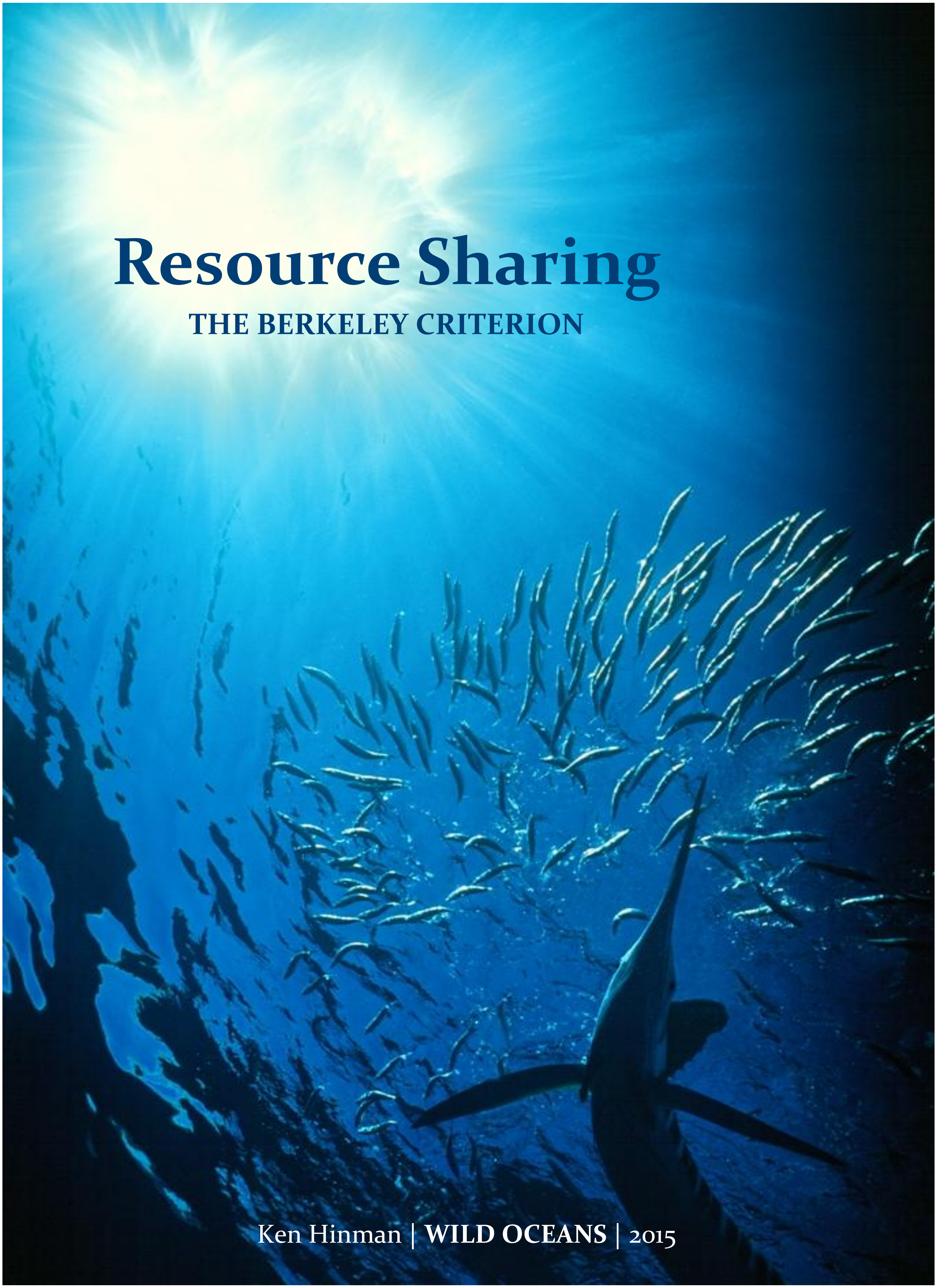
Resource Sharing

THE BERKELEY CRITERION



Ken Hinman | **WILD OCEANS** | 2015

RESOURCE SHARING: The Berkeley Criterion

by Ken Hinman

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WILD OCEANS is an independent 501(c)3 non-profit organization devoted to keeping the oceans wild to preserve fishing opportunities for the future.

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If we see ourselves as part of the natural system, a predator lucky enough to sit at the top of the food chain, then we are far more willing to accept the presence of other predators without thinking of them as competitors, but as creatures with equally important places in the system.

Pat Wray, hunter[1]

Of Predators and Prey

We cannot command Nature except by obeying her.

Francis Bacon

When we fish, we join the ocean world as predators. That is what we are, by nature, and have been since early times. But unlike other predators, we are limited only by the limits we set for ourselves. Or so we'd like to think. We are subject to all the same natural laws as other predators, yet we behave as if we were not - as though we could fish without regard for fishing's impact on the ecosystems we share.

In the modern era, our prevailing policy is to maintain fish populations at levels that optimize yields to commercial fisheries, assuming that other predators, namely fish higher up the food chain, marine mammals and seabirds, are not harmed. But as we are learning, this myopic approach to managing fisheries can lead to mismanaging entire marine ecosystems, and

> *(a)lthough overfished stocks have been known to recover, revival of communities that have changed states can be excruciatingly slow or even impossible.*[2]

Overfishing ecosystems, in other words, has far greater costs – social and economic as well as ecological - than simply mismanaging a fishery.

On a global scale, the numbers of predatory fish have been drastically reduced by industrial fishing.[3] Many predator populations – among them large pelagic species such as billfish, tuna and shark as well as demersal species like cod, grouper and snapper - are the object of determined recovery efforts, not only to revitalize the fisheries but also to restore their vital role as keystone predators, maintaining balance and diversity in marine ecosystems from the top down.[4]

Most of us are familiar with trophic cascades, wherein the presence or absence of top predators influences not just the numbers of their prey but also, through a rippling effect, the structure and character of entire ecosystems. But as we've moved down the food chain and intensified exploitation of fish at lower trophic levels – today, so-called forage species, such as sardine, menhaden, herring and anchovy, account for 37 percent of the total world fish catch[5] - we are shrinking the supply of food and limiting predator populations from the bottom up.

In effect, we are burning the predator-prey candle at both ends, producing an ocean environment no longer capable of sustaining life in all its wild diversity and abundance.

Instead of fishing as one among many predators, “as part of the natural system,” we try and manipulate the ocean in order to catch the species we want in the quantities we demand. Our primary and often only concern is whether or not our catch is “sustainable,” by which we mean making sure not to deplete the stock in ways that would jeopardize future catches.

Country music legend George Jones nailed it when he sang

> *To think I had been permitted*
> *To see a part of nature’s plan*
> *Oh, there’s nothing that stands out more*
> *Than the selfishness in man*[6]

In nature’s plan, all creatures share an evolutionary drive to selfishly advance their own species. But in our case, a narrow view of sustainability, a lack of regard for sustaining other forms of life in the sea, and “a power over the natural world we can no longer afford to use”[7] all work to our collective disadvantage, irreparably harming the environment that supports all of us.

