% of the variance in the 12 characters measured. The remaining components appear to be a measure of shape because they are comparisons (groups of weights with different signs) of significant body dimensions in different cells of the truss network. Thus, PC2 was mainly a constrast of measurements 2, 3, 4, 5, and 6 in the anterior network cell and measurements 7, 9, 10, 11 of the posterior network cell (Fig. 2). Therefore, PC2 was identified with between-cells shape variability. It is significant to note that measurement 12 (lower jaw-fork length), was not significant in any component except in the first which may be indicative of a clear change in body depth localized in the two cells relative to length.

Table 1. Results of the principal components analysis.

Component Number	Percent of Variance	Cumulative Percentage
1	76.09	76.09
2	15.16	91.25
3	2.38	93.63
4	2.00	95.63
5	1.60	97.23
6	0.94	98.17
7	0.78	98.95
8	0.43	99.38
9	0.38	99.76
10	0.17	99.93
11	0.05	99.98
12	0.02	100.00

Normalized coefficients of the first component estimated from the truss network are shown in Figure 3. As suggested by Bookstein et al (1985), dilations of 1.00 ± 0.03 were considered to represent isometry; whereas those greater than 1.03 define positive allometry and those less than 0.97 define negative allometry. Figure 3 reveals that lower jaw-fork length is characterized by negative allometry with respect to general size. Therefore, it indicates that the principal axes of growth are not oriented in an anterior-posterior direction. Conversely, morphometric measurements 1, 3, and 6 in the first truss network cell are 1.05, 1.25, and 1.10,

Table 2. Weights of variables estimated by principal components. Columns in the table are: (Variable, Component) Weight.

(1 , 1) 0.300	(1, 2) −0.049	(1, 3) 0.130
(2, 1) 0.304	(2, 2) −0.207	(2, 3) −0.212
(3, 1) 0.359	(3, 2) −0.208	(3, 3) 0.684
(4, 1) 0.277	(4, 2) −0.261	(4, 3) −0.022
(5, 1) 0.293	(5, 2) −0.274	(5, 3) 0.023
(6, 1) 0.316	(6, 2) −0.233	(6, 3) −0.104
(7, 1) 0.295	(7, 2) 0.346	(7, 3) −0.384
(8, 1) 0.227	(8, 2) −0.170	(8, 3) −0.425
(9, 1) 0.256	(9, 2) 0.584	(9, 3) 0.326
(10, 1) 0.244	(10, 2) 0.399	(10, 3) −0.115
(11, 1) 0.295	(11, 2) 0.254	(11, 3) −0.021
(12, 1) 0.276	(12, 2) −0.026	(12, 3) −0.101
(1, 4) 9.8E-3	(1, 5) 0.514	(1, 6) 0.470
(2, 4) −0.240	(2, 5) −0.306	(2, 6) 0.138
(3, 4) 0.413	(3, 5) 0.024	(3, 6) −3.1E-2
(4, 4) −0.368	(4, 5) −0.015	(4, 6) −0.233
(5, 4) −0.119	(5, 5) −0.128	(5, 6) 0.071
(6, 4) −0.159	(6, 5) −0.261	(6, 6) −0.015
(7, 4) 0.453	(7, 5) −0.329	(7, 6) 0.385
(8, 4) 0.380	(8, 5) 0.371	(8, 6) −0.594
(9, 4) −0.216	(9, 5) 0.255	(9, 6) −0.400
(10, 4) −0.381	(10, 5) 0.496	(10, 6) 0.116
(11, 4) 0.215	(11, 5) 0.011	(11, 6) −0.166
(12, 4) −0.095	(12, 5) −5.0E-4	(12, 6) 0.039
(1, 7) 0.546	(1, 8) −0.184	(1, 9) 0.199
(2, 7) 0.285	(2, 8) 0.439	(2, 9) −0.442
(3, 7) −0.263	(3, 8) 0.111	(3, 9) −0.282
(4, 7) −0.347	(4, 8) −0.355	(4, 9) 0.294
(5, 7) −0.128	(5, 8) −0.299	(5, 9) 1.4E-3
(6, 7) 0.070	(6, 8) 0.130	(6, 9) 0.124
(7, 7) −0.203	(7, 8) −0.333	(7, 9) −0.059
(8, 7) 0.177	(8, 8) −0.107	(8, 9) −0.241
(9, 7) 0.373	(9, 8) −0.258	(9, 9) −0.110
(10, 7) −0.436	(10, 8) 0.172	(10, 9) −0.335
(11, 7) −0.080	(11, 8) 0.556	(11, 9) 0.586
(12, 7) 0.038	(12, 8) 0.037	(12, 9) 0.233)
(1,10) −0.154	(1,11) −0.106	(1,12) 6.8E-3
(2,10) −0.110	(2,11) −0.187	(2,12) −0.367
(3,10) −0.085	(3,11) 0.133	(3,12) −0.047
(4,10) −0.459	(4,11) −0.087	(4,12) −0.336
(5,10) 0.683	(5,11) −0.452	(5,12) 0.162
(6,10) −0.229	(6,11) 0.275	(6,12) 0.759
(7,10) −0.164	(7,11) 9.7E-3	(7,12) −0.047
(8,10) 0.028	(8,11) 5.2E-3	(8,12) 0.038
(9,10) 0.015	(9,11) −0.013	(9,12) 0.013
(10,10) 0.043	(10,11) 0.023	(10,12) 0.169
(11,10) 0.052	(11,11) −0.332	(11,12) −0.049
(12,10) 0.442	(12,11) 0.733	(12,12) −0.337

respectively, indicating positive allometry relative to general size. The second cell in the truss network shows two isometric values corresponding to measurements 7 and 11, whereas the remaining measurements in this cell are connoted by negative allometry with respect to general size. These results clearly indicate, in sailfish, that the principal directions of change in body shape occur ventrally and obliquely in the anterior section of the body. These data are in disagreement with the traditional length measurements used in billfish growth studies. Consequently, anterior-posterior negative allometry and anterior-ventral positive allometry with respect to general size may explain the lack of correlation observed between length and age in fish older than age 3 (Fig. 1).

Categorization of allometric changes in form occurring with age (growth) were carried out by estimating linear discriminant functions. According to the significance levels of the generation of discriminant functions, only function 1 is significant, whereas functions 1 and 2 are very good as expressed by the canonical correlations (Table 3). Estimated unstandardized classification function coefficients given in Table 4 were used to generate a plot of the first two discriminant functions, shown in Figure 4. In accordance with statistics presented in Table 3, age groups in Figure 4 were also distinctive only along the first discriminant function, and their discrimination is expressed by the age-group centroids given in the insertion in the figure. The second discriminant function shows a less clear discrimination, mostly indicating within-age group covariances.

Table 3. Statistical significance of discriminant function estimations.

Discriminant Function	Relative (%) Contribution Explaining Variance	Canonical Correlation
1	95.00	0.994
2	2.70	0.836
3	1.17	0.710
4	0.61	0.587
5	0.44	0.527
6	0.09	0.262

Functions Derived	Chi-Square	DF	Significance
0	146.52	72	0.000
1	55.85	55	0.443
2	31.14	40	0.841
3	16.78	27	0.936
4	8.12	16	0.945
6	1.46	7	0.984

There was very little overlap of the age groups, with only two age-5 fish falling within the ellipse of age-4 fish (Fig. 4), or 93.55% of the cases classifying correctly. The use of a more accurate age determination procedure, such as otoliths and SEM, would undoubtedly have yielded a higher percentage of correct classifications.

The results indicate that discrimination of sail-

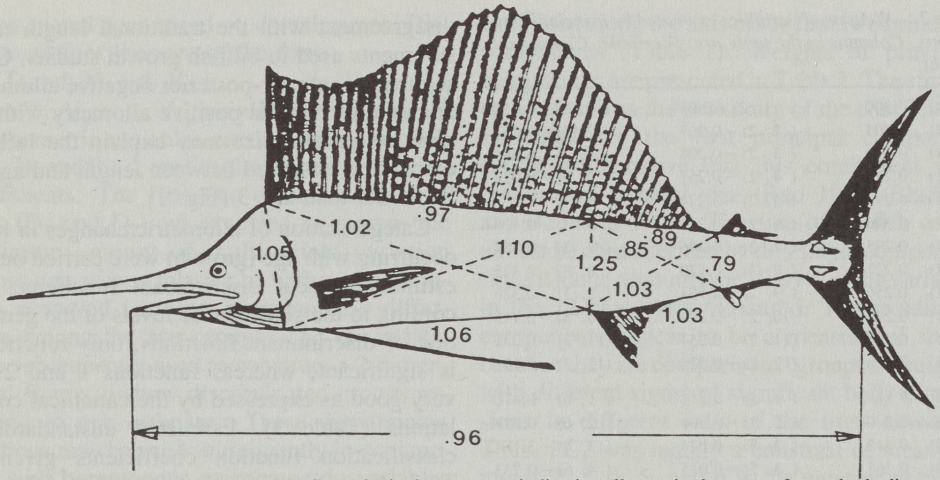

Figure 3. Normalized coefficients of the first principal component indicating allometric character of some body dimensions.

fish by age is possible because of the allometric character of sailfish growth. Therefore, discriminant functions using coefficients in Table 4 are able to identify the likely age-group of sailfish given only a truss network of homologous measurements for each unaged fish in the landings.

Table 4. Unstandarized coefficients for discriminant functions 1 and 2.

Variable	Discriminant Function	
	1	2
V1	0.04218	−0.05928
V2	0.03181	0.01517
V3	0.05007	0.04344
V4	0.04983	−0.03679
V5	−0.03368	−0.00896
V6	−0.04667	−0.01051
V7	0.10107	−0.04137
V8	0.04796	0.16567
V9	0.02963	0.01165
V10	−0.04133	0.02698
V11	−0.06886	−0.08548
V12	0.03032	0.03075
CONSTANT	−64.30900	−9.00501

Conclusions and Recommendations

Evaluation of the character of morphometric variability (allometry) at age by means of discriminant functions estimated from a truss network is an important development to elucidate age composition of billfish landings. The reason for this is the enhanced discrimination of growth at age which is obtained by increasing the number of growth dimensions used in conjunction with powerful statistical techniques, such as principal component analysis and discriminant function analysis.

The procedures outlined in this paper suggest the feasibility of routinely measuring shape (morphometric) information from video images of landed fish with existing optical image analysis capabilities now available in personal computers. Shape (morphometric) information can easily be converted to age if shape-age discriminant functions for each species are developed. In order to generate species discriminant functions, it is recommended that a standard procedure be developed to construct an accurate and precise species morphometric data base, incorporating ages determined from otoliths observed with scanning electron microscopy.

The advantage of the suggested approach lies with the simpler way to collect morphometric data based on video recordings relative to standard procedures. This approach will also allow gathering of a large number of observations with high accuracy and known precision over a wide-spatial-temporal range of fisheries, followed by a straight-forward age classification procedure.

These attributes will facilitate integration of statistically meaningful samples to estimate population age structures which can be used directly to estimate population mortality rates. Implementation of the proposed size-ageing method will circumvent the use of less precise and less accurate length-based mortality estimators usually applied to assess mortality of tropical fish stocks.

The procedures outlined here could be applied to tuna and tuna-like species, as well as to other

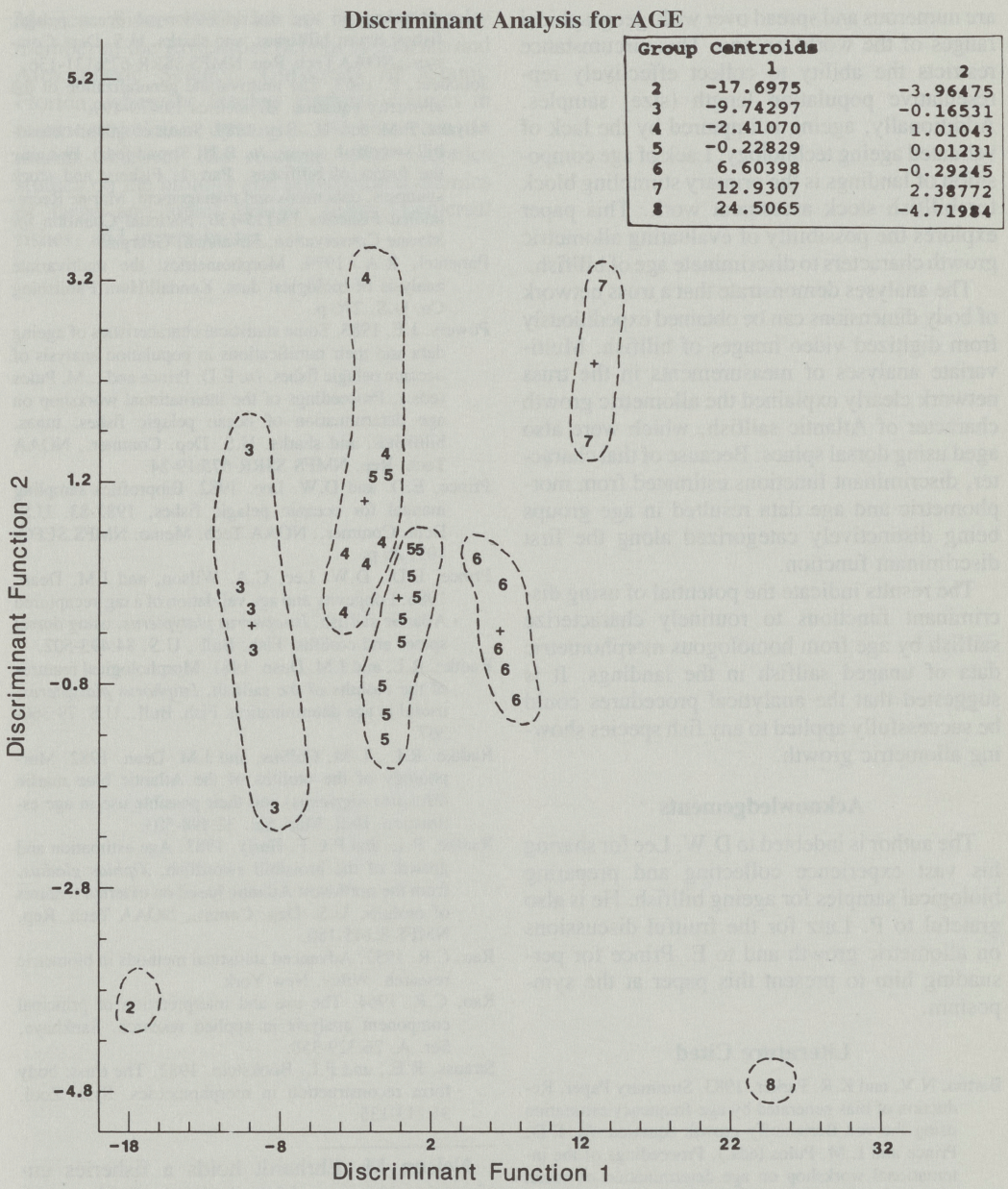

Figure 4. Scatters of age-group discriminations according to the first two discriminant functions estimated from the truss network, and corresponding estimated ages of Atlantic sailfish.

tropical fish species which might also grow allometrically. Among the latter species are the mackerels, groupers, snappers, and reef fishes in general. It is also recommended that an attempt be made to apply this methodology to crustaceans of commercial importance, such as shrimps and lobsters, for which age-shape discriminant functions may be obtained and validated experimentally from hatchery-raised animals.

Summary

Routine ageing of billfish landings is not economically feasible at present because landings

are numerous and spread over wide geographical ranges of the world oceans. This circumstance restricts the ability to collect effectively representative population length (size) samples. Additionally, ageing is impaired by the lack of validated ageing technology. Lack of age composition of landings is the primary stumbling block for billfish stock asessment work. This paper explores the possibility of evaluating allometric growth characters to discriminate age of billfish.

