Wild Oceans Project
Kona Billfish Nursery Status Report
Phase 2 – Period 1
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Introduction

Phase 2 of the project uses information provided from Phase 1 to estimate patterns of larval dispersal and connectivity in billfish, in particular, striped and blue marlin in the Main Hawaiian Islands (MHI). The emphasis of Phase 2 is Kona - the region west of the island of Hawaii, a known nursery habitat where larval billfish of a range of sizes (ages) have been found. Test simulations of larval movements by ocean flows have been conducted to explore whether larval istiophorids of certain ages reported near the MHI could have been hatched in Kona or elsewhere, to gain an understanding of the extent of larval habitat and important factors shaping this habitat so it can be protected and conserved.

Oceanographically, the region west of the MHI is also an area characterized by a highly variable flow environment, dominated by active generation and propagation of mesoscale eddies. An assessment of eddy activity by Lindo-Atichati et al. (2020) suggests an average count of 40 eddies on a 0.5° x 0.5° area per year in the region, with local peaks reaching to 80 eddies. Kona is one such location of peak eddy generation where cyclonic and anticyclonic eddies are spun up in the northern and southern sectors, respectively, in response to the local wind shear. The wind shear is created when the prevailing northeasterly trade winds accelerate through the Alenuihaha Channel to the north of the island of Hawaii and to the south around the South Point combined with the weak winds in the wake of the island with high relief. There is no detectable seasonality in the frequency of their generation. They vary in strength, lifetime and propagation speed - some linger and decay near the generation sites while others drift away from the coastal region. As shown in Figure 1, they can act to transport passive particles (such as larval fish) away from Kona or retain larval fish within the Kona nursery.

Based on the estimated ages (from size information) of istiophorid samples collected in Kona from past cruises (Source: Phase 1 Database), and using flow fields from HYCOM (an eddy-resolving ocean circulation model), estimates of the spawning locations of larval fish have been made by backtracking their routes using the computer tool described next.

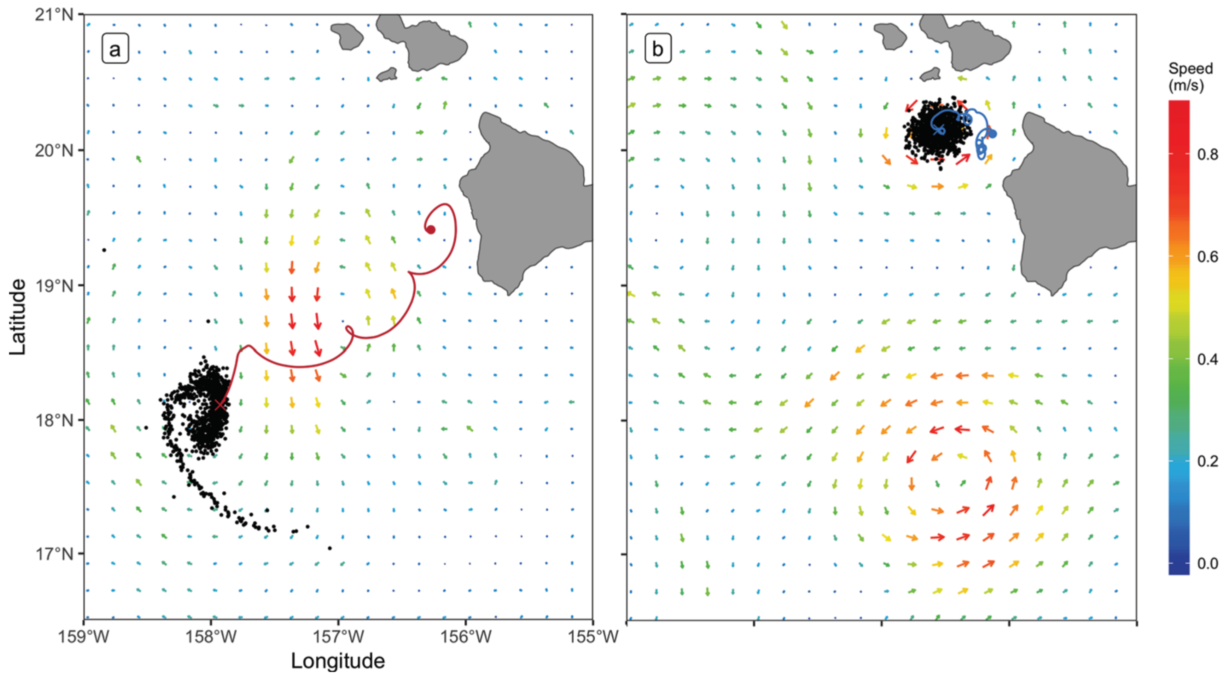

Figure 1. Distribution of simulated larval fish at the end of their pelagic larval duration (45 days assumed) when they are released in eddies with different rotation and propagation speed.
(a) Start location of 1,000 larval fish at the center of an anticyclonic eddy (red dot), average trajectory of all larval fish during their pelagic larval duration (red curve), individual end locations (black dots), and average end location (red cross) of all larval fish.
(b) Start location of 1,000 larval fish at the center of a cyclonic eddy (blue dot), average trajectory of all larval fish during their pelagic larval duration (blue curve), individual end locations (black dots), and average end location (blue cross) of all larval fish.
The lifetime of both eddies is longer than the duration of the simulations. Surface geostrophic currents from an ocean circulation model are superimposed for the end day of each simulation. The current velocity fields range from 0.1 to 1 m s^{-1}. (Ref., Fig. 8 of Lindo-Atichati et al., 2020).