What I call the *Berkeley Criterion*[†] suggests a more balanced, more natural and far wiser approach to managing marine fisheries, grounded in policies that sustain fishing in a way that protects the broader ecosystem and its living communities. It is, quite simply, **Resource Sharing** - a novel concept that is nevertheless essential to our co-existence with wild oceans. The future of fishing, I believe, lies in the balance.

Ken Hinman

[†] This paper is dedicated to the memory and vision of my friend and colleague Steven A. Berkeley (1947-2007), who coined the concept of ‘resource sharing’ in long-ago discussions that eventually evolved into this paper. The opinions, conclusions and any errors contained herein are mine.

Part One

You can't solve a problem from the same consciousness that created it.
You must learn to see the world anew.

Albert Einstein

The buzzword in fisheries these days is "sustainability." What we typically think of as sustainable fishing, however, can dramatically alter living communities. For instance, the way we fish for key prey species, those whose abundance strongly influences population size of predators, can upset the delicate balance between predators and prey, restructuring food webs and reducing biological diversity.[8]

There is little debate among policy makers that we should be moving away from conventional management practices toward an ecosystem-based approach to conserving ocean fisheries.[9] In what is widely acknowledged to be an incremental process, which in some respects is already underway, conserving prey or "forage" species[10] in order to preserve healthy predator-prey relationships is a logical first step.[11] Certainly, one of the central challenges of an ecosystems approach is leaving enough food in the water to adequately feed a wide range of marine predators – including ourselves.

But conserving fish at the ecosystem level requires a change in some of our most basic fishery management concepts. Preventing ecosystem overfishing[12] - that is, fishing to a degree that jeopardizes the integrity of marine communities - means moving away from the goal of maximizing yields to fisheries toward ecologically sustainable yields.[13] To do that, we need to be more forthright about how we are impacting the food web, and then overtly consider these impacts within our conservation and management strategies.

The Myth of Surplus

The epitaph for the concept of maximum sustainable yield, MSY for short, was supposedly written decades ago,[14] yet it remains the basis for today's fishing strategies.[15] Simply put, MSY is the largest amount of fish that can be removed on a continuing basis while maintaining a standing population capable of replenishing itself. It is estimated by calculating the "surplus production" at determined levels of exploitation.

The theory of surplus production in a fish population was first introduced to fisheries science and management in 1926 by Baranov[16] and suggests that the difference between annual population increases (through growth and recruitment) and population losses (through all sources of mortality) equals surplus production. In a population at equilibrium with no fishing, where births balance deaths, there is no surplus, i.e., no population growth. But when the total biomass[‡] is reduced through fishing, the population consists of a higher proportion of younger fish with more food available *per capita*, so that recruitment - the number of fish that grow to enter the fishable population each year - is greater than mortality.

In theory this difference, or surplus, can be harvested on an annual basis while maintaining the population at a new equilibrium, since the population is now producing more offspring than necessary to sustain itself. The population size at which this so-called surplus production is maximized is typically half or less (40-50%) the un-fished population and is the level that fishery managers associate with harvests at MSY.[17]

The notion of surplus is a purely human construct, a myth, created as are all myths to satisfy human desires

So the governing theory of modern fishing is this: Decrease the standing stock; eliminate older, slow-growing fish from the population; replace them with fast-growing, younger fish; increase the growth rate by providing more food *per capita*; and *voila!* We have created new production that is surplus, in the sense that it didn't exist before our intervention. Since it is a surplus, it is there for the taking, no harm done.

The MSY-based fishing strategy, then, implausibly assumes an annual surplus that is actually created *by* fishing, *for* fishing. Developed for managing individual species and employing single-species stock assessment models, it not only assumes that the fishery is sustainable, but that it does not adversely affect natural predators and their prey.[18]

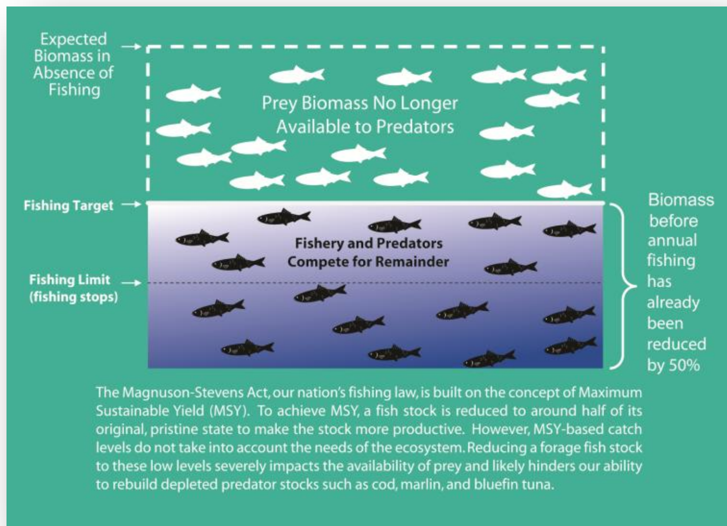
Of course, the notion of surplus production is a purely human construct, an invention to meet human needs and desires. We acknowledge that there is no surplus in an un-fished population, which is at carrying capacity, the maximum number of individuals the ecosystem can support. So we would have to presume that there is never a surplus, defined as an excess of what the system itself will use, when considering any population of fish as part of an ecosystem rather than as an

[‡] Biomass refers to volume in terms of total weight rather than number of individuals

isolated species. As any one component of the ecosystem is diminished, by fishing for instance, the system's own demand for energy to replace it will increase.[19]

The myth of surplus production and its derivative, MSY, consider only the stability and sustainability of the target species and the fishery. But considered in the broader environment, where the quantity and quality of relationships among species define the health of marine communities, fishing at or near MSY is not ecologically sustainable. It is not possible to shrink a fish stock to half or less its carrying capacity, and keep it at that level, without significant ecological consequences.

PREY DEPLETION ASSOCIATED WITH MSY



Competing for Limited Food

The life histories and behavior of prey species evolved over many millennia, primarily in response to predation. The introduction of a formidable new predator – in this case, industrialized man – pushes a species beyond the limits to which it has previously accommodated, altering innate relationships between the prey and its natural predators.[20]

By fishing a prey population down to the level associated with MSY, we strain the fabric of predator-prey relationships. By substantially reducing the amount of prey available to the ecosystem,[§] we directly or indirectly limit the number and type of predators which the prey populations are capable of supporting.[21]

We do this, without acknowledgement, because we look at how predation fits into our fishing strategies through a narrow lens, missing the bigger picture.

[§] The prey field actually changes in three significant ways: 1) the number of prey (abundance), 2) type of prey available (age/size), and 3) distribution of prey throughout its natural range (a result of changes in 1 and 2). All of these alterations lessen prey availability and predation success.