The analyses demonstrate that a truss network of body dimensions can be obtained expeditiously from digitized video images of billfish. Multivariate analyses of measurements in the truss network clearly explained the allometric growth character of Atlantic sailfish, which were also aged using dorsal spines. Because of that character, discriminant functions estimated from morphometric and age data resulted in age groups being distinctively categorized along the first discriminant function.

The results indicate the potential of using discriminant functions to routinely characterize sailfish by age from homologous morphometric data of unaged sailfish in the landings. It is suggested that the analytical procedures could be successfully applied to any fish species showing allometric growth.

Acknowledgements

The author is indebted to D.W. Lee for sharing his vast experience collecting and preparing biological samples for ageing billfish. He is also grateful to P. Lutz for the fruitful discussions on allometric growth and to E. Prince for persuading him to present this paper at the symposium.

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Potential of Dorsal and Anal Spines and Otoliths for Assessing the Age Structure of the Recreational Catch of Striped Marlin

Peter S. Davie and Irene Hall

Recreational anglers land the entire domestic striped marlin *(Tetrapturus audax)* catch in New Zealand as there is no domestic commercial marlin fishery. The average annual catch from 1975 to 1987, was approximately 485 striped marlin. The striped marlin catch ranged from 249 individuals in 1975 to a peak of 792 in 1981, then declined to 240 by 1987. A similar pattern of declining catches was observed between 1951 and 1970, when a steady increase occurred in the number of tuna longline vessels operating in the northern part of New Zealand's 200-mile Exclusive Economic Zone. The trends in catch are difficult to interpret as no effort data are yet available for this fishery. It was believed, however, that an analysis of the age structure of the catch would be helpful in understanding the perceived fluctuations in catch.

The biology of the striped marlin, which visits the coastal waters of New Zealand (Fig. 1) from December till June, is poorly documented. Gregory and Conrad (1939) and Morrow (1952, 1957) studied body form of New Zealand striped marlin and compared them to striped marlin from other areas of the Pacific Ocean. Papers on feeding by Morrow (1953) and Baker (1961), and some papers on hematology (Wells and Davie 1985, Wells et al 1986, Brittain 1985) constitute the current literature on New Zealand marlins. A series of reports to the New Zealand Big Game Fishing Council (Saul and Davie 1984; Davie 1984, 1985, 1986, 1987) have described research on New Zealand big-game fishes funded by that organization. Apart from the review of the catch data from the Bay of Islands Swordfish Club by Saul and Davie (1984), most of the projects described have been on game-fish physiology. There have been no previous attempts to age New Zealand marlin.

Age structure of striped marlin from the western Pacific was estimated by Ueyanagi and Wares (1974) by analysis of modes in size (length) frequency distributions. They discerned six age classes in striped marlin greater than 100 cm eye-fork length. Skillman and Yong (1976) analysed length frequency data of Hawaiian striped marlin and estimated up to six size classes, which they interpreted as age classes. Radtke (1983) examined otoliths (sagittae) from six billfish species, including those from 80 striped marlin from Hawaiian waters whose weights were between 18 and 63 kg. He reported that there were between three and six ridges on the rostrum.

Otoliths of the closely related white marlin *(Tetrapturus albidus)* had between three and five ridges for animals between 10 and 32 kg (Radtke 1983). Prince et al (1984) counted bands in spine sections and ridges on otoliths from 57 white marlin, and counted between three and fifteen bands in dorsal spine sections and between one and fifteen ridges on otoliths, from white marlin having lower jaw-fork lengths between 125 and 200 cm.

The difficulties in studying the biology of pelagic species, ageing in particular, have been described and discussed elsewhere (Prince et al 1984). Attempts to validate reliable techniques for ageing these animals have had limited success (Brothers 1983). Recent research, compiled

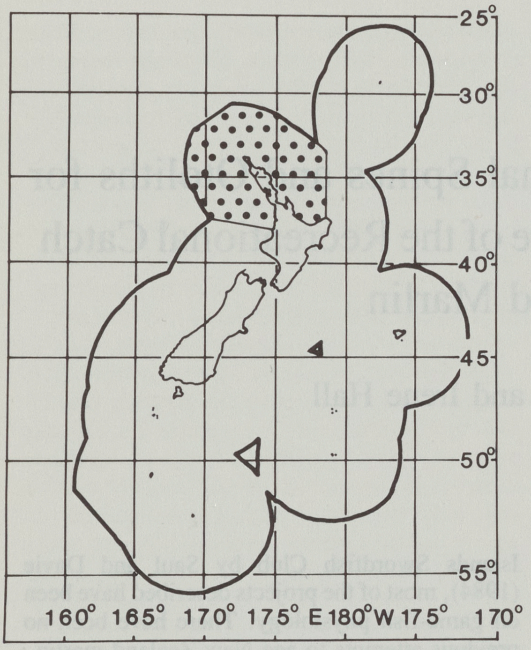

Figure 1. Map of New Zealand and its 200-mile Exclusive Economic Zone. The hatched area is closed to non-New Zealand longline fishing betweeen 31 October and 1 April. At other times of the year, all commercial fishing vessels must either tag and release, or release, all billfish species caught, including swordfish. This policy will be reviewed in 1990.

in the report from the workshop on age determination of oceanic pelagic fishes (Prince and Poulos 1983), and work by Hill (1986) on Pacific blue marlin *(Makaira nigricans),* have stimulated further research in this area.

The objective of the research described here was to estimate the ages of striped marlin caught in New Zealand waters by examination of skeletal structures. Estimates of the age structure of the catch are compared between years. Definitive evidence is lacking for the validity of the methods used in this study, as in many other studies.

Materials And Methods

Sampling of Dorsal Spines (1985–1988)

Fish were captured by anglers off the northeast coast of the North Island of New Zealand (173°E - 178°E: 33°S - 37°S; Fig. 1). Capture of the animals was not part of the sampling programme but provided the opportunity to obtain samples that otherwise would have been difficult to collect. The first five dorsal fin spines were collected from a total of 211 striped marlin between 1985 and 1988 by a variety of people, including anglers, weighmasters of sport fishing clubs, and fish processors. Weight (round weight), length (lower jaw to fork length), sex, and capture data were recorded when possible. Spines were stored frozen until processed. The third dorsal spine was used as it was the largest spine which showed the least erosion of the caudal aspect and core of the spine near the condyle base.

Sampling of Sets of Dorsal and Anal Spines and Otoliths (1988)

Dorsal spines, anal spines, and otoliths were collected from eight specimens by New Zealand government scientists (Ministry of Agriculture and Fisheries, Whangarei). Samples of the second, third, and fourth dorsal spines and from the second and third anal spines were collected and stored frozen. Sagittae were extracted and stored in glycerine until processed.

Preparation and Analysis of Skeletal Structures (1985-1988)

Measurements and techniques used for preparation of spines and otoliths followed previously published methods (Jolley 1977, Hill 1986) so as to facilitate comparisons with previously published data. The total height of the spine and its maximum transverse width at 10% of its height were recorded. Spine sections 0.3 mm thick were cut with a diamond lapidary saw from a location near the condyle base which represented 10% of the spine height. Sections were polished with grades of abrasive down to 800 grit.

Only spine sections (anal and dorsal) having opaque and translucent zones that were continuous around the entire circumference of the structure were accepted for analysis. A band is defined as a pair of adjacent zones of opaque and translucent tissue. Double or triple bands were dealt with by referring to the more compressed cranial part of the spine section where these subdivisions were not visible and using this region to interpret multiple bands in lateral areas of the section. Numbers of bands, spine width, and annuli radii were counted or measured by both authors under a compound stereomicroscope fitted with an occular micrometer at 10 × to 40 × magnification. A black background plus either transmitted or reflected light were used to visualize the bands. Band radius was measured to the distal edge of each translucent zone. Dorsal spine bands seen in sections from

17 fish were counted by the authors and independently by a colleague (Dr. K.T. Hill, University of Hawaii) who is experienced in counting bands in marlin spines.

Vascular erosion in the centre of the spine made it difficult or impossible to identify early growth zones. This problem was dealt with by a statistical replacement of the early bands destroyed by growth of the inner matrix, according to the methods of Hill (1986). In brief, this technique assumes that a predictable number of bands is laid down per mm in the inner core of the spine sections. Growth-band radii were compiled from sections in which the first and second bands were visible. These data were compared to band radii from the remaining sections, and the number of missing bands in these sections was estimated. The number of missing bands was added to the count of visible bands to give band number.

Otoliths were prepared for scanning electron microscopy, according to the methods of Radtke (1983). In brief, after storage in glycerine, otoliths were removed and washed in distilled water, bleached in 5% sodium hypochlorite for one hour, and dehydrated in 95% ethanol before drying at 80°C for 24 hours. Otoliths were weighed to ± 0.0001g, mounted onto stubs with nail polish, and coated with gold before scanning electron microscopic examination.

Otoliths were examined by both authors, and the number of ridges visible on the rostrum, from the core to the distal edge, were counted. Where overburden, or superficial deposition of material, was evident on the rostra of sagittae, ridges could be seen between the overburden projections in most cases. The number of bands or ridges is assumed to reflect the passage of time.

Statistical Analysis

The significance level for all statistical comparisons was 0.05%. Student's t-tests were used to compare mean weights and ages between sexes. Fischer's F-test was used to compare mean band numbers between years and mean numbers of bands or ridges on anal and dorsal spines and otoliths. Product-moment correlations were used to examine linear associations between variables. Least-squares fitting of linear regressions was used to examine the relationships between variables that showed significant correlations. Spearman's rank correlation was used to compare spine band counts between readers. Frequency distributions of estimated ages for each year were compared, using the Kolmogorov–Smirnov test (Hollander and Wolfe 1973).

Findings

Morphometric Data

Of 211 marlin sampled for dorsal spines, only 173 dorsal spine sections were accepted by the authors as readable. Weights of females ranged from 77 to 188 kg and lower jaw-fork lengths were between 1.97 and 2.83 m; weights of males ranged from 36 to 157 kg and lengths were between 1.89 and 2.74 m (Table 1). Length- and weight-frequency histograms showed unimodal patterns. Females were significantly heavier than males (Student's t-test). Lengths and spine widths were not significantly different between the two sexes (Student's t-test).

Table 1. Summary of data from 173 striped marlin from which only dorsal fin spines were analysed: 97 females, 58 males, 18 fish of unknown sex. Not all information is available for each fish (Mean ± SD).

	Weight (kg)	Length (m)	Spine width (mm)
Females	112.2 ± 20.4	2.43 ± 0.18	13.17 ± 2.71
N	94	55	97
Males	99.06 ± 25.09	2.37 ± 1.64	12.97 ± 2.31
N	58	38	58
Males + females + Unkown sex (M/F)	107.6 ± 24.4	2.41 ± 1.76	13.09 ± 2.55
N	173	99	173

Weight and length were significantly correlated ($r = 0.743$, $N = 87$) for all fish represented by such data. Linear regression lines were fitted to males and females separately: Males, weight = 105.2, length − 147.5, $r = 0.593$ ($N = 38$): Females, weight = 52.16, length − 11.4, $r = 0.192$ ($N = 55$). The data for males were less variable and showed better fit of linear regression lines than data for females. Length was not significantly correlated with spine width or spine height. Height of the third dorsal spine was not significantly correlated with any measurement taken except spine width.

Dorsal Spines As Primary Ageing Structures

Sections of striped marlin third dorsal spines showed concentric growth bands. The presence of double and occasionally triple bands, as has been observed in many pelagic species, including billfishes, was seen in spines prepared for this study (see Hedgepeth and Jolley 1983 for references). A paired Student's t-test com-

parison of the band counts by the independent reader and the authors showed no significant difference ($P = 0.43$), and the Spearman's rank correlation coefficient between the two sets of estimates was 0.912. Dorsal spine sections therefore give reliable estimates of band counts (Antoine et al 1983).

Vascular erosion of the core of the spine was observed in most sections and, as already stated, the technique of statistical replacement was used to overcome band loss due to erosion (Hill 1986). Thirteen sections of the 173 total showed little erosion and what appeared to be distinct first annuli. Radius measurements from these sections were compared to the radius measurements of the remaining 160 samples. Fourteen of these 160 samples had band radii that lay within the 95% confidence limits of the measurements of the second through sixth bands of the original 13 sections. The band radius data for these sections was combined with those from the original 13 sections. The number of missing bands was estimated in the remaining 146 sections by comparing the radii of their bands to the radius statistics of these 27 samples (Hill 1986). Thus, the band number is equal to the band count plus the number of missing bands.

Dorsal spine band numbers were significantly correlated with weight ($r = 0.46$), length ($r = 0.35$), and spine width ($r = 0.70$). Band numbers and spine height were not significantly correlated. The relationship between band numbers and weight is illustrated in Figure 2.

The dorsal spine band frequency distribution of females and males were not significantly different, despite the fact that females were heavier than males (Fig. 3, Table 1).

Age structures of the years examined were variable (Fig. 4). Samples collected during 1985 and 1986 showed statistically similar age structures. Mean weights between years were not significantly different except for 1987 and 1988. Mean weight of marlin caught in 1988 was less than that of marlin caught in 1987 (Fisher's F-test, $F = 4.09$, $P = 0.04$). Mean numbers of dorsal spine bands were significantly different for all years except 1986 and 1987 (Fisher's F-test).

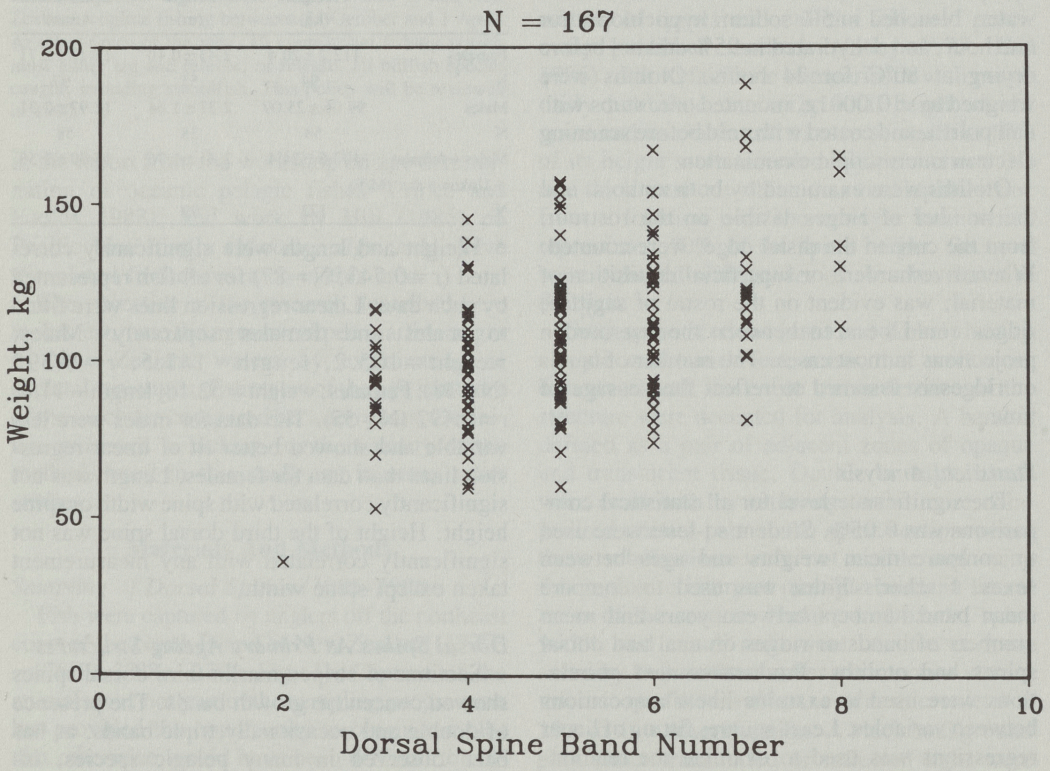

Figure 2. Relationship of dorsal spine band number to weight (kg) for New Zealand striped marlin. Linear regression equation: Weight(kg) = 9.1932 Age + 61.03. n = 167. Mean weights in kg(±SD) at ages are as follows: 3, 92.8 ± 15.6; 4, 97.4 ± 20.3; 5, 108.6 ± 21.4; 6, 112.4 ± 21.7; 7, 125.6 ± 28.0; 8, 145.1 ± ± 21.9.