A tool for tracking the movements of larval billfish

Ocean Parcels (https://oceanparcels.org) is a computer program for conducting particle tracking simulations. It is available under an open source license, free of charge, to any person. The program is computationally efficient and customizable, thus is well suited for tracking particles in an evolving flow environment, such as flow fields generated by ocean circulation models. In this project, the particles of interest are larval billfish. For a given velocity field (steady or time-dependent) and particle locations at specified times, particles can be passively moved either forward in time to explore the range, corridors and direction of particle spread, or backward in time to trace the possible origins of particle occurrences.

Case studies

Several simulations have been conducted to back-track the routes of larval fish for their origins. The details of these simulations are described in the Appendix at the end of this report.

Results from these case studies suggest a wide spread of possible larval spawning origins including Kona and from sites far away from the capture locality of the larval fish. It is important to keep in mind that the accuracy of the results rely heavily on the assumption and conditions that the larval fish are totally passive when riding with the ocean currents and the flow field from HYCOM is a realistic representation of the ocean. In practice, however, these conditions are difficult to meet. Young larvae are likely to be in a passive state although their chances of survival may be challenged in fast flowing water. Older larvae may veer off course while developing their swimming skills. Most importantly, the flow field from HYCOM is an estimate of the real ocean state because model formulation errors exist and the resolution of the model is a limiting factor in capturing the small scale motions. This is true for any model generated velocity fields. In place of model output, satellite products can be used but then instrument errors and frequency of satellite passes can limit their accuracy and coverage, especially in coastal regions. In short, the ocean state represented by existing satellite observations or model output should not be regarded as the absolute truth, and extensive experimentation is required to gain a statistically stable view of larval dispersal.

Next step – Period 2 of Phase 2

The simulations for the Kona region, however, so far demonstrate the possibility of different patterns of larval dispersal and several putative spawning locations. Given the nature of the variable flow fields and paucity of larval collections, information that can be extracted from these cases, though useful, is nonetheless limited. In order to gain a credible estimate of spawning origins, a systematic modelling approach is necessary. One such an approach could be an ensemble of larval tracking simulations that span a temporal range sufficiently long to capture the salient characteristics of the flow variability such that recurrent dispersal pathways can be revealed and highlighted. The information compiled in Phase 1 on larval billfish capture locations and seasons can be used to guide the design of such an ensemble. Results from the ensemble experiments will be compiled to generate a density map in terms of the number of particles per unit area for a given age of larvae, a quantitative measure of probability for a specific region as a billfish spawning habitat.

Here is a demonstration of a mini-ensemble designed to estimate possible spawning habitats for larval billfish captured around Cross Seamount.

On 19 August 1950, larvae of two blue marlin and 1 shortbill were captured to the *southwest* of the summit of Cross Seamount (Figure 2, Phase 1 Database by M. K. Musyl). The marlin larvae were 3.7 mm in length with the estimated age of 5 days. The shortbill was 3.8 mm (age ~6 days).

On the same day (19 August 1950), four (4) blue marlin larvae were collected to the *northwest* of the Cross Seamount summit. They ranged 4.3-5.3 mm in length (age ~7-10 days).

On 8 July 1961, one larval shortbill, 7.6 mm (age ~14 days), was found to the *west* of the summit.

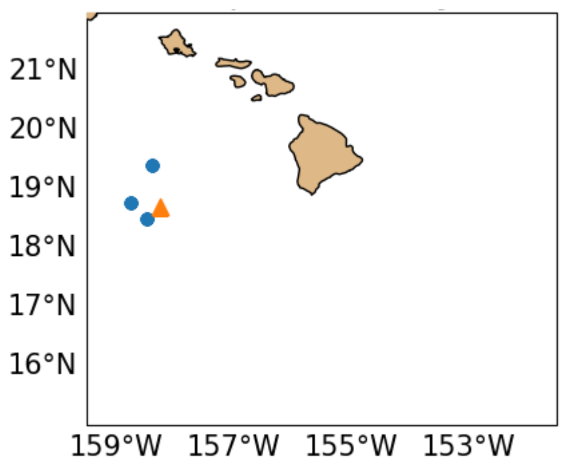

Figure 2. Larval billfish capture locations (blue dots). Orange triangle: summit of Cross Seamount.

Since velocity fields from years 1950 and 1961 are not available in the HYCOM archive (the earliest time is 1992), the flow fields for July-August 2017 are used as surrogates.

In the tracking program, synthetic particles representing larvae are released from the 3 capture sites. One particle is released at each site on each day of 1-31 August 2017 (93 particles in all). Particles are tracked backward in time starting from 31 August 2017 for a total of 45 days, ending on 17 July 2017, such that each released particle is tracked for a minimum of 15 days.

Positions of all particles after being tracked for the indicated number of days (regardless of their release dates) are gathered and plotted in Figure 3. It is seen that the younger larvae (< 7 days) are likely spawn near Cross Seamount. For the older larvae, there is the possibility of their origin being near Kona.

This demonstration is described as a mini-ensemble because the seeding of particles happens during only one month (August 2017) and from only 3 sites. The longer the simulation period, the better to capture a wide range of flow patterns of larval dispersal. Additionally, the coverage of particle placement needs to be expanded to reflect the distribution of known larval capture locality.