For any fish population, total mortality is the sum of deaths from natural causes - predation, disease and environmental stressors - and mortality from fishing. In fisheries science, we usually express mortality as a rate.[**] To estimate the total amount of fish that are dying from natural mortality each year – a crucial component of our stock assessments - we apply the natural mortality rate to the estimated population size (numbers of fish) or biomass (total volume).

When we drastically reduce the population to achieve MSY, the natural mortality rate is applied to a much smaller population. If the rate is constant - that is, if it is the same as before the stock was reduced by fishing - then the absolute amount of mortality attributable to natural causes, including predation, is reduced accordingly. It follows, then, that if most of the assumed natural mortality for prey species is a result of predation – and that is the assumption - the predator population is left with much less available food and must shrink in size in order to come into equilibrium with the amount of prey available.[22]

Perhaps predation mortality increases in response to a diminished supply of food? Do predators take a higher proportion of the available biomass at lower levels of prey density in order to consume the same volume of fish and sustain their numbers? If so, then there would be no such concept as MSY for prey species. If the rate of predation mortality increased to offset competition from increased fishing, it would eliminate any surplus production.[††]

Fishing down a prey population deprives predators of a substantial supply of food and consequently limits their numbers

Moreover, if predation did increase in response to fishing, it would imply that predators can enhance their efficiency of feeding at low prey densities. But if they could actually harvest at a higher rate at low densities, why wouldn't they do so at higher densities in order to maintain their populations at even greater levels?

Another way to look at this is to pose the question - if harvesting a fish stock at MSY provides the largest sustainable catch from that stock on an annual basis, why don't other species harvest their prey at that level, too? If, in fact, there is surplus production waiting to be exploited simply by further reducing the standing biomass, why haven't other species evolved to take advantage of this free food?

[**] For a discussion of how the natural mortality rate is estimated, see pages 12-14.
[††] That is in fact what does occur, but at an ecosystem rather than a species level, as will become clear.

Why isn't the population size associated with MSY the equilibrium for all species of fish and for the ecosystem as a whole?

To realize maximum catch, we reduce the standing stock by half or more. If predators could have done so, thereby increasing the supply of food available to them on an annual basis (our theory of MSY), it seems logical that they would have. Since they did not, it means that there is a very good ecological reason.

Winners and Losers

Ecological theory suggests that if left unchecked, a species will increase until it becomes limited by some vital resource, usually food.[23] Predators and prey generally come into a dynamic equilibrium, one in which the predator population is limited by the availability of its prey and the prey population is held in check by predation. It must be, then, that prior to large-scale human intervention in the ocean's food chain, population levels were fluctuating around this equilibrium. That, in fact, the un-fished prey population is the biomass associated with the predators' own "maximum sustainable yield".

The corollary of this is that a prey population diminished by fishing will result in a reduced predator population *unless* the predators can switch to an alternate food source. But that begs a similar question – if there is an alternate food source, why didn't the predator population grow by utilizing that food supply beforehand, thereby making use of the entire prey field available to it?

The notion that prey-switching – that is, an opportunistic predator whose preferred prey is no longer available will substitute another species that is more abundant – can sustain predator populations assumes that the alternate prey is equally available and of equivalent nutritional value, requiring the same amount of energy to exploit and the same return on the investment of that energy. Given the different life histories of prey species and the evolution of predators based on those histories, that is an assumption we cannot make.

More to the point, in an environment of finite carrying capacity, prey-switching only intensifies competition among predators for limited prey, with a loser for every winner. (*Striped Bass vs. Weakfish*, p. 8)

Predators and prey are in a constant battle for survival, the prey evolving mechanisms to avoid being eaten and the predators evolving means to thwart those mechanisms. Over time, predators and prey find an optimal balance, around which their populations fluctuate, a balance favorable to both. It is the product of their co-evolution and synchronic behavior.

The predators require this amount, this density and this availability of prey in order to maintain their populations at pre-fishing levels. They cannot "fish" harder without adverse consequences for themselves and other predators. And so it is, for every reduction in standing biomass of prey species we realize through fishing, there is a direct and proportionate reduction in the ecosystem's ability to support the full complement of predators that depend on the prey as a food source.

STRIPED BASS vs. WEAKFISH

Scientists theorize that extremely high natural mortality in weakfish – mortality so high that it alone is severely depressing a population that supported stable fisheries for two hundred years – is likely the result of both reduced forage and increased predation. Striped bass, a competing predator, is known to be consuming unusually large quantities of bay anchovy, a staple in the diet of weakfish, along with large numbers of young weakfish, because abundance of its own prey of choice, Atlantic menhaden, is near historic lows.[24]

Resource Sharing

If we are truly going to move to the more enlightened concept of ecosystem-based fisheries management, we must bury the notion of surplus production and all its connotations before we can write its epitaph. We must adopt the more reasonable and more balanced concept of *resource sharing*. That means, according to the late fishery ecologist Steve Berkeley, first and foremost acknowledging that what we may treat as surplus is essential to other predators, and that by reducing populations of key forage fish to near half of their un-fished levels we are taking an inordinate amount of food off the table for other species.

Of course, all predators must compete with other predators for a limited supply of food. But what distinguishes us most from other animals is that they know instinctively how to relate to their environment, where and how they fit in; whereas we alone have the existential problem of having to figure it out for ourselves and the unique capacity to make mistakes of devastating proportions.

What we are talking about, then, is deliberately – in the truest sense of that word, through a deliberative process – sharing the resource with a wide range of other predators. The concept of resource sharing does not mean we have to stop fishing for forage species, only that we need to fish more conservatively,[25] considering the needs of predators before allocating forage species to fisheries.[26]

Certainly, a new concept based on resource sharing requires changes in the way we study and assess fish within their environment. But above all else, what we need are unambiguous ecosystem-based goals, which are science-based but ultimately value-driven, because

[S]cience, which can do so much, cannot decide what it ought to do.[27]

The standards commonly used to judge the health of prey or forage species – the population targets and fishing limits we use to guide our actions - must be replaced with new, innovative policies that incorporate well-established ecological and precautionary principles.[28]

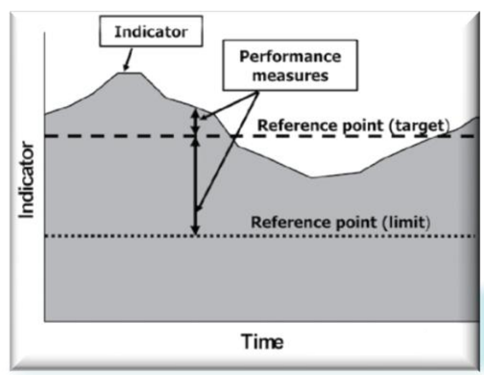
Part Two

Like the mythical sculptor Pygmalion, the creator can fall in love with his creation and become blind to other realities.

Schnute and Richards[29]

The benchmarks fishery managers use to assess the relative status of a fish population, including forage species, are known as biological reference points. In the simplest terms, they are targets that we aim for and thresholds we aim to avoid. The reference points applied to most single-species assessments do not measure the population or stock's capacity to provide adequate prey for other species in the ecosystem.