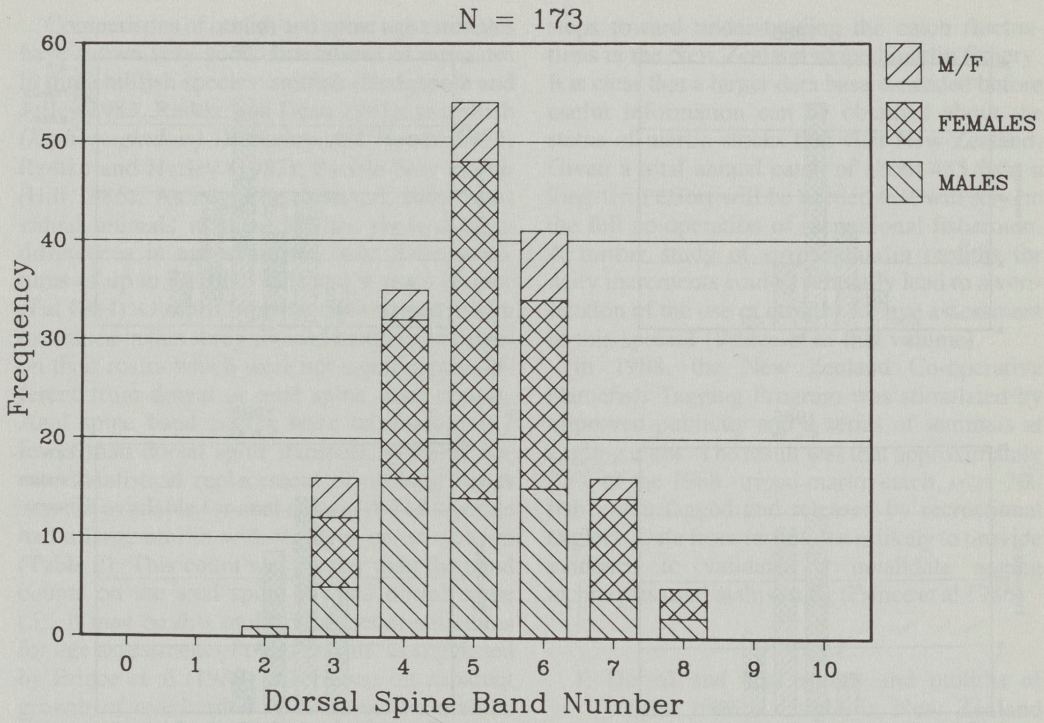

Figure 3. Frequency distribution of estimated ages for New Zealand striped marlin sampled between 1985 and 1988. N = 173. Ages were estimated from cross sections of dorsal spines.

Otoliths as Tissues for Estimating Age of Striped Marlin

There was good agreement between the counts of bands or ridges from dorsal and anal spine sections and from otoliths (Table 2). Anal spine band counts were on average 0.7 bands fewer than dorsal spine band counts. Otolith ridge counts were, on average, 0.5 more than dorsal spine band counts. There were no statistically significant differences between counts from any of these structures, (Fisher's F-test).

Discussion

Numbers of bands in dorsal and anal spines of striped marlin studied here were similar to those observed for other istiophorids by Jolley (1977), Prince et al (1984), and Hill (1986). Numbers of bands in dorsal spine sections of the 173 samples used in this study ranged from between two and eight. The numbers of bands recorded in the present study are consistent with striped marlin age estimates of previous workers (Ueyanagi and Wares 1974, Skillman and Yong 1976, and Radtke 1983), and age estimates for white marlin from dorsal spines (Prince et al 1984). Striped marlin used in the present study were generally larger than in the cited reports; indeed, New Zealand striped marlin are noted for their large size compared with those from other parts of the Pacific Ocean. Within the size ranges reported in other studies of striped marlin (Ueyanagi and Wares 1974, Skillman and Yong 1976, Radtke 1983) and white marlin (Prince et al 1984), New Zealand striped marlin show fewer bands in spine sections and fewer ridges on otoliths. Perhaps striped marlin from New Zealand waters grow faster than those caught in other regions.

Prince et al (1984) suggested that dorsal spine band sections underestimate age because of the problem with vascularization of the spine core. Recent evidence from a tagged and recaptured Atlantic sailfish *(Istiophorus platypterus;* Prince et al 1986) indicated for this species that otolith age more accurately estimated known age in fish $\geq$22 kg than did dorsal spine band age. It is noted, however, that the spine from this sailfish would not normally have been used for ageing, as the erosion of the core was extensive. It is suggested, then that spine rejection on the basis

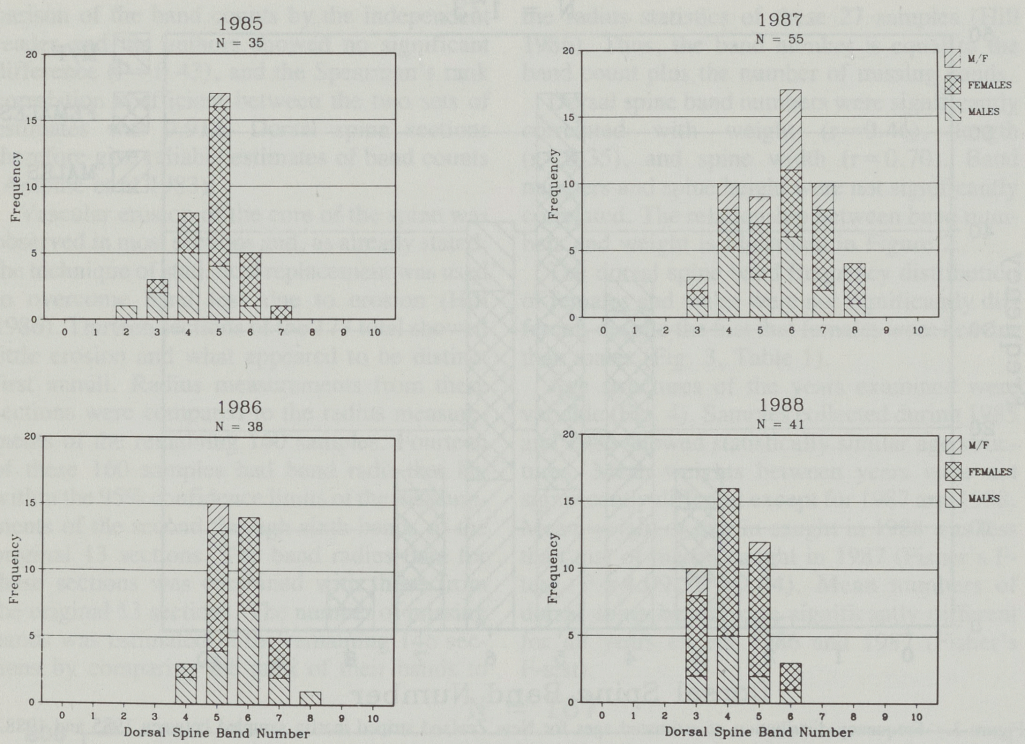

Figure 4. Frequency distributions of estimated ages for New Zealand striped marlin sampled between 1985 and 1988. Ages were estimated from cross sections of dorsal spines.

of an extensive vascular core biases samples against larger/older fish (Powers 1983).

The use of statistical replacement of bands lost by vascular erosion should permit reasonable estimates of age in older animals that show significant erosion of the core. This approach was used in the current analysis and up to 4 lost bands were 'statistically replaced'. The relatively low rejection rate in this study (18%), compared with around 47% for sailfish spines (Hedgepeth and Jolley 1983), has probably removed some of the bias against older animals. Although it is possible that there were fewer old striped marlin in the sample, the weights and lengths of the fish suggest that the samples are from mature fish.

Table 2. Mean counts of bands and ridges from dorsal and anal spine sections, and otoliths, and otolith weights for eight striped marlin collected in 1988. Sex, length (lower jaw — fork length, m) and weight (kg) are given for each sample. Average counts were computed from two readers making three replicate counts of each spine section and three replicate counts of both left and right otoliths.

Sex	Length (m)	Weight (kg)	Average Dorsal spine Band Number	Average Anal spine Band Couunt	Average Otolith Ridge Count	Average Otolith weight (mg)
M	2.35	93	3	3	3	2.3
M	2.51	127	4	3	6	4.3
M	2.47	113	6	5	9	6.1
F	2.26	90.6	4	4	4	2.5
F	2.05	106.3	*	4	5	3.6
F	2.45	119.2	6	4	5	2.9
F	2.42	103	5	4	4	2.7
M	2.32	105	4	3	6	6.3

* Spines 2, 3, and 4 were fused and were uninterpretable

Comparisons of otolith and spine age estimates have shown very good correlations of estimates in three billfish species: sailfish (Hedgepeth and Jolley 1983, Radtke and Dean 1981); swordfish *(Xiphias gladius)* (Berkeley and Houde 1983, Radtke and Hurley (1983); Pacific blue marlin (Hill 1986). As might be expected, some individual animals in these studies showed large differences in age estimates from these structures of up to 7 (Hill 1986) and 9 years (Prince et al 1984). Otoliths from the eight striped marlin examined in this study showed numbers of ridges on their rostra which were not significantly different from dorsal or anal spine band counts. Anal spine band counts were on average 0.7 fewer than dorsal spine numbers, possibly because statistical replacement of missing bands was not available for anal spines. A 113 kg male had a large otolith with 9 ridges on its rostrum (Table 2). This count was greater than the band counts on the anal spine (6) and dorsal spine (5). It may be that otoliths are better structures for age assessment of older marlin, as suggested by Prince et al (1986). There was an apparent growth of overburden in some of the otoliths examined, which obscured part of the rostrum near the core. No attempt has yet been made to examine how this event might affect the usefulness of otoliths in age assessment of New Zealand striped marlin.

The limited age, weight, and length ranges of the data restrict the ability to discern growth patterns from these samples. Therefore, the regression of length and weight, using other than linear models, does not show any marked improvement in fit. Attempts to model growth of males and females, using the von Bertalanffy equation, resulted in estimates for t_o and L_∞ which were unacceptable when compared to the values obtained by Skillman and Yong (1976). Marginal increment analysis has not been attempted because the seasonal nature of the fishery results in sample collections which span only four months.

The age structures of the yearly samples show no significant trends (Fig. 4). The small sample sizes and the high level of variability dictate that any further analysis must await acquisition of more data. The technique of comparing age distributions has the advantage that no presumption of a time period for band formation is made, except that addition of bands represents passage of time.

The data presented here represent the first steps toward understanding the catch fluctuations in the New Zealand striped marlin fishery. It is clear that a larger data base is needed before useful information can be obtained about the status of marlin stocks that visit New Zealand. Given a total annual catch of about 485 fish, a long-term effort will be needed that will rely on the full co-operation of recreational fishermen. A further study of striped marlin otoliths for daily increments could eventually lead to a verification of the use of otoliths for age assessment in this species (Prince et al this volume).

In 1988, the New Zealand Co-operative Gamefish Tagging Program was stimulated by improved publicity and a series of seminars at angling clubs. The result was that approximately 25% of the 1988 striped marlin catch, over 200 fish, were tagged and released by recreational anglers. Data from recaptures is likely to provide evidence to validate or invalidate ageing techniques used in this study (Prince et al 1986).

Summary

1. Dorsal and anal spines and otoliths of striped marlin caught in New Zealand waters show morphological features which appear useful in assessment of their ages. No validation of these techniques is yet available.
2. Numbers of spine bands and otolith ridges of New Zealand striped marlin ranged between 2 and 9. Otoliths gave the highest numbers and anal spines the lowest. There was, in general, good agreement between numbers of bands and ridges from the pairs of different structures analysed.
3. Females were significantly heavier than males, but neither numbers of bands nor band number distributions of males and females were significantly different.
4. Band number frequency distributions for each year studied were variable. Much of this variation was due to the small sample sizes (35 to 55 animals per year). No significant trends were apparent from analyses of these distributions.

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Ageing Young Atlantic Blue Marlin *(Makaira nigricans)* from Otolith Microstructure (Summary Paper)[1]

Eric D. Prince, Dennis W. Lee, James R. Zweifel, and Edward B. Brothers

Published reports on validated age determination methods for billfishes (Istiophoridae) are rare or nonexistent (Lee 1989), yet these data are essential for stock assessment (Beamish and McFarland 1983). Prince et al (1987) examined the problem in estimating age and growth of Atlantic blue marlin *(Makaira nigricans)*. They concluded that age determination for this species may be more difficult than for most other teleosts because of several factors related to the fishery and their life history. This paper examines the use of otolith microstructural analysis for ageing Atlantic blue marlin.

Methods

Data Collection

Juvenile and young Atlantic blue marlin were collected directly by National Marine Fisheries Service (NMFS) samplers from taxidermists, commercial and recreational fishermen, and at billfish tournaments or ports in the Gulf of Mexico, Caribbean Sea, and western Atlantic Ocean. Starting in 1984, rare size categories were collected through the special SAVE IT FOR SCIENCE PROGRAM (Prince 1984). A number of hard structures (including sagittae), lower jaw-fork length (LJFL), round weight, sex, and date of capture were collected from each specimen. Length measurements (cm) were made along the contour of the body. Samples of gonad tissue from specimens which could not be sexed immediately were saved and preserved for later analysis.

Larvae were collected with plankton nets using procedures of Brothers et al (1983). Larvae were measured from the tip of the lower jaw to the tip of the notochord (NL), or to developing hypural plates (SL), to the nearest 0.1 mm, and weights were taken in grams. Vertebral counts were made in order to separate blue marlin from the *Istiophorus-Tetrapturus* group.

Otolith Extraction, Preparation, and Microstructural Analysis

Otolith extraction procedures were the same as those of Radtke (1983) for all juveniles and adults. Extraction methods of Brothers and McFarland (1981) were used for larvae.

Otolith microstructure preparation and analysis was the same as that described by Brothers et al (1983) for larval and juvenile bluefin tuna *(Thunnus thynnus)*. For larger fish, procedures described by Brothers (1987) were used. Preparation of otoliths sections for scanning electron microscope (SEM) examination followed methods described by Brothers et al (1983), Brothers and Mathews (1986), Brothers (1987), and Jones and Brothers (1987). Otolith mass for blue marlin ≥4.3 cm were weighed to the nearest 0.01 mg.

[1]A more detailed paper has been submitted to the Fishery Bulletin, U.S.

Where possible, counts and photographs of the video images of "primary" increments (i.e., opaque and translucent zones or dark and light rings viewed with transmitted illumination; Geffen 1987) are from the dorsal lobe along the anterior axis. Otherwise, counts were made along the posterior axis. The majority of increment counts were made on sagittal views of whole otoliths. Thirty percent of the otoliths could not be read easily and these were excluded from the ageing analysis.