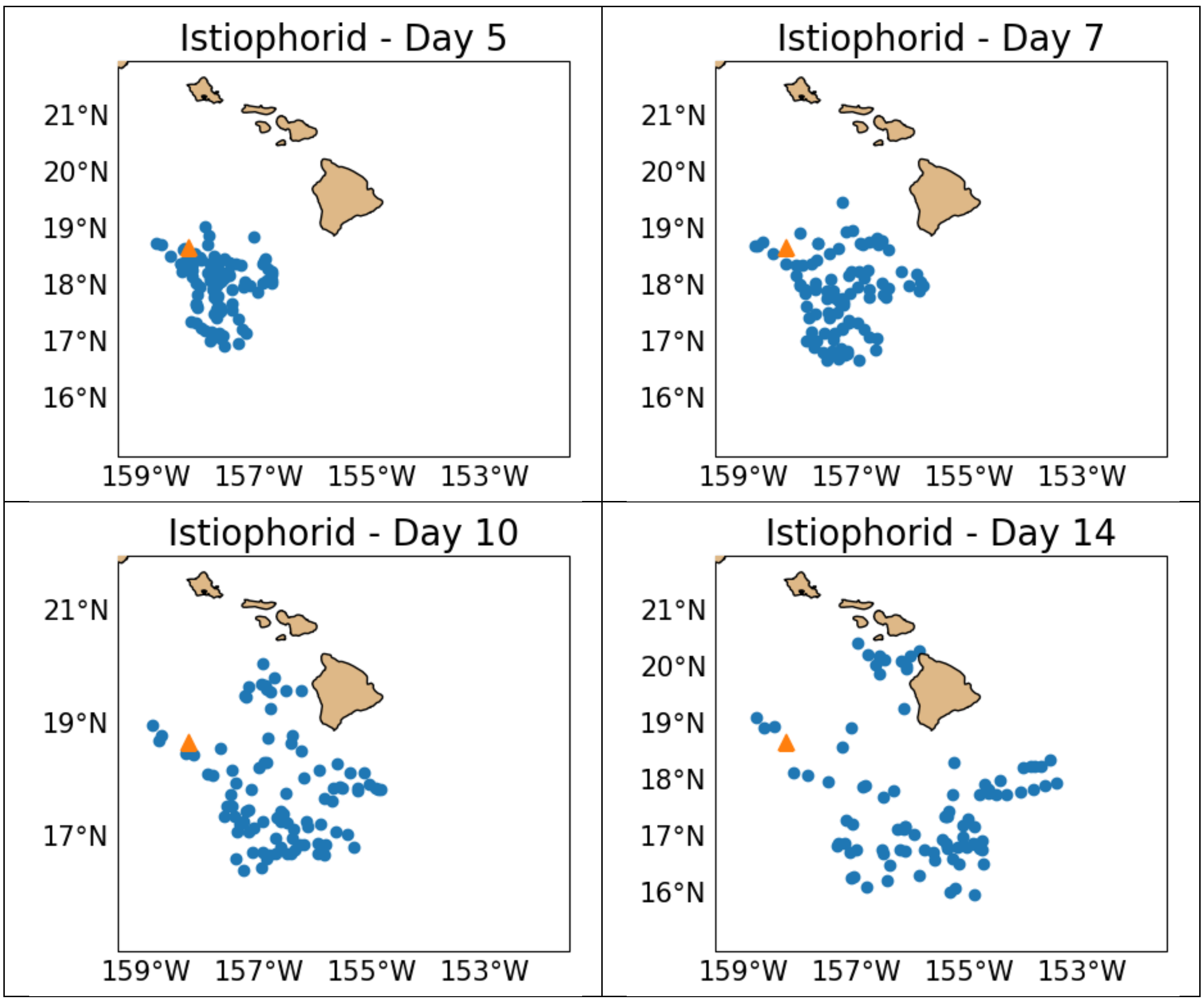

Figure 3. Particle positions (blue dots) after tracking for the number of days as indicated. Orange triangle: Cross Seamount.

Appendix – Case studies

1. Striped marlins – May 2005

In May 2005, seven (7) striped marlin larvae were collected in the waters off the Kona coast of Hawaii Island. They were unambiguously identified through a DNA based method (Hyde et al., 2006). Using the age and growth relationships of Sponagle et al. (2005), their ages are estimated to be 8 to 28 days (Table 1, from the Phase 1 Database by M. K. Musyl).

In the tracking program (Ocean Parcels), the 7 larval fish, represented by 7 synthetic particles and identified by numbers 0-6 (Figure 4, left), are placed at their capture locations. Particle nos. 3 and 4 are almost at the same collection locality. Particle nos. 2 and 6 are also closely located. The HYCOM velocity field is used to track the movements of the particles.

Tracking is preformed <u>backward in time</u>. Start date is the capture date for each particle. Length of tracking for each particle is its age. The end point of each trajectory, therefore, may be considered as the possible spawning location for the larval fish, assuming it remained in a passive state throughout the tracking period (Figure 4, right).