Target and threshold (or limit) reference points are used to monitor abundance and fishing mortality to ensure that the stock is capable of sufficient production to sustain itself while also supporting a viable fishery.[30] These conventional benchmarks are set to determine whether "overfishing" is occurring or the stock is "overfished", but only in the sense that the rate of removals by the fishery does not exceed the ability of the stock to replace itself over time. They do not account for the possibility that a fish population is over-exploited from an ecosystem perspective even if it is not overfished in the traditional sense.[31]



Sainsbury & Sumalia 2001

Fortunately, standard reference points can be modified to achieve new, ecological goals. The process of developing and applying what are known as "ecological reference points" to stock assessments is comparable to the process used to establish biological reference points, in that each are targets and limits set to achieve agreed upon management objectives. The indicators can be the same, only the objectives and performance measures will differ. We can use the traditional currency, such as population size and mortality rate, but link it to ecosystem goals, such as setting aside a specified amount or percentage of the prey population to serve predator needs.

But before examining how to do this in Part Three, it is necessary to dispel several common misconceptions about what we are doing now relative to where we need to go: Myth #1: MSY-based reference points, flawed though they may be, are grounded in objective science, whereas reference points to achieve broad ecological goals can't help but be subjective, even arbitrary. Myth #2: Estimates of natural mortality used in single-species stock assessments include estimates of predation and therefore predator needs are already accounted for. Myth #3: We are not yet prepared, scientifically or otherwise, for such a complex undertaking as developing ecological reference points and using them to regulate our fisheries.

An Allocation Decision

Performance measures to achieve ecosystem objectives will be grounded in policy, allowing for social, economic and ecological factors, as are all such measures, including those currently in use.[32] Science does not and cannot, in and of itself, reveal to us what amount of fishing for a forage species should be allowed or what amount to leave in the water. Just like managing for MSY, it is ultimately an allocation, between human and natural predators.

MSY is not about the health of the fish or the ecosystem, it's about fishing. It's a means to achieve social and economic ends - ecological considerations are left out of the equation

We know how to maximize yields to our fisheries, unmindful of the broader impacts on the ecosystem, because we've been doing that for decades using MSY-based strategies. Likewise, we know how to maximize yields to the ecosystem; we could stop fishing. To choose to do either is not science, it is policy. Choosing something in-between, a resource sharing arrangement that balances societal and ecosystem needs, is a policy decision, too.

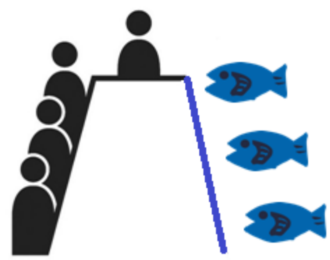
To paraphrase Dickens, this must be distinctly understood, or nothing useful can come of the recommendations I am going to make.[33]

Yet some fishery professionals, scientists and managers alike, dismiss alternatives to our current system of setting population targets and fishing limits as arbitrary, *ad hoc* or unscientific. It is as though the doctrine of maximum sustainable yield were as much a product of natural evolution as the species we fish.

> *Although the concept of [MSY] has served fisheries science well over the years, it has tended to become an inflexible goal which has*

permeated the management philosophy of fishery researchers. As a result, the researcher's sensitivity to the needs and wishes of society has become dulled and his awareness of the intricacies of nature has been ignored in favor of the simplicity and positiveness of his methodology.[34]

MSY can be a useful tool, precisely because it allows scientists to bypass modeling a complex ecosystem.[35] But it's just that, a tool, a means serving human ends. MSY inarguably is grounded in the science of population dynamics, but only in so far as the "best available science" is used to determine the population that will produce the highest yield to the fishery on a continuing ("sustainable") basis. If we're going to be honest, it's not about the health of the fish or the ecosystem, it's about fishing. The targets and limits managers set, and which scientists then provide advice on, are based primarily on social and economic objectives, i.e., optimizing yields. The third element to be considered in achieving the so-called "optimum yield"[36] from a fishery – protecting marine ecosystems – is not part of the equation.



Managing and conserving prey fish to balance the needs of fishermen and non-human predators, using ecologically-based reference points, isn't arbitrary, it's arbitration. Stock assessment scientists can estimate what portion of the standing population is available to predators, or what would be available at different levels of fishing, but they cannot tell managers whether that is adequate – *unless* fishery managers first provide them with ecological objectives that make an explicit allocation among fisheries and the ecosystem. In that negotiation, we may have a bigger voice than other predators, but no greater interest in the outcome.

Accounting for Predator Needs

Knowing the amount of natural predation on a population of fish is an integral part of any stock assessment and vitally important for lower trophic level prey species. Natural mortality is also the most difficult parameter to measure. By comparison, estimating fishing mortality, both fish landed and those discarded at sea, is a cinch; which, of course, it is not.

Notwithstanding, some fishery professionals assert that allocations to fisheries account for predator needs because estimates of natural mortality are included in stock assessments. Logic alone controverts this assumption, but helpful new research does, too.

The purpose of a single-species stock assessment is to determine what level of fishing can be permitted while maintaining the stock and future yields at the desired levels. Estimating the number of fish that will die each year of natural causes is an essential component, despite being extremely tough to approximate and thus fraught with uncertainty.[37] All the same, the natural mortality rates we do use are only a guess at current rates of predator consumption, which is not at all the same thing as determining what predators actually need.

First of all, the natural mortality rate (expressed as *M)* is rarely estimated from empirical data on prey consumption by predators and other sources of natural mortality. Instead, it is usually a textbook estimate based on life history characteristics of the species, or rates already in use for similar fish, or data from tag-recovery surveys. It is often applied to the stock as a whole - all age classes, all areas - and constant over time. Estimates of age-specific and time- and space-varying *M* are considered appropriate and desirable for most species, but add new levels of complexity and demands for data while amplifying uncertainty.[38]

If predator needs are not adequately accounted for, yields to the fishery will be set too high and lead to overfishing of the prey population and negative impacts to predators

Secondly, natural mortality is an estimate of predation on a population that is in a fishing-induced equilibrium and thus substantially smaller than it would be if the population were at carrying capacity. So at best, conventional estimates of predation are merely a measure of consumption under prevailing conditions. They are most assuredly not a measure of predator demands - past, present or future - or an indicator of whether or not those demands are being met.