Primary increment counts and measurements were made off the video monitor at 100× to 2500× magnification and were not corrected for age at first increment formation because known age larvae were not available. Subdaily increments described by Brothers (1979) were easily identified by their vague appearance and regular clustering within the more prominent primary units but were not tallied. Back-calculated spawning dates were computed by subtracting the total count of primary increments for each sample from the date of capture.

A size-selected subsample of otoliths from 7 adult males (213 to 274 cm) and 16 adult females (213 to 369 cm) were examined to evaluate ageing of older fish. These otoliths were prepared and analyzed according to the methods of Brothers and Mathews (1986) and Radtke (1984). The compound light microscope and SEM were used on whole otoliths and transverse sections, respectively, to evaluate the primary increments observed between presumed annuli.

Precision of Age Determination Technique

Except for larvae, three non-consecutive blind counts were made by the same reader on the same otolith to assess the repeatability (precision) of microstructural analysis using the average percent error (APE) approach of Beamish and Fournier (1981).

Statistical Procedures

Size-at-age. Continuous estimates of size-(length and weight)-at-age and daily growth rates for the age range in our data were calculated using Gompertz equations:

$$L = P_1 * \exp(-P_2 * \exp[-P_3 * t]) \quad (1a)$$

and

$$W = Q_1 * \exp(-Q_2 * \exp[-Q_3 * t]) \quad (1b)$$

on data up to 110 cm LJFL, and the von Bertalanffy equation:

$$L = P_1 * (1 - \exp[P_2 * (t - P_3)]) \quad (1c)$$

and equation 1b for larger fish. Weight-at-age parameters (Q) were calculated directly for fish <110 cm using the parameters (P) of the length-at-age equation and the length-weight relationship, $\ln W = a + b \ln L$, i.e.,

$$Q_1 = \exp(a) * P_1 ** b \quad (1d)$$

$$Q_2 = b * P_2 \quad (1e)$$

and

$$Q_3 = P_3. \quad (1f)$$

For fish >110 cm, individual lengths were converted to weights before estimating the weight parameters (Q) using equation 1b. Least-squares estimates of the parameters of the growth equations were obtained using the algorithm of Marquardt (1963) and the methods of Conway et al (1970).

Length-weight relationships. The analysis of covariance was used to test for sexual dimorphism in the length-weight relationships for both immature and mature fish.

Increment counts. Spearman's rho rank correlation coefficient (SRRC; Conover 1971) was used to evaluate the association of total increment count with LJFL, otolith weight, and round weight.

Results And Discussion

Otolith Microstructure

Otolith microstructure of larval blue marlin (Fig. 1A) was indistinguishable from that of frigate mackerel *(Auxis thazard),* as well as many other pelagic species of similar size (Fig. 1). For some of these fishes, daily increments have been validated by rearing experiments, otolith marking, or other methods (Brothers et al 1976, Wild and Foreman 1980, Brothers et al 1983).

There is an optically dense region (primordium) about 5 μm in diameter in the center of blue marlin sagittae which is usually encircled by one or two diffuse dense layers. We refer to the area circumscribed by the first clear growth increments as the core; this region includes the primordium and an area of "non-incremental" growth.

Subunits (light and dark rings when viewed optically) of primary increments are of about equal thickness for the first two or three increments, thereafter gradually changing so that the optically transparent subunit becomes progressively wider relative to the denser subunit (Fig. 2). As evidenced by the comparison with other species (Fig. 1), increments on larval blue marlin otoliths appear visibly distinct for most specimens, and are structurally analogous to the

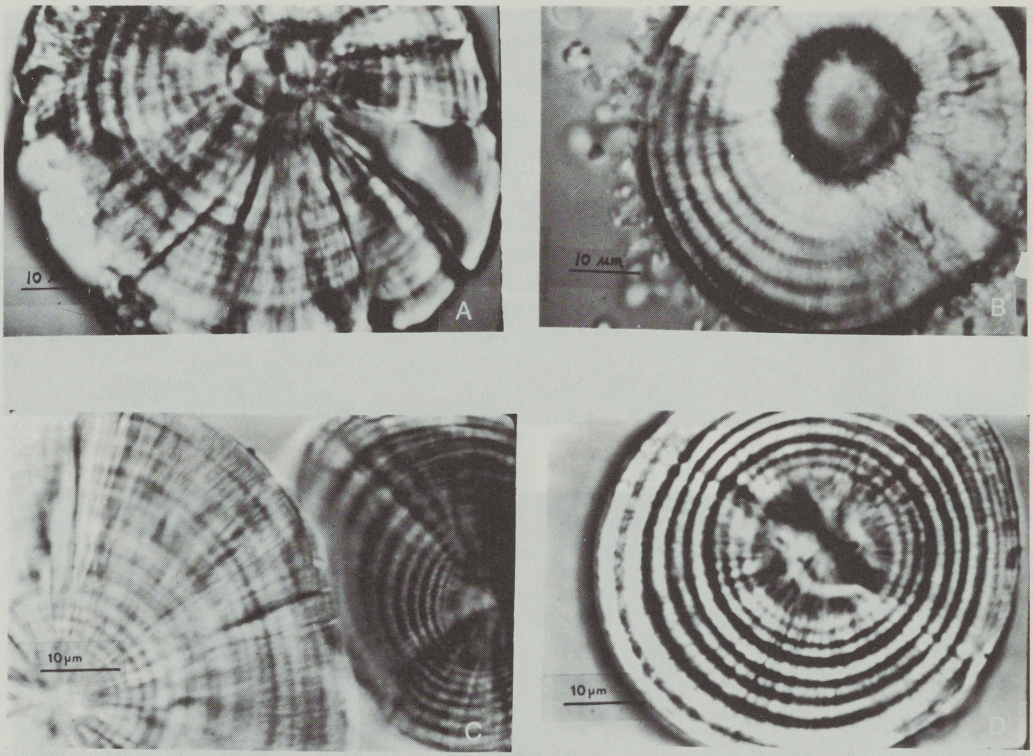

Figure 1. Photomicrographs of the video image of whole otoliths for: (A) Sagittae from a 5.74 mm NL blue marlin larva. Black bar = 10 µm: (B) Sagittae from an 8.5 mm NL swordfish *(Xiphias gladius)* larva. Black bar = 10 µm; (C) Sagitta (left) and lapillus (right) from an 8.61 mm SL yellowfin tuna *(Thunnus albacares)* larva. Black bar = 10 µm: (D) Sagittae from a larval frigate mackerel *(Auxis thazard)*. Black bar = 10 µm.

daily growth increments seen in many other species, including some tropical pelagic species (Brothers 1979, Pannella 1980).

Otolith Analysis

Otolith microstructural analysis was successfully applied to 18 larvae (5 to 10 mm NL) and 77 juvenile and young adult blue marlin (4.3 to 212 cm SL). The entire microstructural record from a 23 cm long juvenile, illustrated in Figure 2, exemplifies the regular undisrupted record of increments observed in young fish. Of the 135 samples ≤212 cm long, 40 could not be aged using the otolith microstructural method (30%). Within the age range 9 to 495 days, confidence and reliability of the ageing method decreased progressively with increasing age. Interruptions and discontinuities of the microstructural record usually occurred at counts of about 400 to 500 along the antirostrum dorsal lobe counting path. The depositions of individual increments on the otoliths of all adult fish from 213 to 369 cm were so close to one another, and difficult to distinguish, that we lacked confidence that accurate counts could be made. For this reason, we concluded that, application of the otolith microstructure method to fish >212 cm, or at an age greater than about 1.4 years, was inappropriate with current technology. For the reasons discussed below, references to increments, primary increments, or daily increments generally imply daily deposition.

Age Range of Confidence and Precision

The range in estimated ages, based on counts on the whole sagittae of the 18 larval blue marlin, was 9 to 12 days (Table 1). The range in estimated ages of the 77 juvenile and young adult blue marlin was 21 to 495 days or a maximum of 1.4 years (Table 1).

Average percent error values for blue marlin (0.3 – 4.0%), in the age range 21 to 495 days, compare favorably with those published for other species and ageing methods (Brown 1988,

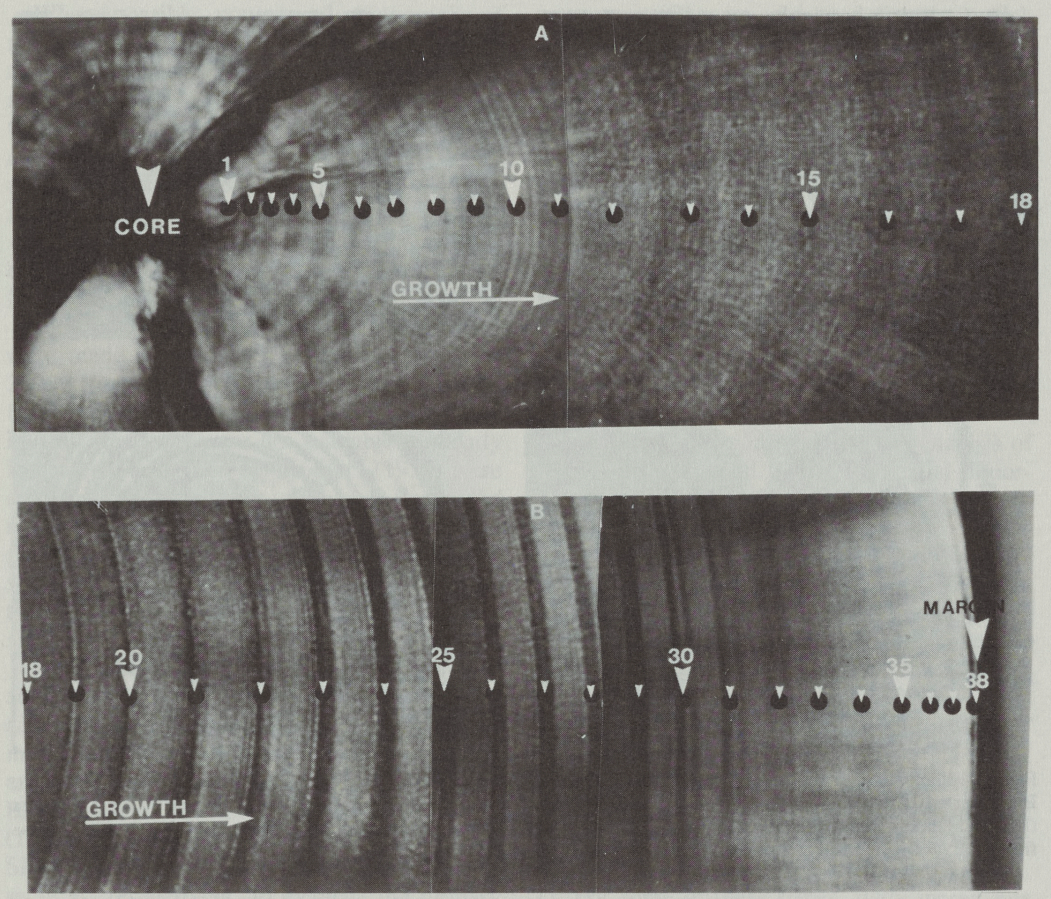

Figure 2. Composite photomicrograph of reader interpretation (E. B. Brothers) of primary increments along the entire counting path of a whole ground sagittae from a 23 cm LJFL juvenile Atlantic blue marlin. Location of core, direction of growth, and margin are shown for A (counts from 1 through 18) and B (counts from 18 through 38). Because of problems inherent in sectioning increments on a counting path whose axis of growth is continually changing, mid-increments (20 to 30) appear in better focus than increments closer to the core and margin. A few increments near the core are not visible in the photograph and, thus, the total (38) does not match the mean count of three replicate counts (40). Black bar = 10 μm.

McGowan et al 1987, Cayre and Diouf 1983). Both the overall mean (1.6%) and maximum APE indicate that the otolith microstructure method applied to young blue marlin clearly meets the requirement (<10%) described by Powers (1983) for an acceptable level of precision for use of an ageing technique in stock assessment.

Back-Calculated Spawning Dates

Back-calculation of spawning dates and descriptions of otolith microstructure are inherently less informative for age validation than direct approaches, such as rearing fish of known age in captivity or chemical labeling (e.g., oxytetracycline; Geffen 1987). When these methods are precluded, however, indirect methods become critically important.

The primary back-calculated spawning dates were from May through November (Fig. 3A). Except for the 18 larvae which were all sampled in the month of August, the distribution of back-calculated spawning dates did not appear to be associated with the dates of capture (Fig. 3B). The large variation in ages of the juveniles and young adults (about 3 to 16 months) also reduced the possibility that calculated spawning dates are a simple reflection of the distribution of capture dates of age- or size-selected fish.

Our data on back-calculated spawning dates

Table 1. Summary of results of the otolith microstructure method applied to sagittae of young Atlantic blue marlin. Range in estimated age (days), sample size (n), mean increment count (days), mean observed and estimated (in parentheses) LJFL (cm), average growth rate (cm/day), LJFL range (cm), mean observed and estimated (in parentheses) round weight (kg), and round weight range (kg) are given for each age category.

Range in Estimated Age (days)	Sample Size (n)	Mean Increment Count (days)	Mean LJFL[1] (cm)	Average Growth Rate (cm/day)	LJFL Range (cm)	Mean Round Weight[1] (kg)	Round Weight Range (kg)
1–20	18	10	0.6[2] (0.7)	0.1	0.5 – 1.0	—	—
21–30	1	21	4.3 (3.9)	0.3	4.3	0.6[3] (0.4[3])	0.6[3]
31–60	1	40	23.0 (23.1)	1.0	23.0	0.1 (0.1)	0.1
61–90	1	89	95.3 (91.3)	1.5	95.3	4.3 (4.7)	4.3
91–120	7	105	103.3 (102.3)	0.5	88–118	6.2 (6.6)	3.5–10.0
121–150	3	141	114.7 (119.0)	0.3	100–126	9.6 (12.1)	8.4–11.4
151–180	5	169	128.5 (129.5)	0.5	116–136	13.5 (15.1)	10.9–17.5
181–210	9	193	143.9 (137.2)	0.7	129–173	17.5 (17.9)	12.7–21.8
211–240	7	229	147.4 (147.6)	0.1	139–152	24.5 (22.6)	19.5–39.0
241–270	4	254	161.8 (153.9)	0.6	150–172	30.5 (26.1)	20.0–43.1
271–300	5	292	158.8 (162.3)	-0.1	153–173	30.7 (31.9)	22.7–45.8
301–330	7	317	156.9 (167.3)	-0.1	140–170	30.1 (36.1)	24.0–36.3
331–360	4	341	170.6 (171.4)	0.6	149–180	43.6 (39.9)	38.5–47.2
361–390	9	373	172.4 (176.4)	0.1	160–193	40.5 (45.5)	30.8–58.0
391–420	3	411	199.8 (181.4)	0.7	196–207	62.5 (52.0)	51.7–72.4
421–450	8	432	183.1 (184.0)	-0.8	154–196	49.7 (55.8)	35.4–58.0
451–480	2	454	190.9 (186.3)	0.4	173–209	56.1 (59.6)	40.0–72.2
481–510	1	495	212.1 (190.1)	0.5	212.1	83.9 (66.6)	83.9

[1]Average for male and female fish > 110 days.

[2]Notochord length.

[3]Grams.

(Fig. 3A) agree with the spawning season (April-November) reported by Mahon and Mahon (1986) and the peaks of spawning (mid-summer and fall) documented by Erdman (1968) and Yoe (1978). The absence of conflicting results in these comparisons is consistent with the hypothesis that the increments on sagittae from Atlantic blue marlin are formed once each day.