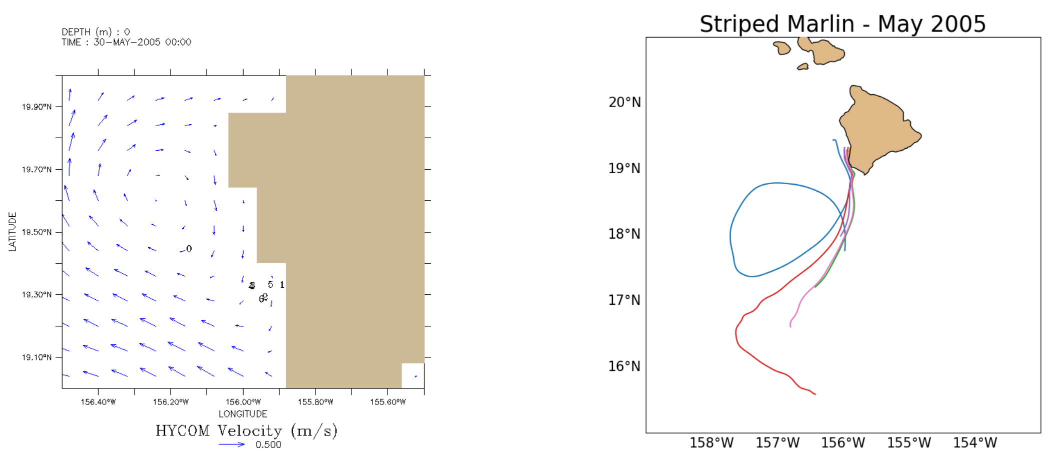

Figure 4. Left: Capture locations of the 7 larvae, with flow vectors from HYCOM (Color beige represents land cells in HYCOM). Right: Particle trajectories - particle nos. 1 and 5 stayed close to their initial positions (too close to land on the HYCOM grid).

Particle no.	Color	Age (days)	Length (mm)	Capture date
0	Blue	22	15.2	30/05/2005
1	Orange	11	6.1	28/05/2005
2	Green	12	6.4	28/05/2005
3	Red	28	26.7	28/05/2005
4	Purple	8	4.6	27/05/2005
5	Brown	11	6.2	27/05/2005
6	Pink	14	8.0	27/05/2005

Table 1. Details of the 7 striped marlin larvae.

2. Istiophorids – August 2017

In 2017, sixteen (16) neuston tows were conducted 0.77-6.32 km off the Kona coast of Hawaii Island from R/V *Oscar Elton Sette* (Gove et al., 2019). The tow locations, numbered 0–15, are shown in Figure 5 (left). Samples of collected istiophorids measured 12-14 mm in size, and their estimated ages are approximately 19-21 days (M. K. Musyl, Phase I Database).

In the computer tracking program, synthetic particles representing larvae are released from 16 sites on a 4 x 4 grid approximating the area of the tows (Figure 5, right). One particle is released at each site on 31 Aug 2017, a randomly selected date of the tows since the exact dates of the tows were not reported. Particles are tracked backward in time in a time-varying flow field (Figure 6) for 28 days. Particle trajectories are shown in Figure 7.

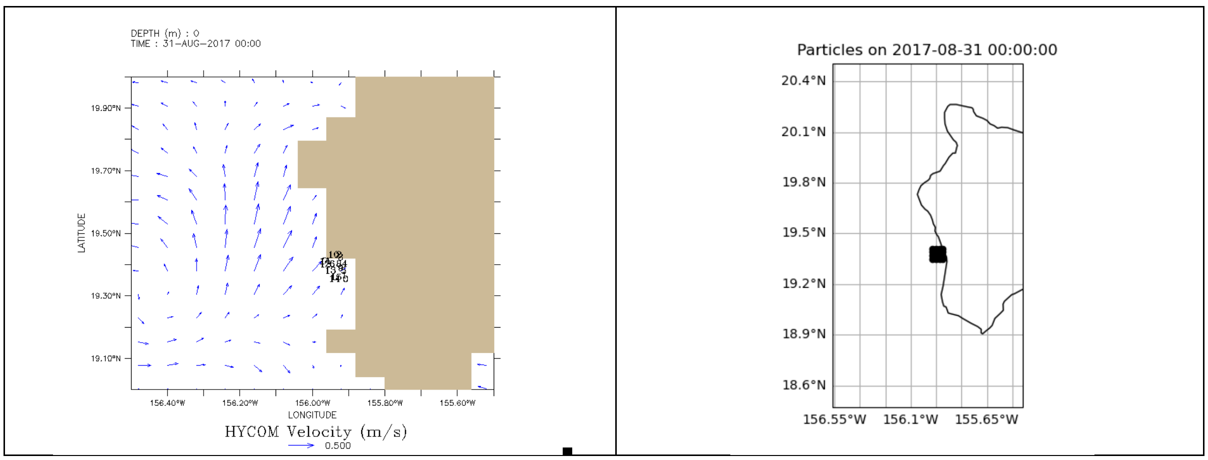

Figure 5. Left: Reported positions of tows. Right: Initial placement of particles in the computer tracking simulation.

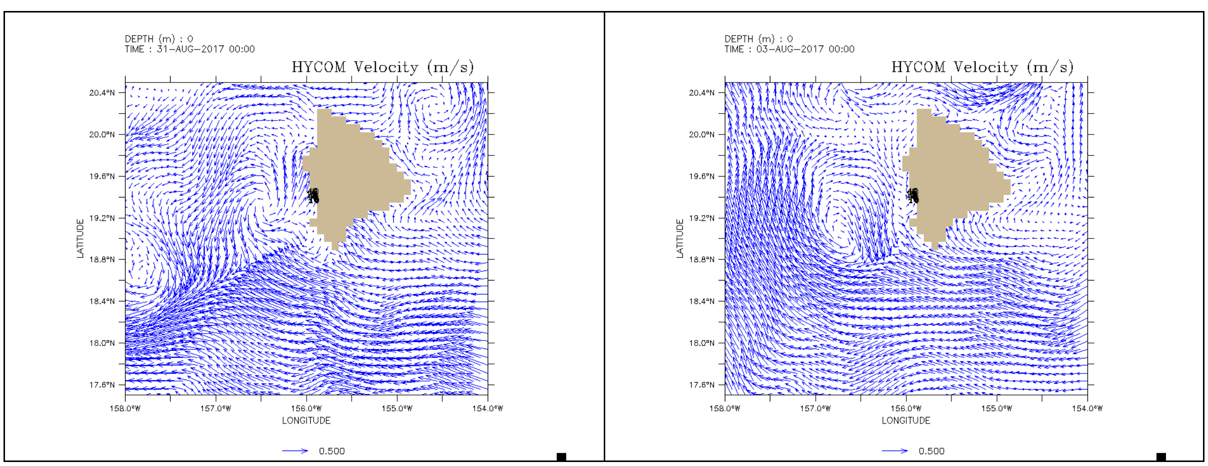

Figure 6. HYCOM velocity fields at the start (left) and end (right) of the backward tracking simulation. The flow is highly variable both spatially and temporally.