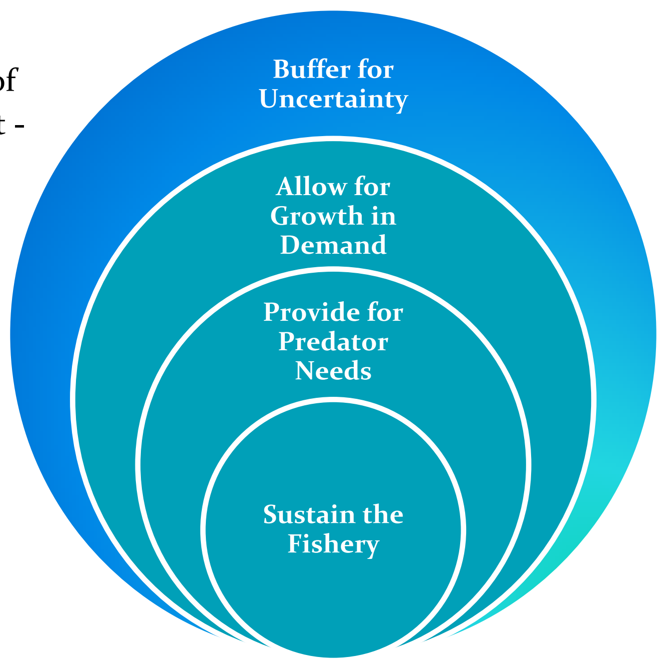
In an un-fished population at a natural equilibrium, total mortality for a prey species equals natural mortality, which is primarily predation. In a population that is at a fishing-induced equilibrium, such as the biomass associated with MSY, the amount of predation has been reduced to accommodate desired fishery yields. As a result, estimates of natural mortality are influenced by the fishing mortality rate and, indirectly, by the management goals that set that rate. The *M* that we “determine” is actually an *a priori* allocation to predators – i.e., they get what’s left over - rather than a determination of actual predator needs.

Several recent studies[39] conclude that traditional stock assessments for forage species do not fully or accurately account for predation. In the cases of Atlantic herring and mackerel, respectively, the natural mortality rates used, along with the assumption that they are constant, underestimate the population size needed to simultaneously sustain a wide range of predators and fishing, thereby overestimating the amount of fish that can be safely allocated to the fisheries. If natural mortality is under-estimated and the estimate does not reflect the dynamic nature and needs of predator populations, allowable yields to the fishery may be set too high and lead to overfishing of the prey population and negative impacts to predators.

It is further noted in these studies that the herring and mackerel assessments, like most others, do not account for increasing prey demand of predatory fish stocks in the northeast and mid-Atlantic regions as they recover from overfishing. To this uncertainty add the difficulty of projecting the size of the prey populations themselves into the future, as they fluctuate over time due to a combination of changes in environmental conditions, reproductive success and fishing pressure.[40]

For all these reasons, management policies must acknowledge deficiencies in the ability of single-species stock assessments to both fully account for predation (present consumption) on the one hand and predator needs (the demands of a healthy ecosystem) on the other.

In the end, our current method of accounting for predation is just that - accounting. Even if you conscientiously record every deposit and expenditure in your check book, it may prevent you from spending more than you have in the bank, but it will not ensure that you have enough on hand to cover all of your bills. For that, you need a prudent plan for allocating your resources.



Arts and Science

A century ago Teddy Roosevelt wisely noted that, while the profession of the "modern" naturalist is more than ever a science, it has also become an art. That insight is even more pertinent today, as our ever-accumulating knowledge about the world we live in and our impact on it, rather than telling us what we ought to do, can freeze us into inaction. Because science can tell us so much, we want more - unassailable science – before we act, often at the expense of doing what is intuitively obvious.

Finding ways to fish that serve the enduring public interest, while preserving the natural world that formed us and sustains us, is not rocket science. It doesn't require an endless stream of data to plug into staggeringly complex models to make it fly. To pursue that course is to chase an ever-receding horizon. What it does require is imagination.[41]

Precision and Uncertainty

Developing ecosystem-based targets and limits is resisted by some fishery professionals who argue we are not prepared to re-allocate prey species between fisheries and predators given our current state of science and understanding of the trade-offs involved.[42] I might agree, *if* our goal were to quantify and analyze all potential trade-offs within the ecosystem. However, such an undertaking is not only unrealistic, it is entirely unnecessary.

It is well understood, first off, that uncertainty is inherent in all fisheries science, whether we are assessing the impact of fishing on a single fish population or the effects on multiple inter-related species. That's why there is a widely accepted precautionary principle that calls for risk analysis and risk-averse decision-making. Uncertainty should be treated as reason for caution, not an excuse for inaction.[43]

Concerns that our current state of knowledge cannot support revising our management strategies to consider ecological factors are at once self-contradicting and disingenuous. In fact, it is our present approach that is the least supported by science, precisely because the fishery targets and limits we use now do not take into account impacts on other species and trade-offs within the broader food web. The enormous ecological uncertainties and inevitable risks inherent in this approach are simply not part of the equation and, therefore, moot. To demand a level of scientific precision and rigor of ecological reference points that we do not demand of our current biological reference points is, in a word, unscientific.

Finally, even if it were possible to create an accurate mathematical model of a complex marine ecosystem for fishery management purposes - and that is a highly questionable proposition[44] - the demands on fishery managers, let alone their scientific advisors tasked with creating and feeding data into such a model, would be unbearable. It would require making innumerable decisions throughout the system about desirable targets and thresholds for numerous interconnected species, monitoring them simultaneously, assessing cause-and-effect, and taking multiple complementary actions through numerous individual fishery management plans governed by separate management bodies. It is a black hole from which we would likely never emerge.

To demand a higher level of scientific precision for ecological reference points than we require of our current standards is disingenuous

Intuition!

Science in support of ecosystem-based fishery management will have to move beyond quantitative assessment methodologies.[45] No less a figure than Beverton, a founding father of modern fish stock assessment and management theory, noted the subservience of biology to mathematics.[46] It brings to mind Einstein's observation, particularly apt in this context, that "(a)s far as the laws of mathematics refer to reality, they are not certain; and as far as they are certain, they do not refer to reality." As an alternative, Francis suggests we'd be better served by "more primitive logical systems" that are "holistic" and "qualitative" in nature.[47]

Pat Wray, an elk hunter advocating for the return of timber wolves to Yellowstone National Park in the mid-1990s[48], wrote in answer to opponents worried about the unknown consequences: "We want to understand the way everything fits together and we want it to be empirical, exact, certain. We want data. But the accumulation of dependable scientific data is often nearly impossible, at least in wild country where wolves are meant to roam. Our dependence on data blinds us to the truths that should be intuitively obvious… An ecosystem, like a piece of machinery or a team, works best when it is complete, when it has all its parts."[49]

By waiting for unassailable science, for demonstrated cause-and-effect, we ignore truths that are "intuitively obvious."

The study of nature began with the meticulous identification and classification of species, and proceeded linearly from there, until we discovered that nature can't be wisely stewarded the way we study it - piecemeal. "Nature is through and through relational," writes Alan Watts, "and interference at one point has interminable and unforeseeable effects. The analytic study of these interrelations produces an ever-growing accumulation of extremely complicated information, so vast and so complex as to be unwieldy for many practical purposes, especially when quick decisions are needed."

The predictable outcome, scientifically, would be total self-strangulation, said Watts. "That it has done so only in some degree is because the scientist actually understands interrelations by other means than analysis and step-by-step thinking. In practice he relies heavily upon intuition."[50]

Based on what we know right now, we are more than capable of making a qualitative assessment as to the relative risks and benefits associated with our current strategies and the sensible alternatives being proposed. Indeed, a more holistic, ecosystem approach requires it.