Length-Weight Relationships

Covariance analysis showed no difference in the slopes ($P = 0.136$) or Y-intercepts ($P = 0.843$) for the length-weight regressions for males, females, and and unknown sex in the immature size range (≤140 cm). The allometric length-weight relationship for blue marlin ≤140 cm is:

$$\ln W = -11.950 + 2.9921 \ (\ln \text{LJFL}); \quad R^2 = 0.98 \qquad (3)$$

For males and females >140 cm, all available length and weight data collected from 1972 to 1988 (1,969 males and 3,260 females) by the SEFC recreational billfish survey program were used. Separate length-weight equations were developed for the entire mature size range of both sexes and covariance analysis was used for fish in the common length range 140 cm to 277 cm. The difference between slopes of the length-weight regressions was highly significant ($P = 0.0001$). The allometric length-weight relationship for male and female blue marlin >140 cm are:

$$\text{males:} \quad \ln W = -12.568 + 3.1583 \ (\ln \text{LJFL}); \quad R^2 = 0.87 \qquad (4)$$

$$\text{females:} \quad \ln W = -13.121 + 3.2734 \ (\ln \text{LJFL}); \quad R^2 = 0.92 \qquad (5)$$

Growth

Observed and estimated lengths and weights-at-age for monthly intervals are shown in Table 1. All length-at-age data are shown in Figure 4 for males and females combined. Lengths and weights-at-age, absolute growth rates (AGR, cm or kg/day), and relative growth rates (RGR, percent body length or weight/day) were computed for the first 495 days using the appropriate growth equation as shown in Table 2. The maximum AGR for blue marlin (sexes combined, 1.66 cm) occurred at a length of 39 cm and an estimated age of about 50 days (Table 2). The AGR decreased continuously from this point to about 0.09 cm/day at 495 days. Relative growth rates decreased continuously from about 21 percent to 0.04 percent from 10 to 495 days (Table 2).

Our data indicate that the early absolute

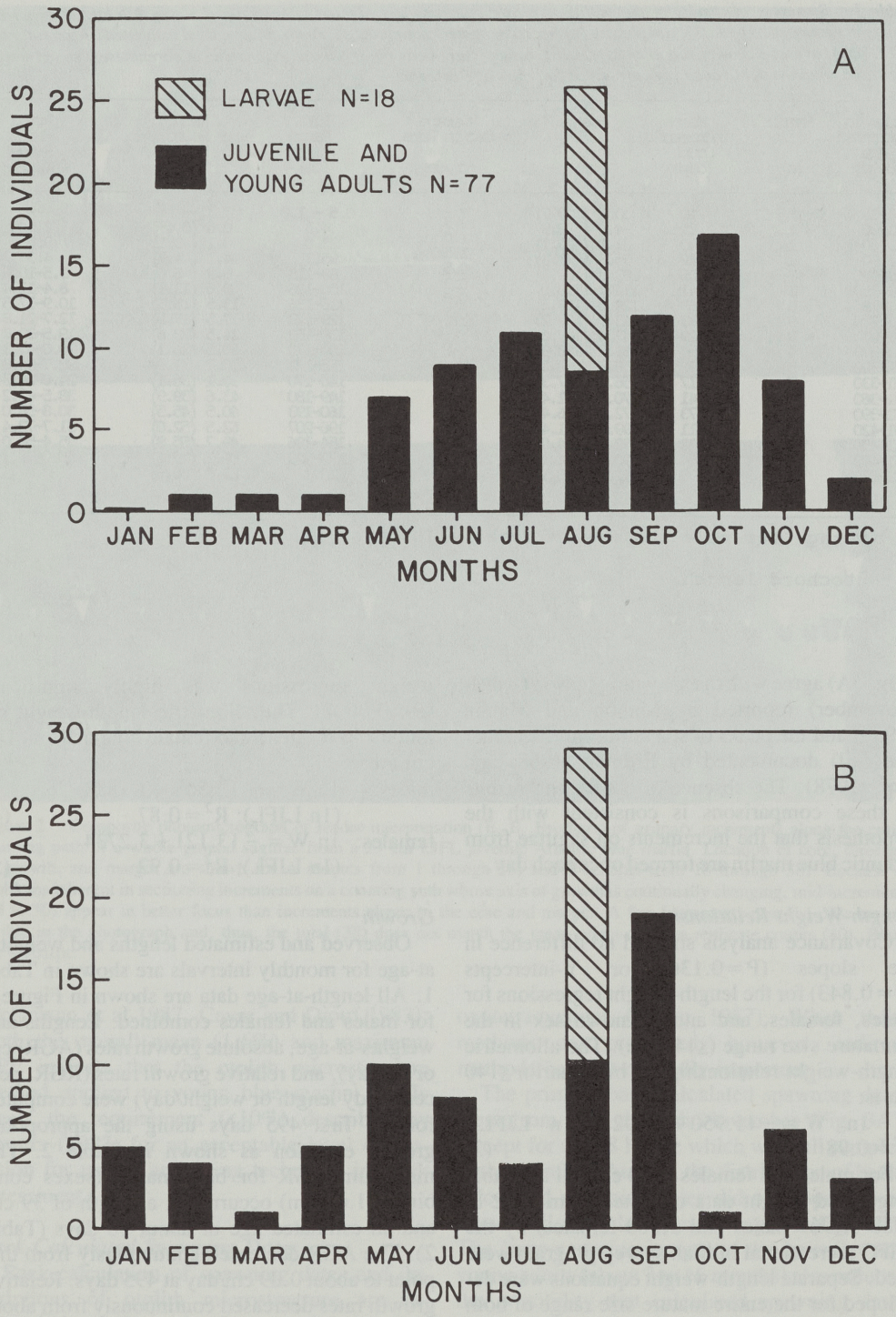

Figure 3. (A) Back-calculated spawning dates for 18 larvae and 77 juvenile and young adult Atlantic blue marlin. Total increment count on the otolith (sagittae) and date of capture were used to back-calculate spawning month; (B) Distribution of capture dates for 18 larvae and 77 juvenile and young adult Atlantic blue marlin collected from 1980 to 1988.

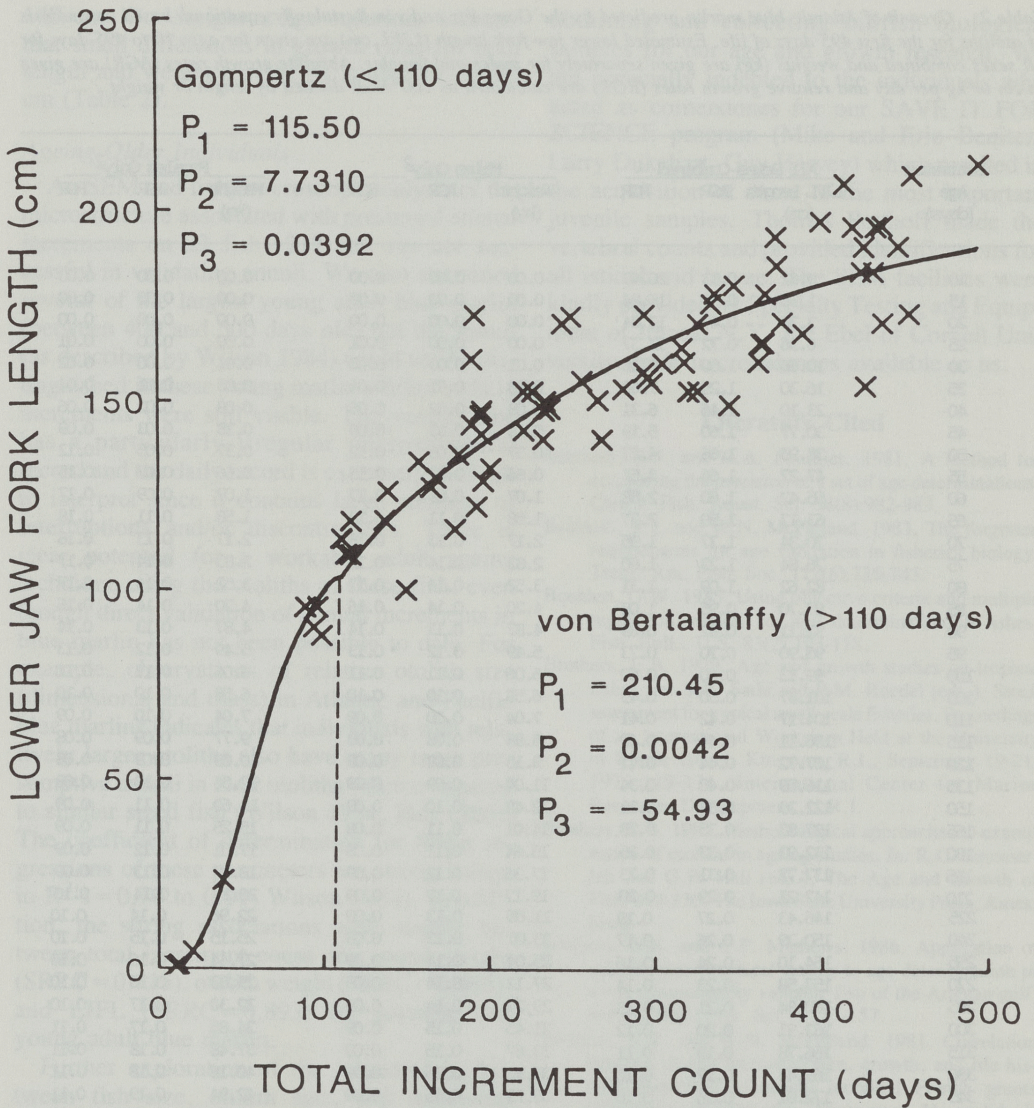

Figure 4. Length-at-age data fitted to the Gompertz equation (to theleft of the vertical line) for the first 100 days of life (24 larvae and juvenile Atlantic blue marlin). Parameters (P_1, P_2, and P_3) are given, $R^2 = 0.98$. Length-at-age data fitted to the von Bertalanffy equation (to the right of the dashed vertical line) for the age range 110 to 495 days (71 juvenile and young adult blue marlin). Parameters (P_1, P_2 and P_3) are given, $R^2 = 0.77$.

growth rates of blue marlin exceed those of most teleosts, particularly in length, but that larval, juvenile, and young adult growth are not particularly exceptional measured on a relative scale. In addition, interspecific comparisons of linear growth rates can be misleading without considering differences in body shape and resultant patterns of growth in body weight. Juvenile blue marlin are highly elongate fishes and the very high rates of growth in length correspond to only moderate rates of increase in weight. Since swimming speed usually increases with increases in body length, this early growth period is no doubt advantageous for survival, and sets the stage for the fast-swimming and wide-ranging capabilities of adults.

Sexual dimorphism in linear growth was not evident from our samples (perhaps due to small sample size), but significant differences in the length-weight relationships were found above

*Table 2. Growth of Atlantic blue marlin predicted by the Gompertz and von Bertalanffy equations[1] based on analysis of otoliths for the first 495 days of life. Estimated lower jaw-fork length (LJFL,cm) are given for ages 10 to 495 days for all sexes combined and weights (kg) are given separately for males and females. Absolute growth rates (AGR) are given in cm or kg per day and relative growth rates (RGR) are calculated as 100*AGR divided by length or weight.*

Estimated Age (days)	All Sexes Combined			Males Only[2]			Females Only[2]		
	LJFL Length (cm)	AGR	RGR	Weight (kg)	AGR	RGR	Weight (kg)	AGR	RGR
10	0.62	0.13	20.49	0.00	0.00	0.00	0.00	0.00	0.00
15	1.58	0.27	16.84	0.00	0.00	0.00	0.00	0.00	0.00
20	3.39	0.47	13.84	0.00	0.00	0.00	0.00	0.00	0.00
25	6.36	0.72	11.37	0.00	0.00	0.01	0.00	0.00	0.01
30	10.66	1.00	9.35	0.01	0.00	0.02	0.01	0.00	0.02
35	16.30	1.25	7.68	0.03	0.01	0.04	0.03	0.01	0.04
40	23.10	1.46	6.31	0.08	0.02	0.06	0.08	0.02	0.06
45	30.77	1.60	5.19	0.18	0.03	0.09	0.18	0.03	0.09
50	38.95	1.66	4.27	0.37	0.05	0.12	0.37	0.05	0.12
55	47.27	1.66	3.51	0.66	0.07	0.15	0.66	0.07	0.15
60	55.42	1.60	2.88	1.07	0.09	0.17	1.07	0.09	0.17
65	63.17	1.50	2.37	1.58	0.11	0.18	1.58	0.11	0.18
70	70.34	1.37	1.95	2.17	0.13	0.18	2.17	0.13	0.18
75	76.84	1.23	1.60	2.83	0.14	0.18	2.83	0.14	0.17
80	82.62	1.09	1.31	3.52	0.14	0.17	3.52	0.14	0.17
85	87.70	0.95	1.08	4.20	0.14	0.16	4.20	0.14	0.16
90	92.11	0.82	0.89	4.87	0.13	0.14	4.87	0.13	0.14
95	95.90	0.70	0.73	5.49	0.12	0.13	5.49	0.12	0.13
100	99.13	0.60	0.60	6.06	0.11	0.11	6.06	0.11	0.11
105	101.87	0.50	0.49	6.58	0.10	0.10	6.58	0.10	0.10
110	104.17	0.42	0.41	7.04	0.10	0.09	7.04	0.10	0.09
115	106.11	0.44	0.42	8.88	0.08	0.08	9.77	0.09	0.08
120	107.72	0.44	0.41	9.18	0.08	0.08	10.09	0.09	0.08
135	116.59	0.40	0.34	11.04	0.09	0.09	12.06	0.10	0.08
150	122.39	0.37	0.31	12.48	0.10	0.08	13.60	0.11	0.09
165	127.83	0.35	0.28	14.01	0.11	0.08	15.25	0.11	0.09
180	132.93	0.33	0.25	15.64	0.11	0.08	17.01	0.12	0.09
195	137.72	0.31	0.23	17.36	0.12	0.09	18.88	0.13	0.09
210	142.21	0.29	0.20	19.17	0.12	0.09	20.87	0.14	0.10
225	146.43	0.27	0.19	21.05	0.13	0.09	22.96	0.14	0.10
240	150.39	0.26	0.17	23.01	0.13	0.09	25.15	0.15	0.10
255	154.10	0.24	0.16	25.04	0.14	0.09	27.44	0.16	0.10
270	157.58	0.23	0.14	27.12	0.14	0.09	29.83	0.16	0.10
285	160.84	0.21	0.13	29,27	0.14	0.09	32.30	0.17	0.10
300	163.91	0.20	0.12	31.45	0.15	0.09	34.85	0.17	0.11
315	166.78	0.19	0.11	33.67	0.15	0.09	37.48	0.18	0.11
330	169.48	0.17	0.10	35.93	0.15	0.09	40.18	0.18	0.11
345	172.01	0.16	0.10	38.21	0.15	0.09	42.94	0.19	0.11
360	174.39	0.15	0.09	40.50	0.15	0.09	45.76	0.19	0.11
375	176.62	0.14	0.08	42.80	0.15	0.09	48.62	0.19	0.11
405	180.67	0.13	0.07	47.41	0.15	0.09	54.46	0.20	0.11
435	184.23	0.11	0.06	51.97	0.15	0.08	60.40	0.20	0.11
465	187.37	0.10	0.05	56.45	0.15	0.08	66.39	0.20	0.11
495	190.14	0.09	0.05	60.81	0.14	0.08	72.38	0.20	0.11

[1]Parameter estimates are shown below. Definitions for P_1, P_2, and P_3 are given in text.

Variable	Age Interval	Equation	P_1	P_2	P_3
Length	< 110 days	Gompertz	115.506	7.731	0.039
Length	> 110 days	Bertalanffy	210.453	0.004	-54.933
Weight	< 110 days	Gompertz	9.581	23.132	0.039
Weight (M)	> 110 days	Gompertz	118.428	3.820	0.004
Weight (F)	> 110 days	Gompertz	179.862	4.064	0.003

[2]The AGR and RGR for male and female weight are the same for 10 to 110 days.