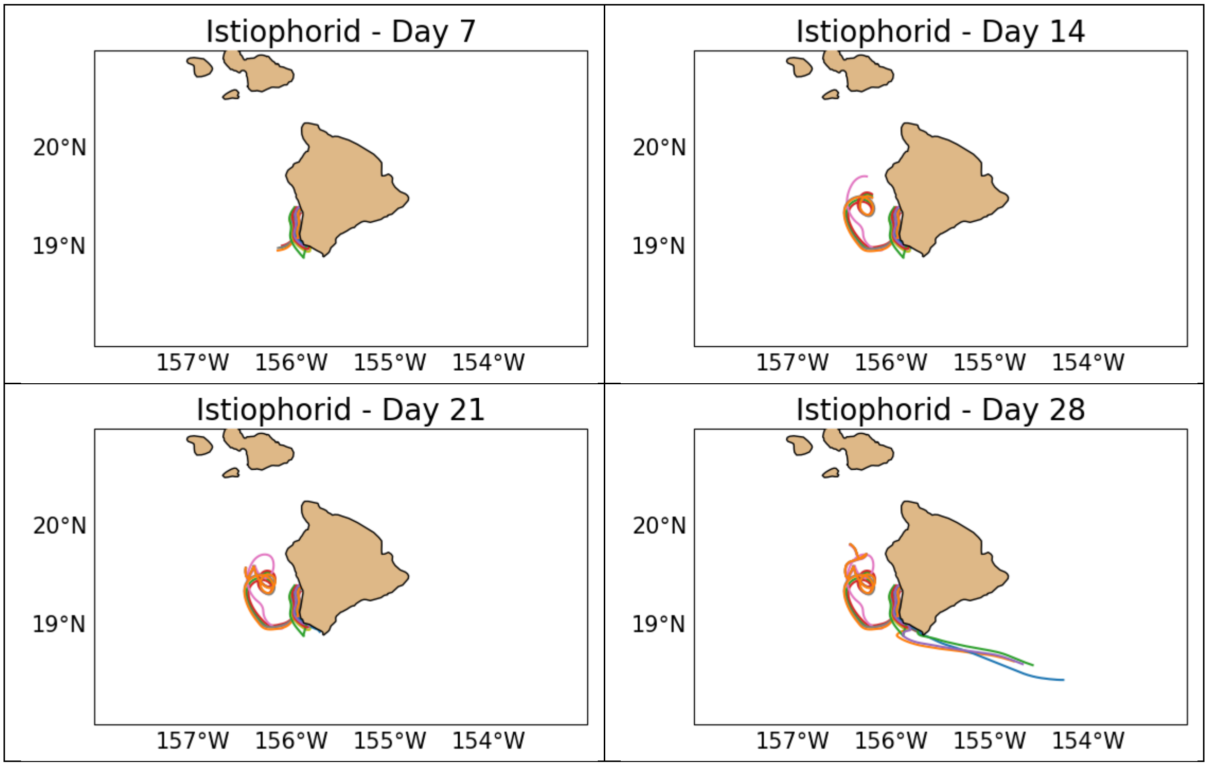

Figure 7. Trajectories of the 16 particles – length in days as shown. The end points of the trajectories may be considered as possible spawning locations for larvae with the corresponding age (day) in each panel. For larvae less than 3 weeks in age, the region off the Kona coast may represent both a spawning ground and a nursey habitat.

3. **Istiophorids and swordfish – May 2003**

During 2-7 May 2003, surface net tow operations for billfish larvae and eggs were conducted 3-25 nmi off the Kona coast of Hawaii Island from R/V *Oscar Elton Sette*, Cruise 03-03 (OES-04). Approximate tow area is shown in Figure 8 (left, between Keahole Point to the north and Milolii to the south). Samples of the collected istiophorids and swordfish measured 9-29 mm in size, and the estimated ages are approximately 16-29 days (M. K. Musyl, Phase 1 Database).

In the tracking program, synthetic particles representing larvae are released from 9 sites numbered 0-8 (Figure 8, right). One particle is released at each site on each day of 2-7 May 2003. During this period, a tight anticyclonic eddy is present next to the shore (Figure 9). Particles are tracked backward in time starting from 7 May 2003 for a total of 33 days, ending on 4 April 2003. Particle trajectories are shown in Figure 10.