Part Three

Nature cannot throw out the obsolete model and start again. She must always modify existing plans.

Greg Iles, The Footprints of God

If a principal aim of ecosystem-based fishery management is to protect the integrity of the food web through conservation of the forage base – and it is - the questions before us are straightforward: How much food do we leave in the water for other species? And how do we decide how much is enough? How do we fairly allocate between fisheries for prey species and their predators - among them fish that support valuable commercial and recreational fisheries themselves? This is where our discussion of "ecologically sustainable yield" and the reference points needed to achieve it brings us.

There are two kinds of reference points for determining the status of a fish population - conceptual and technical, in that order.[51] Conceptual reference points first define the management goal, whether it's to maximize catches for the fisheries, incorporate other societal values into an optimum yield, or better protect a species' ecological role. Next, technical reference points are developed for regulating the fisheries to achieve that goal.

Models don't produce ecosystem objectives, people do

The lack of clearly defined management objectives[‡‡] is a major impediment to establishing reference points of any kind.[52] It's worth noting here that fishery managers, accustomed to looking to their stock assessment teams to provide model-based reference points for already-established MSY-based management goals, are sometimes unaware that this whole process actually begins with them, not with their science advisors.

In the conceptual stage, then, fishery managers must first articulate an objective of providing a specific forage set-aside for other species in the ecosystem, in order that technical reference points may be developed to control the fishery and achieve this objective.[53]

[‡‡] A goal defines the intent of the action and the general result we want to achieve. An objective is a precise and measurable target for attaining the goal within a set timeframe.

Innovative ecosystem models are being explored to try and quantify the functional relationships between predators and prey.[54] Theoretically, such models could someday help fishery managers test responses to concurrent management strategies for multiple species. However, the more complex the model, the more speculative it is, as the reliable data that go into it are outnumbered by the assumptions required to make it work.[55] And as we've discussed, even the most sophisticated and precise models cannot produce ecosystem goals, people do. Models cannot reveal what amount of fishing for a key prey species should be allowed or what amount to set aside as forage. That is ultimately an allocation of prey between human and natural predators, a policy decision based on agreed-upon ecosystem (societal) goals.

So, how should this forage set-aside be determined? Fortunately, considerable effort has been devoted over the past two decades to finding a practicable approach to defining ecological reference points for forage species that can be implemented now. In fact, a consensus has emerged in the scientific literature around just what those targets and limits should be, based on the ecological importance of forage species, the impacts of fishing on predator-prey relationships, well-known trophic principles, the needs of fisheries, and the precautionary approach.

How should a forage set-aside be determined? Considerable study has been devoted to that question, with general agreement on the answer

In this section, I review what are clearly becoming accepted standards for conserving and managing forage species and summarize recommendations for *ad hoc* ecological reference points. *Ad hoc*, I should note, does not suggest the pejoratives "improvised" or "unplanned", but rather the Latin "with respect to this" and the primary dictionary meaning "for a specific purpose, case or situation." The following ecological reference points were arrived at after extensive research and deliberation by some of the best minds in the business and are designed to be applied to fisheries decisions now.

Readers will note that some reference points are defined relative to MSY, which we've shown to be an unrealistic and risky goal, for forage fish in particular. In all cases, it is used as a baseline or threshold for setting substantially more conservative targets, whether abundance or fishing mortality.

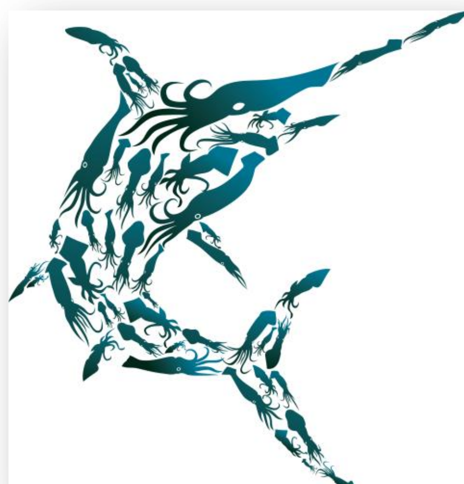
Given our reliance on single-species stock assessments for the foreseeable future,[56] it makes sense to use what we have now as a platform for moving to the next level. In any case, we must avoid the danger of "waiting for Godot" to mathematically model wild oceans - natural systems that cannot be replicated with the simplifications and assumptions inherent in fishery models - meanwhile allowing those ecosystems to be further degraded.

Managing for Higher Abundance

When conserving forage in an ecosystem context, where the standing population of prey is the critical measure of "success", it makes sense to define the goal not in terms of sustaining a yield, but in terms of sustaining an optimum population size.[57]

Although other factors such as age structure of the population and geographic distribution are also important to determining adequate availability of prey, population size – or abundance - constitutes the principal indicator of whether or not there is sufficient prey available to meet the needs of predators. Higher abundance means a larger set-aside to accommodate predators, projected or desired increases in their numbers, fluctuations in other species making up the overall forage base, climate change, and a buffer against inevitable uncertainties.

Reference points that would be responsive to the ecological role of a forage species would be ones which optimize population abundance, while taking into regard the allocation of fish between natural mortality and fishing mortality.[58] First consideration, then, should be given to how targets and limits for population abundance and associated fishing mortality might be established in a manner that provides an adequate forage set-aside.[59]



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An Emerging Consensus

In the United States, the National Marine Fisheries Service (NMFS) prepares federal guidelines for implementing annual catch limits consistent with the Magnuson-Stevens Fishery Conservation and Management Act's National Standard 1 (NS1). NS 1 states that "Conservation and management measures shall prevent overfishing while achieving, on a continuing basis, the optimum yield from each fishery…" Optimum yield was conceived as a modifier to MSY, requiring fishery managers to consider a range of factors in setting management goals, including the effects of fishing on marine ecosystems.[60]

Up until 2009, NMFS provided no guidance as to how fishery managers should take into account the protection of marine ecosystems when they set catch limits, or how MSY should be reduced by ecological factors, or even what those factors are. The predictable result: ecological factors have rarely if ever been taken into account. But under revised Guidelines published in February 2009, NMFS recognized the need for this to change and now encourages fishery managers to set a population target for forage species higher than the level associated with MSY with a goal of "maintain(ing) adequate forage for all components of the ecosystem."[61]

Taking a more precautionary approach with regard to forage species abundance was already established in the scientific literature,[62] something which no doubt influenced the agency's advice. NMFS, however, did not go so far as to recommend how much higher than the stock size at MSY (B_{MSY}) forage species abundance should be maintained. But a number of other well-regarded scientists and institutions have, before and since, revealing a remarkable consensus.[63]

The 75 Percent Solution

The Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) is generally credited as the first regional body to apply an ecosystems approach to forage fisheries management. Recognizing the key role of krill as forage in the Southern Ocean's ecosystem and that prey species with high predation rates are less resilient to intensive fishing mortality than higher trophic levels, CCAMLR in 1991 adopted more conservative reference points than commonly used in traditional fisheries management.[64]

The Antarctic krill policy, sometimes called the 'predator criterion', incorporates the requirements of krill predators (whales, fish, seals, penguins *et al*) by establishing a level of escapement of 75% of the pre-exploitation (un-fished) biomass, instead of the 40-50% level normally used in single-species management.[65]

Choosing an optimum population level for krill of 75% of an un-fished population, according to CCAMLR's scientific advisors, amounts to splitting the difference between a population at or near MSY, which fails to take predator needs into account, and maintaining the population at carrying capacity, which gives complete protection for predators but allows for no fishing.[66] Each yields equally to the other.