140 cm. Our weight-at-age equations indicate that small differences in growth rates for both length and weight may begin at about 110-120 cm (Table 2).

Ageing Older Individuals

An SEM and light microscope analysis of the microstructure associated with presumed annual increments on 23 fish >212 cm was not successful in validating annuli. We also examined several of the largest young adult blue marlin (between 400 and 500 days old) but the annuli (as described by Wilson 1984) could not be distinguished in these young marlin while the daily increments were still visible. The ventral lobe has a particularly irregular microstructural record and the daily record is extremely difficult to interpret since it contains large numbers of interruptions and/or discontinuities. There is clear potential for a workable adult ageing technique using the otoliths of these fish, even though direct validation of annual increments in blue marlin has not been possible to date. For example, observations of relative otolith size (dimensional and mass) in Atlantic and Pacific blue marlins indicates that individuals with relatively larger otoliths also have many more presumptive annuli in their otoliths when compared to similar sized fish (Wilson 1984, Hill 1986). The coefficient of determination for linear regressions of these parameters are strong (range in R^2's = 0.70 to 0.91; Wilson 1984). In addition, the strong associations were similar between total increment count and round weight (SRRC = 0.915), otolith weight (SRRC = 0.895), and LJFL (SRRC = 0.893) for juvenile and young adult blue marlin.

Further exploration of the relationships between fish size, otolith size, and increment counts, coupled with validated ages for younger fish, could lead to more robust regression techniques (Boehlert 1985) for estimating the ages of adult blue marlin. Further validation of the daily increment method is more likely to be successful with the more common istiophorids, such as sailfish, since comparable data on length frequencies, complete sequence of small sizes, and tag-recaptures are already available.

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Consideration of Marlin Sexual Dimorphism in Billfish Management

(Abstract)

Charles A. Wilson, John M. Dean, and Edward C. Cyr

Recent revitalization of the tuna longline industry has intensified user-group concern and culminated in the submission of a billfish management plan by the South Atlantic Fisheries Management Council. Attempts to formulate this management plan for the Istiophoridae and Xiphiidae have again documented the serious lack of information about their biology and life histories. Regardless of shortcomings in the data, management agencies are forced to react by developing management plans based on the best available biological information. Given this dearth of available biological data on billfish, some insight into the impact of proposed regulations may be gained through examination of the life histories of billfish, particularly sexual dimorphism.

The present available scientific data on the life histories of two Atlantic billfishes, blue marlin *(Makaira nigricans),* and white marlin *(Tetrapturus albidus),* were summarized in the Billfish Source Document by the South Atlantic Fisheries Management Council. Blue marlin sections dealing with sex-related size differences report that males rarely exceed 105 kg (230 lbs) and female maximum size is known to exceed 275 kg (600 lbs). Females attain greater lengths and weights than males. Likewise, male white marlin rarely exceed 70 pounds and females achieve size in excess of 150 pounds. Although sexual dimorphism is not as pronounced in white marlin as it is in blue marlin, most of the white marlin caught greater than 100 pounds are females.

Proposed management regulations of minimum sizes of males were designed to reduce significantly billfish mortality in the recreational fishery by releasing billfish under the premise that the practice can increase the availability of fish to the recreational fishery. The rationale of setting a size limit of 86″ (200 lb) and 62″ (50 lb) for blue marlin and white marlin, respectively, was that those size limits would reduce recreational fishing mortality by 50% and still allow sufficient fish for recreational catches so that billfish fishing and tournaments would not be greatly impacted. Despite these sound objectives, the management plan gives little consideration to the reported sex-related size differences of these species although those differences could have critical effects on the efficiency of the plan.

Under the plan, and based on our present understanding of sexual dimorphism, anglers will release predominantly male marlin back to the population while retaining large fish, predominantly females. Most important, from the anglers' point of view, such actions may not effectively increase the number of fish that will grow to be trophy fish in the future. We do not know the ecological impact of protecting, and possible enhancing male abundance while selectively reducing the number of females in these populations. Sex specific, surplus production models should be developed to determine potential effects of this approach.

Given the strong sexual dimorphism that exists between males and females in both white

marlin and blue marlin populations, management agencies should concern themselves only with the mortality of the females, if they are going to look at a minimum size limit as the regulatory mechanism, assuming that biology plays a critical role in the decision-making process. Categorically releasing small fish will not decrease female mortality in blue marlin particularly, although this may contribute to a more widespread release ethic. Further research into female fecundity and reproductive contribution at size of both species should allow the consideration and development of future management measures that take these important life history characeristics into account.

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Edward C. Cyr is a Ph.D. candidate in the marine sciences program at the University of South Carolina, studying age, growth, and reproductive biology of tarpon in the Atlantic Ocean. His master's degree work was on the reproductive biology of blue marlin.

Age, Growth, and Reproduction of Blue Marlin and Black Marlin from the Indian Ocean

E.C. Cyr, John Mark Dean, I. Jehangeer, and M. Nallee

The blue marlin *(Makaira nigricans)* and black marlin *(Makaira indica)* from the Indian Ocean are considered to be comprised of one Indo-Pacific stock for each species (Nakamura 1985), and their age distributions have not been described. Age estimates for Pacific blue marlin have been made by Radtke (1983), Hill (1986), and Wilson (1984), while no black marlin age estimates are available. In addition, evidence for validating estimates of age for these species is rare or non-existent.

No Indian Ocean state has, to date, developed management policies for the Indian Ocean marlins, as there has been little perceived need for the intensive management of these fishes. If such a need should arise in the near future, these policies would be difficult to develop, due to a lack of fundamental life-history information, such as age distribution of the populations.

Mauritius is the only major sport fishing center for marlin in the Indian Ocean, which makes it a logical base for sampling operations in that region. Smaller sport fisheries occur in Kenya and South Africa (Stroud 1985). The Mauritius sport fishery is also relatively productive, with an average of over 500 marlin caught per year, mostly during November, December, January, and February. However, many of the basic life-history aspects of the marlin in this fishery are unknown.

The objectives of this work were to examine the marlin caught in the Mauritius recreational fishery to: (1) estimate the age structure of both the localized blue and black marlin populations; (2) determine the size distribution of both species with respect to sex and to model relationships between estimated age, otolith size, and morphometric characters; (3) describe the reproductive characteristics of both species; and (4) detect potential changes in the size distribution of female marlin over time as a result of fishing mortality.

Materials and Methods

Blue marlin and black marlin (n = 210) were collected from the Mauritius recreational billfish fishery from November, 1985, to March, 1988, at Black River and Le Morne. Fish were weighed to the nearest half kilogram, and the lower jaw-fork length (LJFL), pectoral girth, and pelvic girth were measured to the nearest centimeter.

Fish were sexed, but gonads were not weighed; neither were gonad specimens retained for histological examination due to sampling constraints. Instead, gonads from each fish were visually inspected for gamete development, and each was assigned to one of the following stages: (1) not developed, (2) developing, (3) ripe, and (4) running very ripe.

Sagittae were removed from the cranium according to the methods of Radtke et al 1982 and Rivas 1956. The sacculus was removed from the otolith by immersion in bleach (sodium hypochlorite, 5.25%) for approximately 10 minutes. The otoliths were then rinsed in 95% ethanol and air-dried before being placed in vials for shipment to the University of South Carolina. Once received, the sagittae were weighed and prepared for age estimation according to the methods of Haake et al (1982) and Wilson (1984).

Thin sections of the sagittae were viewed under a compound light microscope using transmitted light at 40× and 100× magnification.

Presumed annuli were identified using a combination of internal and external features. The most useful features for our age estimates were the internal discontinuities on the rostral lobe of the sagittae, which were counted from the core to edge of the otolith. Alternatively, external ridges on the medial surface of the rostral lobe were counted when internal features were obscure. These features have previously been interpreted by others as potentially being formed with annual periodicity (Radtke and Dean 1981, Radtke et al 1982, Wilson 1984). Direct evidence for age validation has not been reported for these species. Due to sampling constraints, it was beyond the scope of this study to address the issue of validation. Age was estimated twice for each fish by two independent readers, and averaged by reader.

We computed a weighted regression of percentile versus year to detect possible changes in the size distibution of large female fish over the past 10 years. This procedure first calculated the weights, by year, of female blue marlin in the 80th percentile of the female weight distribution. These values were then weighted by sample size, and regressed on year, with a correction factor for autocorrelation. The resulting regression is an indication of possible trends in the sizes of large females landed over the past 10 years. Historical data, which were used in weight distribution comparisons, were collected from the log books of the Le Morne Anglers Club, Centre de Peche Fishing Center at Black-River, and The Beachcomber Fishing Center at Le Meridien.

Statistical Procedures

A significance level of alpha = 0.05 was established for all statistical procedures. When possible, we tested data to insure that critical assumptions for each procedure were fulfilled.

A significant difference in weight was found between the right and left paired otoliths (paired t-test, $n = 163$, $p = 0.026$). Age was estimated twice for each fish by two independent readers, and averaged by reader. A significant difference was found between the averaged ages assigned by each reader (paired t-test, $p = 0.002$). A 't'-test was used to evaluate differences in estimated age and body weight and length between the sexes. An ANCOVA was used to test for a difference in the otolith weight/age relationship between the sexes.

Multiple linear regressions were used to model relationships between fish weights and estimated ages and a variety of morphometric and otolith measurements for blue marlin. Variables used in the fish weight model were LJFL, pectoral girth, and vent girth. Variables used to model age were weight, LJFL, vent girth, pectoral girth, and otolith weight. The coefficients of determination were maximized in the prediction model using the SAS (Statistical Analysis System) STEPWISE procedure. The black marlin sample size was too small to model these relationships effectively.

Results

Blue Marlin

Size distribution in the Mauritius blue marlin was distinct between the sexes (Fig. 1). Female fish in this study ranged from 67 to 401 kg, and only ten females (of 75) weighed less than 115 kg (Fig. 2). Conversely, male blue marlin ranged from 45 to 112 kg. Thus, with the exception of the ten small females, both sexes encompassed non-overlapping size ranges.

Female blue marlin, with an average estimated age of 10.6 years, were significantly older than male marlin, which averaged 8.7 years of age (t-test, $p = 0.014$). This difference is reflected in the age-frequency distribution (Fig. 3). Female fish were significantly heavier, had a greater LJFL and pectoral and vent girths, and significantly heavier otoliths compared to males (t-test, $p = 0.04$) (Table 1).

The relationship between otolith weight and age did not differ significantly between the sexes (ANCOVA, $p = 0.5513$), so data from both sexes were pooled. The resultant regression of otolith weight on age for the combined sexes had $R^2 = 0.44$ (Fig. 4).

Male blue marlin weight was modeled using multiple linear regression. The variables which best described male blue marlin weight were LJFL ($p = 0.0014$) and pectoral girth ($p = 0.0028$) in the regression: Weight = $-21.585 + 0.29011$(LJFL) $+ 0.46921$(pectoral girth), ($R^2 = 0.406$). Estimated age in males was also modeled using multiple linear regression techniques, with the variables fish weight ($p = 0.079$) and otolith weight ($p = 0.0001$) in the regression: Estimated age = $-3.3716 + 0.06874$(weight) $+ 2.52897$ (otolith weight), ($R^2 = 0.66$).

Stepwise multiple linear regression indicated that female blue marlin weight is correlated to LJFL ($p = 0.001$) and pectoral girth (0.0027) in

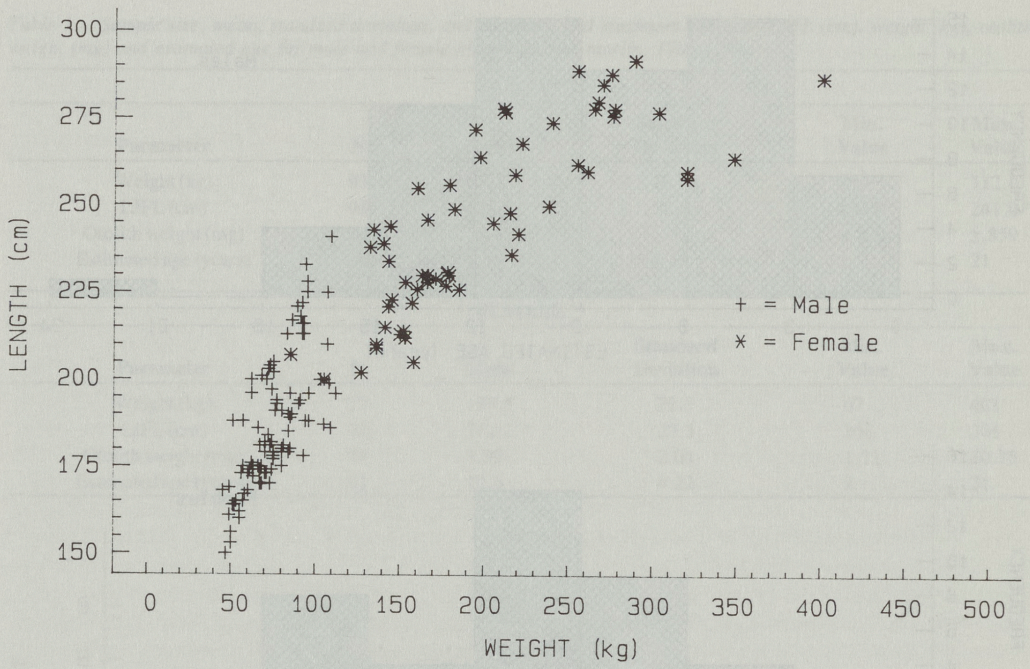

Figure 1. Mauritius blue marlin length/weight relationship.

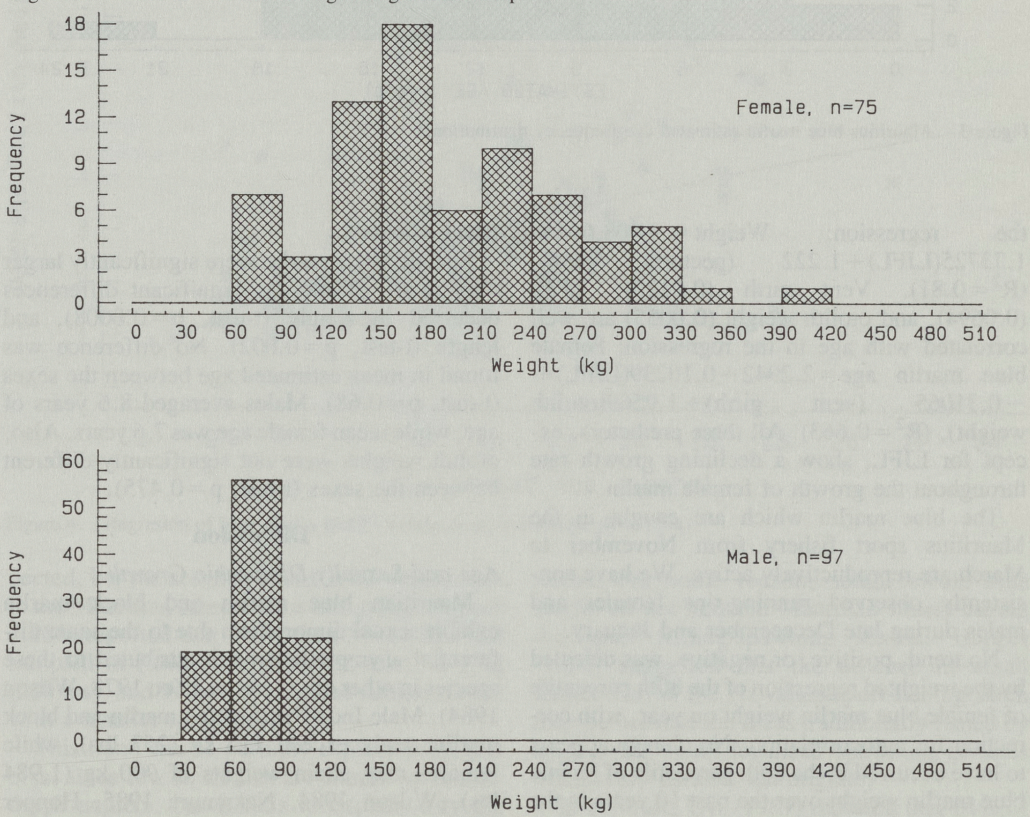

Figure 2. Mauritius blue marlin weight-frequency distribution.