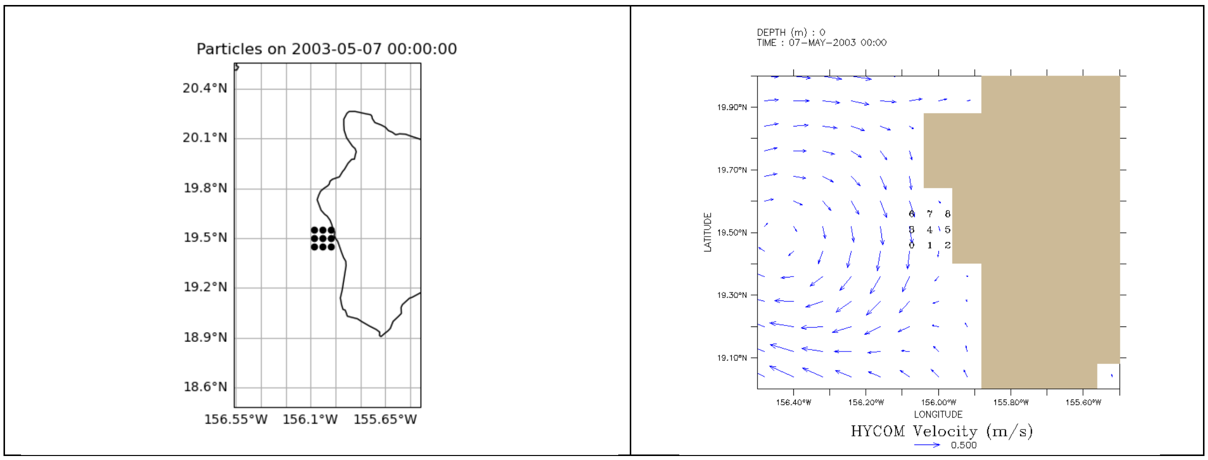

Figure 8. Left: approximate area of tows. Right: initial placement of particles in the particle tracking simulation.

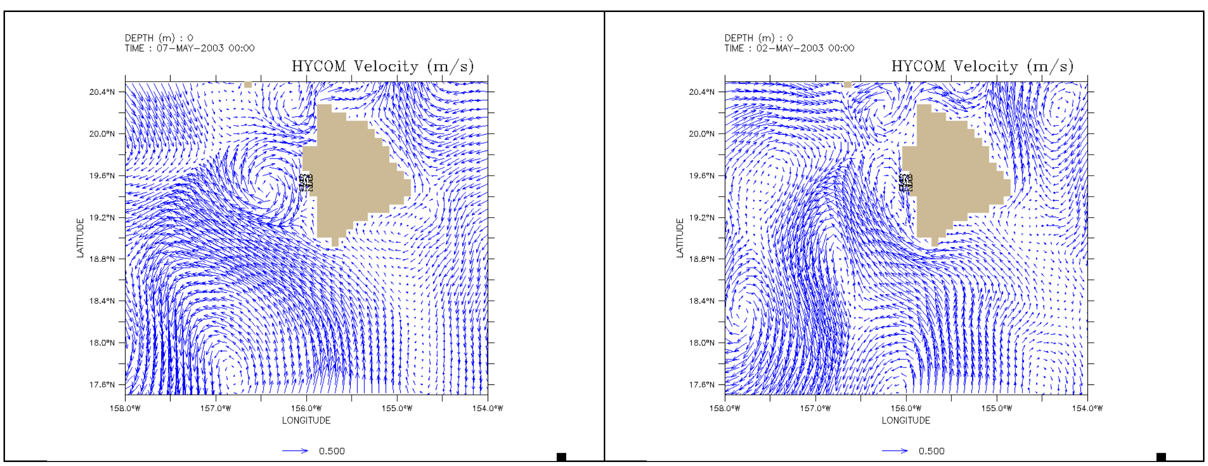

Figure 9. HYCOM velocity fields on the first (left) and last (right) particle release dates of the backward tracking simulation.