At the 2001 Reykjavik Conference on Responsible Fishing, Sainsbury and Sumalia cited CCAMLR in their paper on 'best practice' reference points and proposed that "(f)ishing mortality or biomass targets for significant prey species [be] modified to give 80% chance that spawner biomass is no less than mid-way between the un-fished level and the MSY level" (or about 75% of un-fished biomass).[67]

The United Nations Food & Agriculture Organization, in its Technical Guidelines for Responsible Fisheries published in 2003, suggests "maintaining selected prey populations above 75% of the un-fished biomass to allow for predator feeding."[68]

The Marine Stewardship Council, which develops international standards for certifying sustainable fisheries, convened a Low Trophic Level Task Force to produce guidelines for assessing the sustainability of forage fisheries in order to award the MSC label. Its recommendations were released in 2011. The new guidelines apply to key low trophic level species, such as menhaden, herrings and sardines (family *Clupeidae*), anchovies (family *Engraulidae*), krill (family *Euphausiidae*) and other small pelagic species that form dense schools, feed mostly on planktons, and transmit a large volume of energy to higher trophic levels by serving as prey.[69]

After reviewing research funded by the council to determine the amount of precaution necessary for forage species,[70] the MSC suggests that the default recommended target reference point for these species is 75% of an un-fished population.

Significantly, the researchers (representing a dozen ecologists from 6 countries) concluded that "(s)etting a target of 75% of un-fished biomass for LTL [low trophic level] species (25% depletion) reduces the impact on other species within the ecosystem by more than half while maintaining (fishery) yields above 80% of the level that would be achieved with a target of 40% of un-fished biomass. Such a target is usually achieved at fishing mortality rates less than half those needed to achieve MSY."

Two aspects of the MSC research are particularly noteworthy: (1) The researchers explicitly considered trade-offs between maintaining biodiversity (including ecosystem structure and function) and fisheries production based on model predictions, while advising that these models are helpful in making recommendations at the macro level but not for micromanaging fisheries *vis á vis* the ecosystem; and (2) they view the target population of 75% un-fished biomass as a trade-off that nevertheless allows fisheries to operate with "ongoing substantial yields."

Weighing in with their own published study in 2011, a team of scientists advising European fisheries agencies suggests a "precautionary biomass target" for forage fish of 1.5 B_{MSY}, which just so happens to correspond to about 75% of unexploited biomass.[71]

Preventing Ecosystem Overfishing

The corollary to maintaining a higher target population for key forage species is setting a higher "overfished" threshold. The standard single-species definition of an overfished stock – the point at which fishing is curtailed and rebuilding begins – is approximately ½ B_{MSY}, a population level that may still be capable of rebuilding, but which is only about 20 – 25% of an un-fished population. It is clearly risk-prone to permit a forage population to be reduced to this level, drastically diminishing the ecosystem's capacity to support healthy and abundant populations of predator species, before taking remedial action.[72]

The Lenfest Forage Fish Task Force, an assemblage of 13 ecologists representing 5 countries (and no overlap with membership of the aforementioned MSC Task Force), compared conventional MSY strategies - used to prevent overfishing of most forage fisheries within the U.S. - to more precautionary approaches and found that "the only fishing strategies that reliably prevented a decline in dependent predators were those that limited fishing to half the conventional rate." Ecological sustainability is improved by doubling the minimum biomass that is left in the ocean, from the conventional minimum to at least 40% of the un-fished biomass; that is, Lenfest recommends making B_{MSY} the overfished threshold, instead of the target, below which all fishing stops.[73]

The information available to fishery managers, according to the Lenfest report (published as Pikitch *et al*), is an important consideration in determining the magnitude of precaution to apply. Halving fishing rates and doubling minimum biomass from conventional levels may be sufficient when managers are knowledgeable enough about forage fish status and interactions with predators and the environment to mitigate the impacts of fishing. However, in data-poor situations, they recommend maintaining a biomass floor of at least 80% of an un-fished level for existing fisheries. New forage fisheries should be prohibited from developing until information improves, a recommendation repeated often since it first appeared in the 1999 NMFS report, *Ecosystem-Based Fishery Management*.[74]

To summarize, then, target populations of forage species should be set no lower than 75% of un-fished biomass – a generic goal Lenfest also endorses - while the overfished threshold should be set correspondingly higher than traditional levels and no lower than the biomass level associated with MSY.

Allocating Mortality

Fishery managers should "(c)onsider explicitly strong linkages between predators and prey in allocating fishery resources," recommends NOAA's Chesapeake Bay Office, in *Fisheries Ecosystem Planning for Chesapeake Bay*.

> *Be precautionary by determining the needs of predators before allocating forage species to fisheries*.[75]

A mortality-based reference point, as an allocation between predators and fishing to achieve the abundance target for forage species, is suggested by the MSC and Lenfest. Both studies recommend fishing mortality (or F) for forage species no higher than half the MSY level, or $\leq 0.5F_{MSY}$.

Controlling fishing mortality is not an end itself, but a means for achieving the target abundance

Other mortality-based reference points have been suggested or are already in use for forage species. Collie and Gislason, in an examination of the use of single-species reference points in a multi-species or ecosystem context, conclude that conventional MSY-based reference points are inappropriate for forage species, which have natural mortality rates that fluctuate substantially. They suggest a more appropriate alternative is to manage for total mortality by decreasing fishing mortality when natural mortality increases.[76] In other words, Z (total mortality) – M (natural mortality) = F (fishing mortality). In practice, this can be problematic since real-time fluctuations in predation mortality are difficult if not impossible to observe. The concept, however, reinforces the NOAA CBO's advice to determine predator needs *before* allocating forage species to the fishery.

Another type of mortality-based reference point used to approximate fishing at the MSY level for data poor stocks, or when there is a high degree of uncertainty about stock status, is F as a fraction of M.[77] It is commonly assumed that when harvesting at MSY, F is roughly equal to or lower than M, so M is sometimes used as an F_{MSY} proxy. If the goal is to maintain a higher biomass, as in the case of forage species, then the target fishing mortality rate would be set substantially lower than M,[78] recalling the MSC and Lenfest recommendations.

The North Pacific Fishery Management Council, which uses a tiered system for setting buffers between overfishing limits and target catch levels based on stock life history and uncertainties in the assessment, establishes an overfishing level for walleye pollock, an important forage fish in Alaskan waters, equal to M and a target **F** that is set at 0.75M.[79] Lenfest goes further, recommending that, for species with "intermediate" information available on stock status and mortality, F should be the lesser of 0.5*M* and 0.5F_{MSY}.