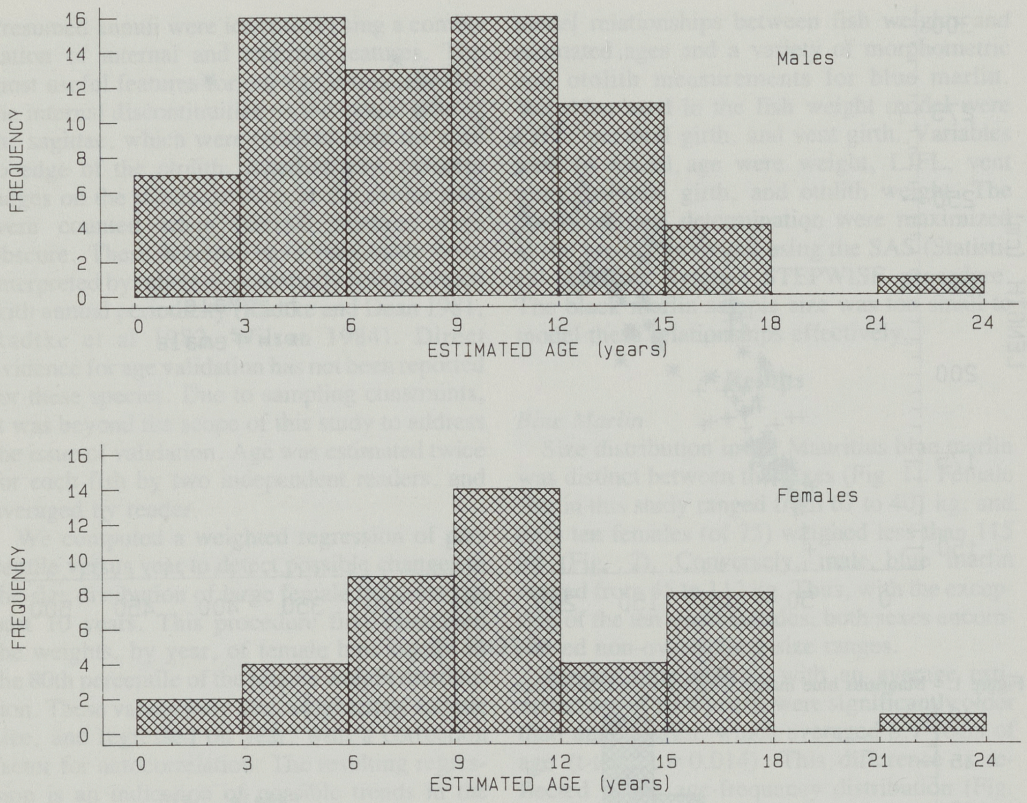

Figure 3. Mauritius blue marlin estimated age-frequency distribution.

the regression: Weight = −408.664 + 1.73725(LJFL) + 1.222 (pectoral girth), ($R^2 = 0.81$). Vent girth (0.0125), LFJL (0.0694), and otolith weight (0.0055) are well correlated with age in the regression: Female blue marlin age = 2.2942 + 0.10239(LJFL) + −0.31065 (vent girth) + 1.9569(otolith weight), ($R^2 = 0.663$). All three predictors, except for LJFL, show a declining growth rate throughout the growth of female marlin.

The blue marlin which are caught in the Mauritius sport fishery from November to March are reproductively active. We have consistently observed running-ripe females and males during late Dececember and January.

No trend, positive, or negative, was detected by the weighted regression of the 80th percentile of female blue marlin weight on year, with correction for autocorrelation. No change appears to have occurred in the 80th percentile of female blue marlin weight over the past 10 years in the Mauritian sport catch.

Black Marlin

Female black marlin were significantly larger than males (Table 2). Significant differences occurred in weight (t-test, $p = 0.0008$), and length (t-test, $p = 0.002$). No difference was found in mean estimated age between the sexes (t-test, $p = 0.68$). Males averaged 8.6 years of age, while mean female age was 7.6 years. Also, otolith weights were not significantly different between the sexes (t-test, $p = 0.475$).

Discussion

Age and Sexually Dimorphic Growth

Mauritian blue marlin and black marlin exhibit sexual dimorphism due to the same differential asymptotic growth attributed to these species in other ocean basins (Yeo 1978, Wilson 1984). Male Indo-Pacific blue marlin and black marlin rarely exceed 115 kg (253 lbs), while females may attain weights of 900 kg (1,984 lbs) (Wilson 1984, Nakamura 1985, Hopper 1986). The absence of large male fish is ex-

Table 1. Sample size, mean, standard deviation, and minimum and maximum values of LJFL (cm), weight (kg), otolith weight (mg) and estimated age for male and female Mauritius blue marlin, 1985-1988.

MALE

Parameter	N	Mean	Standard Deviation	Min. Value	Max. Value
Weight (kg)	97	75.2	16.49	45.0	112.0
LJFL (cm)	94	185.6	21.15	102.0	241.0
Otolith weight (mg)	82	2.63	1.19	0.882	5.859
Estimated age (years)	68	8.7	4.58	1	21

FEMALE

Parameter	N	Mean	Standard Deviation	Min. Value	Max. Value
Weight (kg)	75	189.5	72.3	67	401
LJFL (cm)	73	242.1	29.5	168	301
Otolith weight (mg)	44	3.99	2.04	1.21	10.75
Estimated age (years)	42	10.6	4.22	2	21

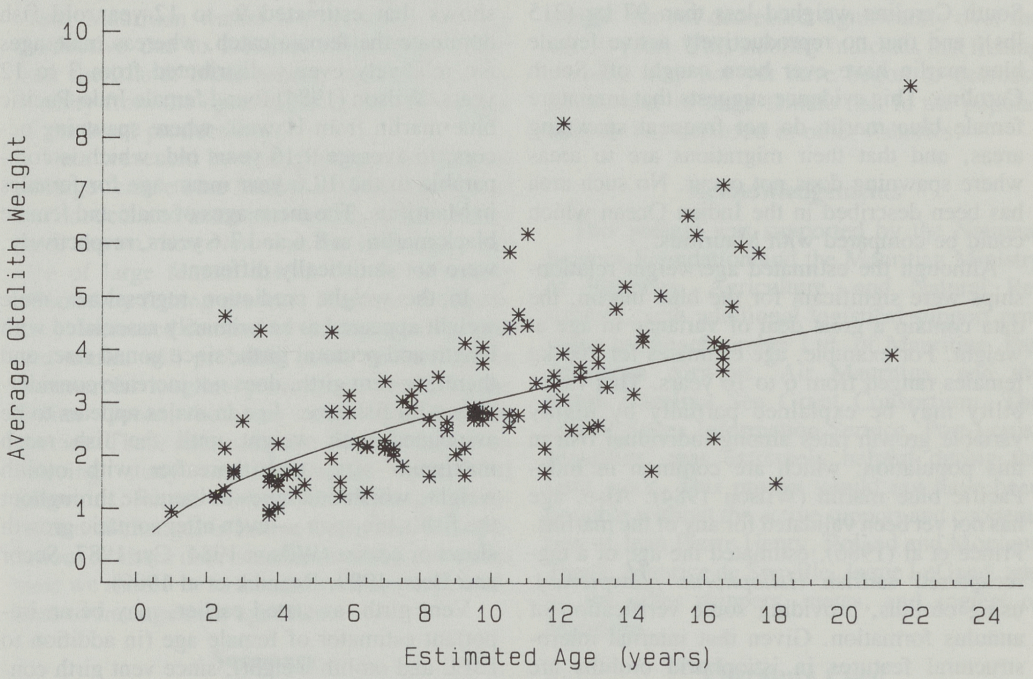

Figure 4. Regresion of blue marlin otolith weight on estimated age ($R^2 = 0.44$).

pected, but the absence of any small female fish in the Mauritian sample set is intriguing. Hopper (1986) reported that fewer than 5% of 693 fish sampled in Hawaii weighed less than 90.7 kg (200 lbs), and Wilson (1984) had similar results with a smaller sample set.

This trend can be partially explained by gear bias, since few small fish are caught by recreational anglers, but it fails to explain why the small fish that are caught are predominantly males. For some reason, small female blue marlin do not frequent Mauritian waters during the sport fishing/spawning season. Hopper (1986) suggested that the absence of small female fish in the Hawaiian sport-fishing catch may be because the areas traditionally fished by anglers are small localized spawning grounds where only mature fish migrate.

In contrast, Cyr (1987) reported that 24% of the tournament-caught female blue marlin in

Table 2. Sample size, mean, standard deviation, and minimum and maximum values of LJFL (cm), weight (kg), otolith weight (mg) and estimated age for male and female Mauritius black marlin, 1985-1988.

MALE					
Parameter	N	Mean	Standard Deviation	Min. Value	Max. Value
Weight (kg)	5	89.4	13.3	75	105
LJFL (cm)	5	193.2	10.5	182	207
Otolith weight (mg)	4	2.58	1.13	1.75	4.16
Estimated age (years)	4	8.6	3.9	5	13
FEMALE					
Parameter	N	Mean	Standard Deviation	Min. Value	Max. Value
Weight (kg)	33	167.8	47.3	97	275
LJFL (cm)	31	234.0	17.1	188	313
Otolith weight (mg)	22	3.13	1.43	1.505	7.931
Estimated age (years)	17	7.3	5.6	1	20

South Carolina weighed less than 97 kg (215 lbs), and that no reproductively active female blue marlin have ever been caught off South Carolina. This evidence suggests that immature female blue marlin do not frequent spawning areas, and that their migrations are to areas where spawning does not occur. No such area has been described in the Indian Ocean which could be compared with Mauritius.

Although the estimated age/weight relationships were significant for the blue marlin, the data contain a great deal of variance in age at weight. For example, age estimates for 160-kg females ranged from 6 to 16 years. This variability may be explained partially by highly variable growth rates among individual fish in this population, which are common in Indo-Pacific blue marlin (Wilson 1984). Also, age has not yet been validated for any of the marlins. Prince et al (1986), estimated the age of a tag-recaptured sailfish *(Istiophorus platypterus)*, using otoliths, providing some verification of annulus formation. Given that internal microstructural features in istiophorid otoliths are strikingly similar, the estimation techniques used by Wilson (1984), and Prince et al (1986), which we also utilized, should apply to the Indian Ocean blue marlin and black marlin.

The fact that Mauritius female blue marlin are statistically older than males may simply be because all females in the area are reproductively mature. Such circumstance may elevate the mean age since blue marlin are presumed to reach reproductive maturity at 6 to 8 years of age (Wilson 1984, Hopper 1986). The age distribution of the Mauritius blue marlin (Fig. 3) shows that estimated 9- to 12-year old fish dominate the female catch, whereas male ages are relatively evenly distributed from 3 to 12 years. Wilson (1984) found female Indo-Pacific blue marlin from Hawaii, where spawning occurs, to average 9.16 years old, which is comparable to the 10.6 year mean age for females in Mauritius. The mean ages of male and female black marlin, at 8.6 and 7.6 years, respectively, were not statistically different.

In the weight prediction regressions, male weight appeared to be primarily associated with length and pectoral girth, since gonad size, and therefore vent girth, does not increase considerably with fish size. Age in males appears to be associated with weight until the fish reach maximum size, and thereafter with otolith weight, which continues to increase throughout the fish's life span — even after somatic growth slows or ceases (Wilson 1984, Cyr 1987, Secor and Dean 1989, Reznick et al 1989).

Vent girth, as stated earlier, may be an important estimator of female age (in addition to LJFL and otolith weight), since vent girth continues to increase even after growth in LJFL and pectoral girth slows significantly. The regression of female blue marlin LJFL and pectoral girth on age had $R^2 = 0.81$.

Reproduction

Spawning of blue marlin in Mauritius, as in Hawaii, is coincident with the local summer and the peak of the sport fishing season. Undeveloped and spent fish are caught early (September-October) and late (March-April) in the season, respectively; however, all gonads of

fish caught from December to February are developing, ripe, or running ripe. Also, the male:female ratio in the Mauritian sport-fishing catch is 1.25:1.0. High ratios in favor of males are generally indicative of a spawning population (Wilson 1984, Hopper 1986).

Apparently, black marlin do not spawn while in Mauritian waters. Spawning of black marlin has been suggested to occur in the Coral Sea and the South China Sea (Nakamura 1985), but no spawning areas have been identified in the Indian Ocean. Peak black marlin abundance occurs in Mauritian waters in November, and declines as water temperature increases and blue marlin become more prevalent. The reason for this annual influx of marlin is obscure. It is speculated that Mauritian black marlin may be on an annual trans-oceanic spawning migration. Also, Mauritian waters are known to be very productive due to localized upwelling centers near the island. Black marlin may travel to the vicinity from the open ocean to take advantage of the local productivity.

Data presented here suggest that the number of large female blue marlin in Mauritian waters has not declined in the past decade. Other studies have shown, however, that the abundance and size of large female marlin can be adversely affected by fishing pressure (Dean et al unpub. ms.). Increased demand by the Japanese for tuna and marlin will probably cause an increase in commercial longline pressure on marlin in the Indian Ocean, both as target and bycatch species. These data comprise one segment of an ongoing study on the marlin fishery of Mauritius. Future work should allow for the detection of changes in Indian Ocean marlin populations as more data become available, at which time we should be in a better position to provide data to management agencies.

Summary

Blue marlin (n = 223) caught in the Mauritius recreational fishery from December, 1985, to May, 1987, were examined. Lower jaw-fork length, weight, and girth were measured for each fish. Sagittae were removed for age estimates, and the stage of gonadal development was determined.

Female blue marlin (n = 93, $\bar{x}$ = 202 kg) were significantly heavier than males (n = 106, $\bar{x}$ = 75 kg). Males and females were discrete with respect to size range; no male fish exceeded 110 kg, while only 10 female fish weighed less than 115 kg. Estimated age was significantly different between the sexes, although both are equally long-lived. Male and female blue marlin sagittae weights were also significantly different.

Reproductively active blue marlin were caught in Mauritian waters from December to late February, which coincided with the season of peak abundance, suggesting the presence of a local spawning ground.

Black marlin (n = 39) were examined along with the blue marlin, and corresponding data and samples were collected for these fish. Female black marlin were significantly larger than males, although neither age nor otolith weight was significantly different between the sexes. Black marlin apparently do not spawn in Mauritian waters.

The 80th percentile of female blue marlin weight has not decreased significantly over the last 10 years. This stability indicates that fishing pressure may not yet have begun to decrease the number of large female fish in the population, as has occurred in other fisheries.