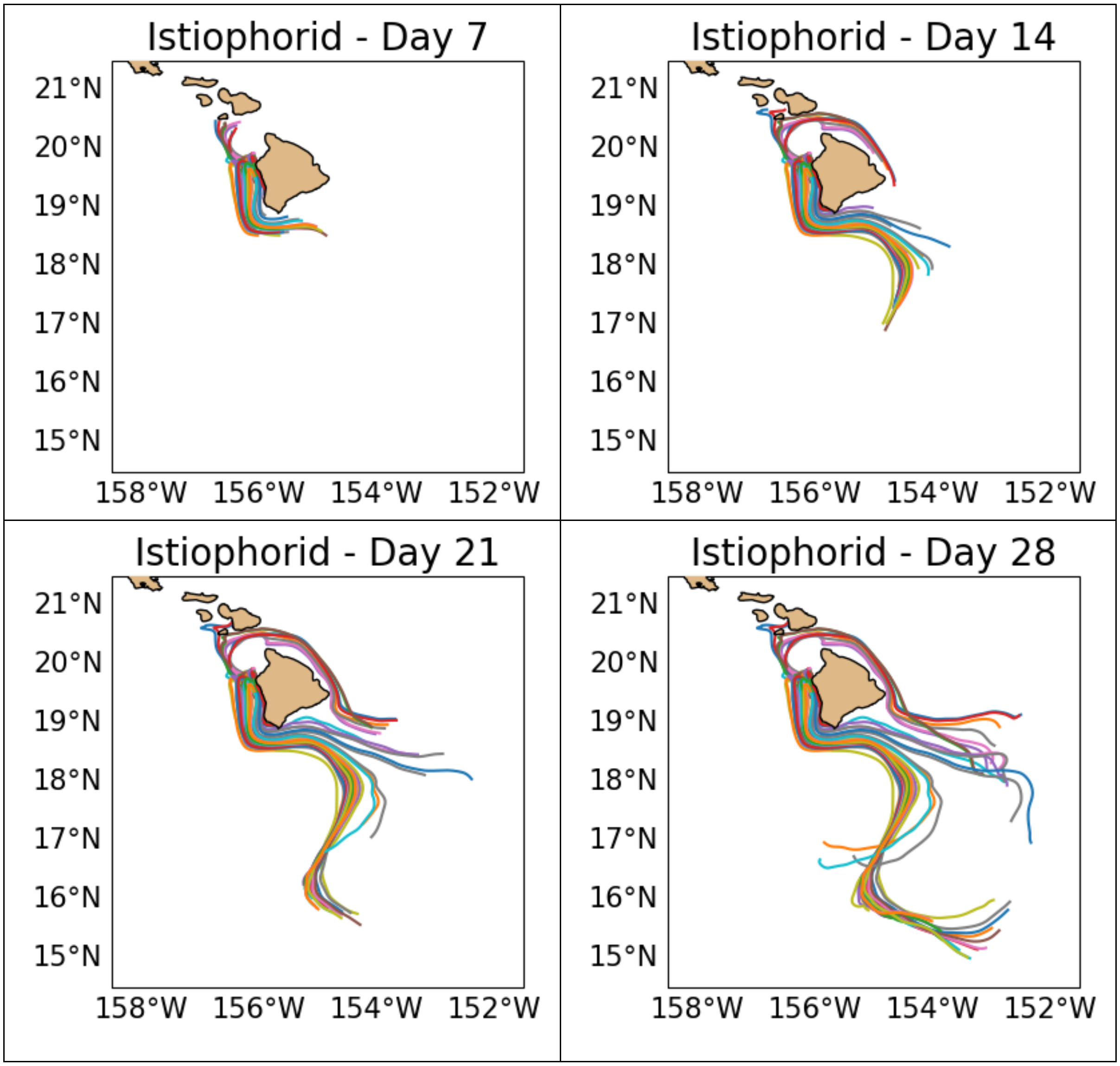

Figure 10. Particle trajectories – length in days as shown. The end points of the trajectories may be considered as possible spawning locations for larvae with the corresponding age (day) in each panel. Except for larvae less than 1 week in age, the predicted spawning grounds in other cases are far from the island's shore. Since eggs were also collected during the expedition, this result may be considered as a confirmation that Kona is both a spawning ground and a nursery habitat used by spawners elsewhere.

4. Istiophorids – July 2004 (OES-18)

During 21-24 July 2004, a total of 287 larval istiophorids were collected 2.5-5 nmi off the west coast of Hawaii in tows by R/V *Oscar Elton Sette*, Cruise 04-09 (OES-18). Approximate tow area is shown in Figure 11 (left, from Keauhou to Kealakekua Bay). Samples from the collection measured 5-20 mm in size, and the estimated ages are approximately 9-25 days (M. K. Musyl, Phase I database).

In the tracking program, synthetic particles representing larvae are released from 9 sites numbered 0-8 (Figure 11, right). One particle is released at each site on each day of 21-24 July 2004. Particles are tracked <u>backward in time</u> starting from 24 July 2004 for a total of 28 days, ending on 26 June 2004. During the tracking period, flow offshore is strong and is directed towards the sites where particles are released (Figure 12).

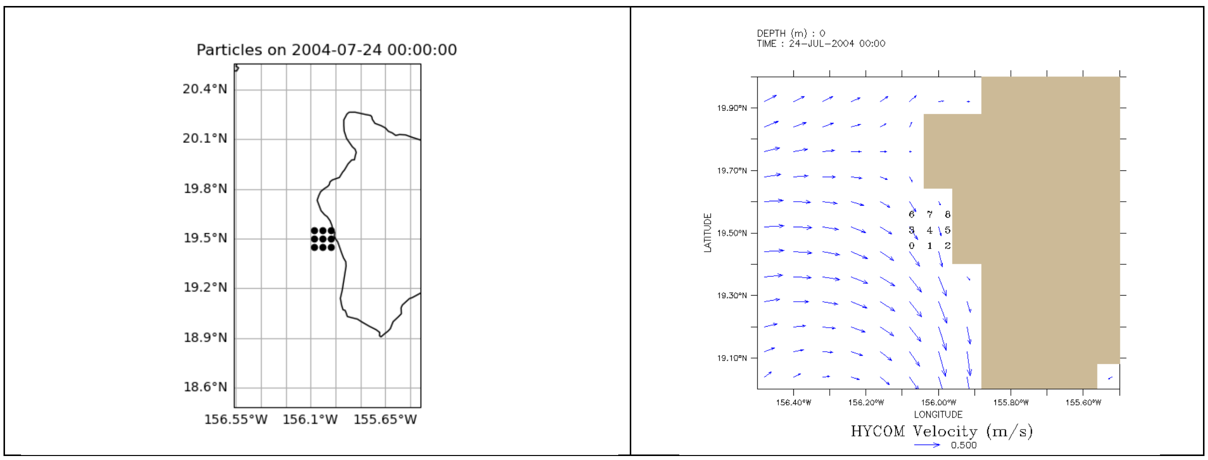

Figure 11. Left: approximate area of tows. Right: initial placement of particles in the particle tracking simulation.