What is most important to remember, however, is that an F-based reference point is a means to an end and not an end in itself. Population size or standing biomass constitutes the best indicator of the amount of prey available to meet the needs of the ecosystem and dependent predators. Controlling mortality, therefore, is a tool for achieving the target biomass reference point, and fishing mortality-based reference points should be set consistent with achieving the desired abundance.

Managing for Availability (and Avoiding Localized Depletion)

Maintaining high abundance of a forage fish does not wholly protect the species' role in the ecosystem. Fishing a prey population also affects the size (age) of prey available and distribution throughout their natural range.[80] Indeed, the two are linked, since different age groups can exhibit distinct patterns of movement and behavior. Because spatial and temporal availability of prey of the right size is critical to predators finding an adequate supply of food where and when they need it, precautionary catch limits alone cannot prevent localized effects on predators and the ecosystem.[81]

By way of example, the conservative catch limits established by CCAMLR for Antarctic krill, cited earlier as a pioneering model of precautionary management, were not enough to buffer shore-based predators, such as penguins and seals, from the effects of localized depletion. Spatial management is necessary to prevent fishing fleets from concentrating effort and competing directly with predators for subpopulations of krill within their foraging range.[82]

The Policy on Fisheries for Forage Species set down by Canada's Department of Fisheries and Oceans explains:

> *Management plans for commercial fisheries on forage species should include explicit provisions to ensure that fisheries do not unduly concentrate harvest and do not produce local depletions of the forage species… Forage species should be managed in ways which ensure local depletion of population components does not occur. Local depletion of the forage species could result in food shortage for the dependent predators, even if the overall harvest of the forage species was sustainable.*[83]

To avoid localized shortages and maintain prey availability, management strategies for forage fish should consider, in addition to abundance and mortality targets and limits, other measures, including regional sub-quotas and reserves,[84] to achieve: 1) The desirable age structure, i.e., an age distribution reflecting that of a healthy, pre-exploitation population; and, 2) Population density, i.e., prey availability distributed in time and space approximating the un-fished range to avoid local or regional depletions.[85]

Protecting the Whole Forage Base

An ecosystems approach to managing marine fisheries recognizes the importance of abundance and biodiversity for ecosystem *and* fisheries stability. With it, we acknowledge that intensively fishing single, targeted species alters marine communities and recognize the importance of conserving forage species to the health of the ocean environment. It follows, then, that the status of individual forage species ultimately should be considered within the broader context of monitoring and protecting the forage base *as a whole* – managed and unmanaged, fished and un-fished species - since the broad field of predators depends on a diversity of prey and an abundance of diversity.

The broad field of predators depends on a diversity of prey and an abundance of diversity

A major challenge of developing performance measures at the ecosystem level is identifying and cultivating reliable indices of abundance and availability. While ecosystem-based targets and thresholds are the priority for individual forage species, in accordance with emerging standards as discussed, it may be equally important to develop a forage status indicator, including an overall forage base "cutoff" or biomass threshold to augment species-specific goals. Because oceanographic or ecological conditions that result in poor survival across species could have even broader impacts on the system than fluctuations in a single species' population level, an aggregated treatment of forage could better detect these changes and inform efforts to mitigate them.[86]

Fishery ecologists concerned with maintaining predator-prey relationships, energy flow within the system, and species diversity, suggest potential indicators along these lines.[§§]

- Livingston *et al* recommend developing a quantitative index of total forage biomass, with a threshold for management action, as an indicator for maintaining pelagic forage availability.[87]
- A forage status indicator, according to FAO scientists, could be modeled after the reference points currently used in single-species management, employing overall biomass targets and thresholds.[88]
- Biomass Size Spectra models, which depict the abundance and distribution of organisms at each level of the food chain, could serve as ecological indicators, as constituents of a trophic level, e.g., prey species, respond to natural or human-induced stresses.[89]
- Prey-predator ratios might be used to index availability and probable vulnerability of prey to predators and serve as an indicator of expected prey mortality and predator abundance.[90]
- Select species, such as seabirds whose abundance is readily monitored and are highly-dependent on prey availability throughout a wide range of habitats, could serve as indicators.[91] Alternatively, a suite of predator species indicators could be used to inform fishery managers as part of an annual ecosystem assessment.

As noted, fishery scientists and policy makers are in general accord on ecological reference points for individual forage species (target level of 75% of a virgin population and minimum stock threshold of 40-50%). Because the ecological value of the overall forage base is at least equal to the sum of its constituent parts, it would make sense to apply similar performance measures to the forage base as a whole.

[§§] Ecosystem models are more practical and likely more useful in the near term at this macro level, where the objective is to provide fishery managers with a broader context to inform decisions at the fishery level.

The Berkeley Criterion

The study of Ethics is part and parcel of the study of Nature; for man must learn his place in the world before he can act rightly and reasonably.

W. Somerset Maugham

Our present goal of achieving sustainability for all marine fisheries means maintaining fish stocks at levels that will enable utilization by present and future generations of humans.[92] It's a laudable goal, as far as it goes, but it's not nearly far enough. Any definition of sustainable fishing that does not include the effects of fishing on other components of the ecosystem and on overall ecosystem health is, by definition, unsustainable.

Fish populations have limits that cannot be exceeded without causing harm at the ecosystem or community level.[93] This is especially true for forage species that serve the critical role of providing food and energy for all of life above them on the food chain, including us. The first principle of conserving forage should be to meet the needs of the ecosystem, before determining the allocation of fish to fishing. That means deliberately setting aside a share of the forage resource to serve as a reserve for dependent predators.

Ocean science literature and emerging standards in fishery policy suggest populations of forage species should be maintained at a level approximating 75% of the un-fished population (B_{MAX}). Fishing mortality should be significantly lower than natural mortality, as proposed here, but in any case set at a level that is consistent with maintaining abundance at the proposed target level. Conservative catch limits should be augmented with spatial and temporal measures to guard against localized depletion.

Ecological Reference Points	Proposed Targets	Proposed Thresholds
Abundance[***]	$B_{MAX75\%}$	$B_{MAX40\%}$
Mortality	$F \leq .5M$ ($.5F_{MSY}$)	$F \leq .75M$ ($.75F_{MSY}$)

The targets and thresholds derived from these precautionary standards are easily implemented using existing stock assessments while accounting for substantially more factors that can affect both the species and its ecological role as prey.[94] Above all, they provide for

[***] Abundance means population size measured as biomass or numbers of fish. For example, B_{MAX} is the abundance in the absence of fishing and $B_{MAX75\%}$ is 75 percent of the un-fished population.

sharing the resource in a way that not only protects the ecosystem but provides for reasonable fishing opportunities.[95]

In the end, the concept of **Resource Sharing** satisfies three fundamental criteria. It is based on the best available science, it is ecologically sustainable, and it fairly balances the needs of all marine predators, including humans.

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Notes

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