Acknowledgements

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A Potential Problem in Estimating the Ages of Striped Marlin Using Dorsal Fin Spines (Summary Paper)[1]

Hiromichi Yatomi

In recent years, several attempts have been made to estimate the ages of billfishes (Istiophoridae and Xiphiidae) using the dorsal and anal fin spines as the ageing structures (Jolley 1974, 1977; Berkeley and Houde 1980, 1981; Hedgepeth and Jolley 1983; Prince et al 1984, 1986a, 1986b; Hill 1986). The accuracy of age determination using this method, however, has not been validated for the full size range of any of these species. Accuracy of the dorsal-spine ageing method was examined by Prince et al (1986b). They pointed out that estimates of age based on sections of dorsal fin spines substantially underestimated the age of one Atlantic sailfish *(Istiophorus platypterus)* known from tagging records. Presumably, this underestimation occurred because the porous vascularized cores of spine sections become enlarged in older/larger sailfish and obscure early growth zones, making them difficult to count.

In this paper, I have tried to examine the process of incremental erosion on spine sections that occurs with growth, as a preliminary study of age determination of striped marlin *(Tetrapturus audax)*.

Methods And Materials

Dorsal fin spines 1 to 8 were sampled from 69 striped marlin caught by the harpoon fishery in the waters off Izu Peninsula in the western Pacific Ocean during the summer seasons (June to August) of 1985 to 1987. Eye orbit-fork lengths (EOFL) were taken to the nearest cm from each fish, but sex was not recorded. The fish ranged in size from 122 to 189 cm EOFL.

The fourth dorsal spine was used since this spine was among those used in other studies (Prince et al 1986b). Spines were cut with a slow-speed saw at a position 1/5 of the length of the spine from it's condyle base. Each cross section was 1 to 2 mm thick. Cross sections were mounted in Canadian balsam on a glass slide and ground to 200 to 700 μm thick using a whetstone. The following measurements (Fig. 1) were taken from each cross section using an ocular micrometer in a profile projector at 20 × magnification: (1) spine diameter — SD (the maximum lateral distance at a right angle to the spine axis); (2) spine radius (calculated as one-half of the spine diameter); (3) width of cortical bone (solid bone); (4) increment radius (calculated as spine radius minus increment width); (5) increment width — Ln (distance from the edge of the structure to each increment). For the purposes of this paper, references to increments are synonymous with the term annuli (Wilson et al 1987) and are assumed to equal one calendar year in the life of the fish.

Results and Discussion

As is shown in Figure 1, there are two distinct parts in the spine cross section. The outer part consists of cortical bone (i.e., solid bone) and the inner part includes an area of spongy bone and vascularized core. Increments in the cortical bone area are distinct, whereas increments formed in the spongy bone area are often obscure, disrupted, or completely eliminated.

[1]Translated from Japanese.

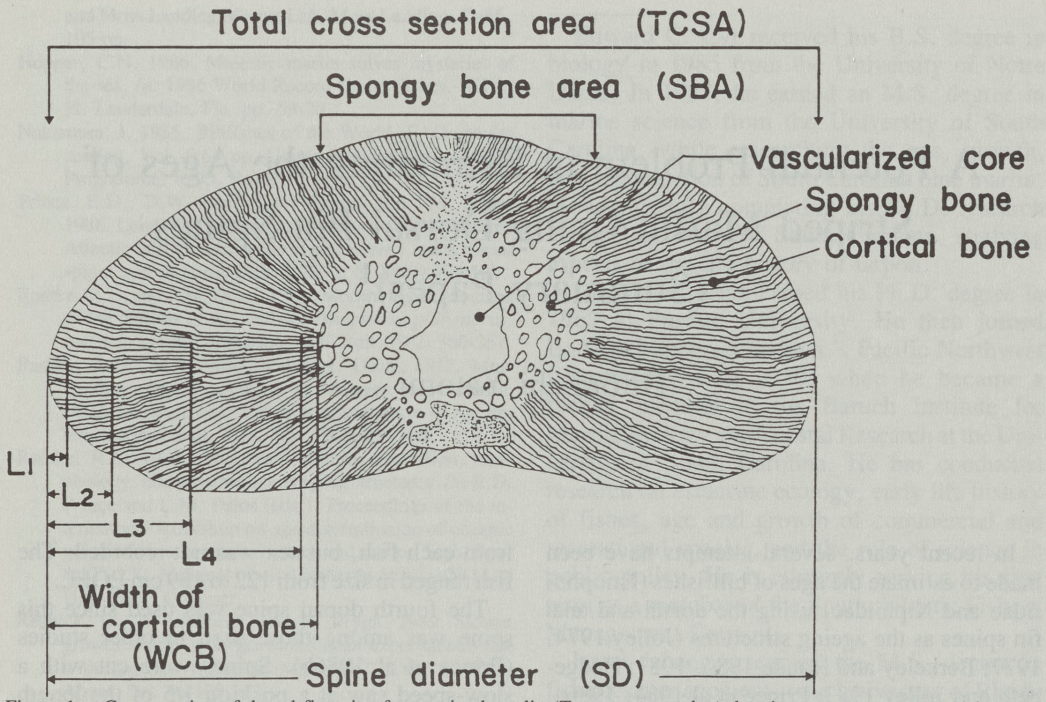

Figure 1. Cross section of dorsal fin spine from striped marlin *(Tetrapturus audax)* showing measurements used for age and growth analysis.

Spine diameters were plotted against EOFL and resulted in the linear relationship observed in Figure 2. Since the spine growth is proportional to the growth of the fish (in length), this structure appears to be a likely candidate for estimating the ages of striped marlin. The relationship between cortical bone width and EOFL was also examined (Fig. 3). Considerable variability was observed, but a decreasing trend was evident between the width of cortical bone and EOFL (i.e., the longer the fish, the less cortical bone area).

These results indicate an increase of inner spongy bone area (and decrease of cortical bone) as the fish grows larger. They suggest that the clarity and integrity of increments closest to the core are affected by expansion of spongy bone near the core. The extent of increment erosion in dorsal spines of striped marlin, however, has not been reported.

In order to examine this potential problem more rigorously, relative increment radius (increment radius/spine radius) was plotted against EOFL (Fig. 4). This analysis is limited by the sample size and size range of fish examined (122 to 189 cm EOFL). Since increment erosion on spines of smaller fish (≤140 cm EOFL) is minimal, a larger sample size in this size category would have been preferable. Large dots indicate the clear increments and small dots indistinct ones. The area of spongy bone is noted to increase with growth and the loss of innermost increments with growth is seen to occur as a loss of roughly one increment for each 10 cm interval between 140 and 180 cm EOFL.

Since the smallest fish in my sample were not severely affected by enlargement of the vascularized core, further study on small fish is probably necessary to clarify the process of increment erosion. For example, Hill (1986) examined one approach to this problem by statistically replacing missing increments based on an analysis of young marlin where the amount of spongy bone did not affect increment resolu-

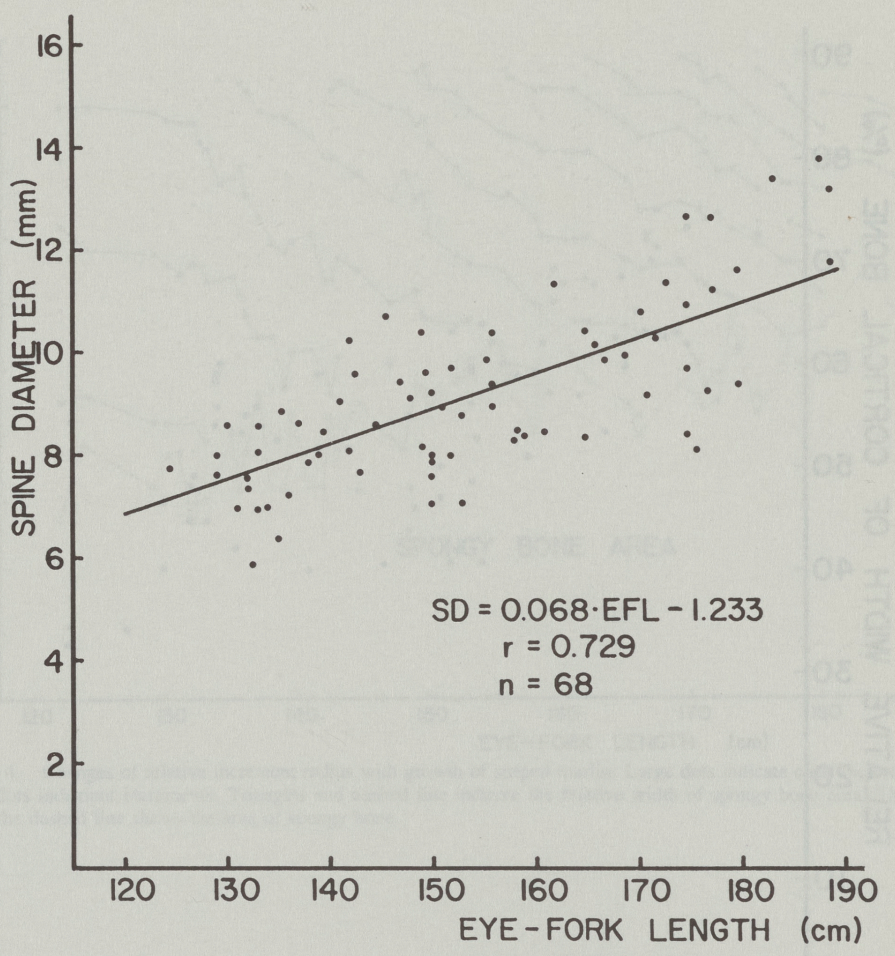

Figure 2. Relationship between spine diameter and eye orbit-fork length for the striped marlin.

tion. Since increment resolution in dorsal spines has been reported to occur in scombrids (Cayre and Diouf 1983), as well as istiophorids, some replacement of lost increments to resolve under estimates of age seems appropriate for pelagic species. This procedure is particularly important for long lived species since underestimation of age is more severe for older fish. In addition, a more detailed examination of the growth of dorsal spines, including the developmental aspects of spongy bone, might provide insight into the processes of increment erosion in the spines of pelagic teleosts. This information seems necessary if these structures are going to be used with confidence for age determination.

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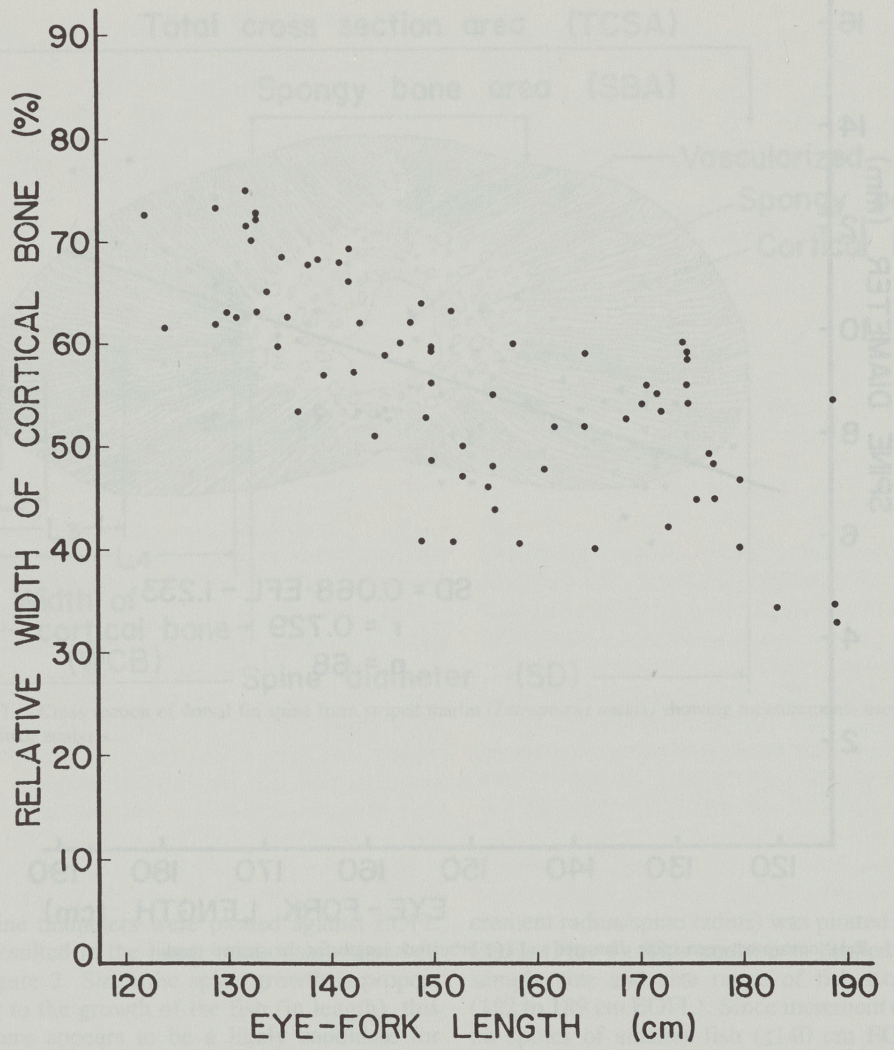

Figure 3. Relationship between relative width of cortical bone and eye orbit-fork length in the striped marlin.

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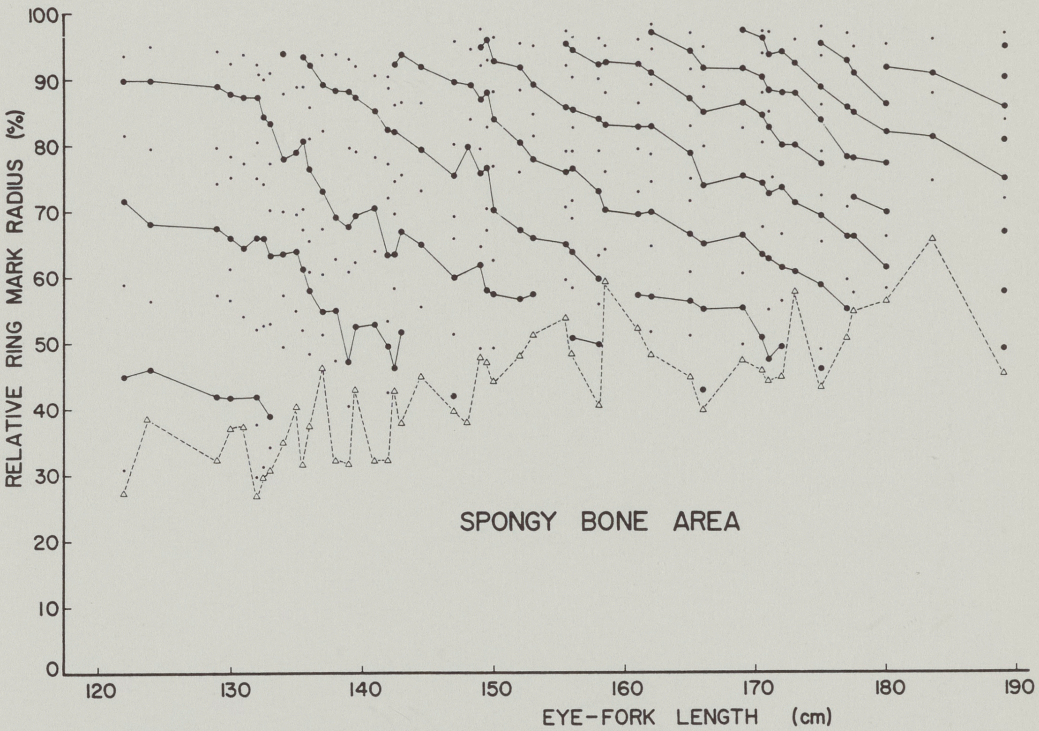

Figure 4. Changes of relative increment radius with growth of striped marlin. Large dots indicate clear increments and small dots indistinct increments. Triangles and dashed line indicate the relative width of spongy bone area. The region under the dashed line shows the area of spongy bone.

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