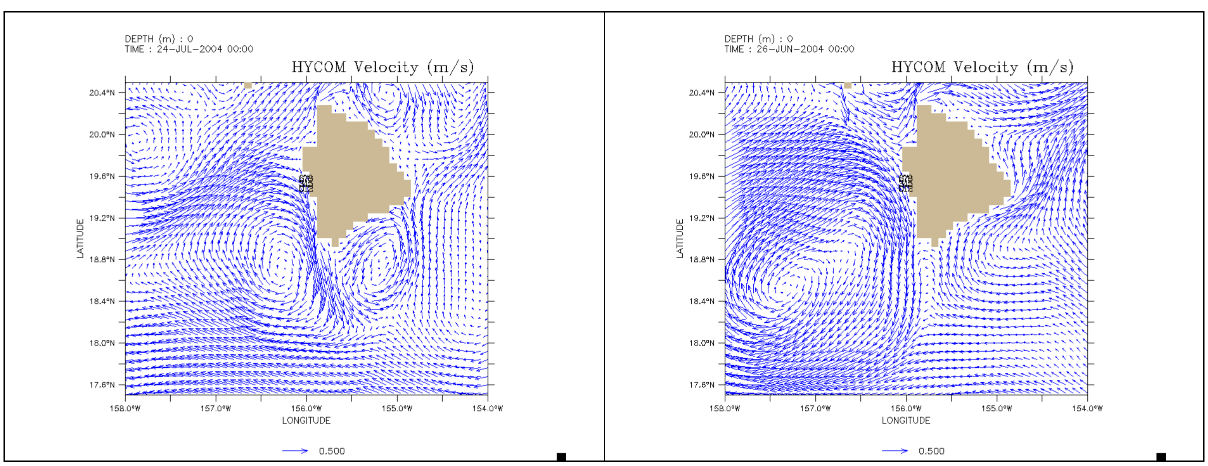

Figure 12. HYCOM velocity fields on the first (left) and last (right) days of the backward tracking simulation.

Particle trajectories are shown in Figure 13. Even though the initial placement of particles is the same as for the May 2003 case (primarily for simplicity since no precise tow coordinates were provided in the cruise reports), the dispersal characteristics differ greatly between the two cases. Here, young larvae (< 1 week old) might have been spawned off the Kona coast if they were able to survive under the strong flow conditions. For older larvae (> 3 weeks), however, it is perhaps not realistic to expect them being carried around by the eddy flow to reach the Kona coast. It is unclear at what size (age) larval istiophorids shift from passive to active swimming but they start to disappear from catches at ~20-25 mm.

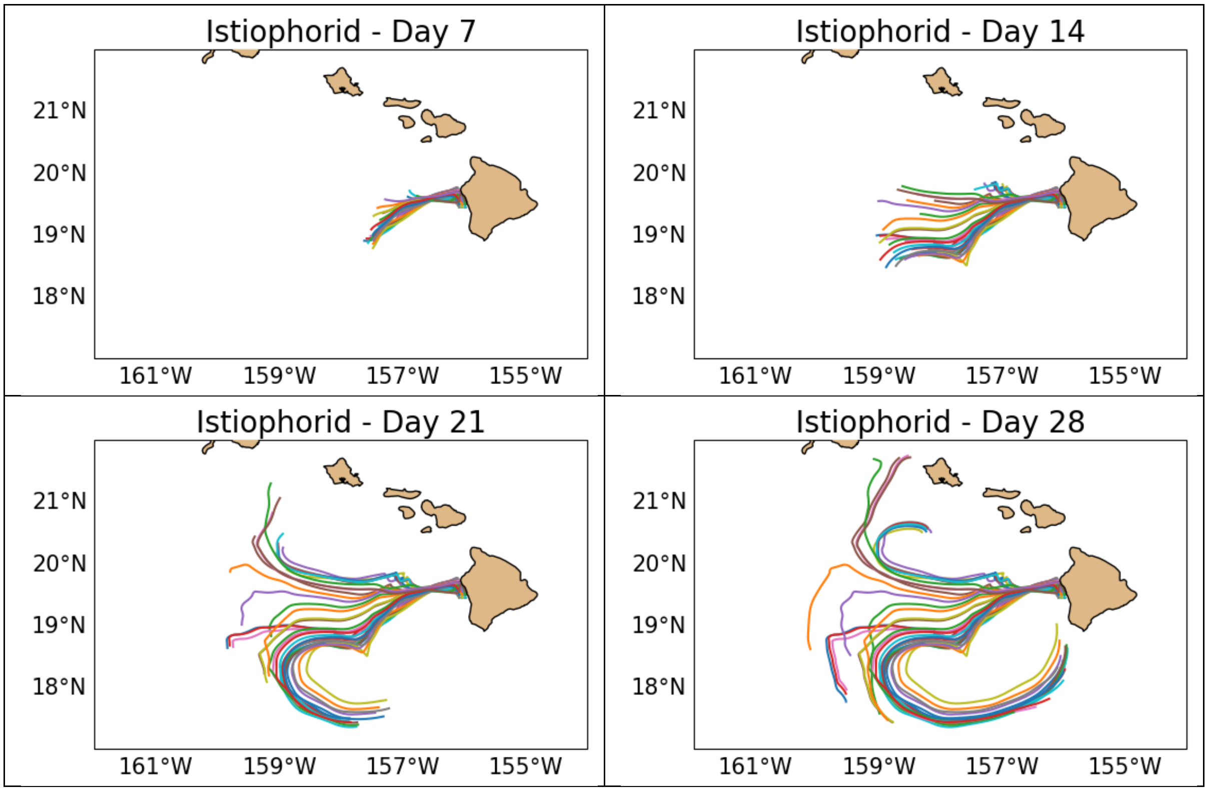

Figure 13. Particle trajectories – length in days as shown. The end points of the trajectories may be considered as possible spawning locations for larvae with the corresponding age (day) in each panel.

References

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