Wild Oceans Project
Kona Billfish Nursery Status Report
Phase 2 – Period 2
(June-August 2023)

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Background

In Phase 2 of the project, information on larval billfish in terms of their age and spatial-temporal distribution compiled in Phase 1 was used as inputs to a particle tracking tool (see next section). This allowed us to estimate patterns of larval dispersal and connectivity in the Kona region of the Main Hawaiian Islands, with the flow fields calculated from HYCOM (an eddy-resolving ocean circulation model) generating the physical environment.

In Period 1 of Phase 2, a number of simulations of larval movements were conducted to trace the spawning origins of larval billfish of certain ages captured off the Kona coast from past collections on various dates (Source: Phase 1 Database). Results from these case studies were presented in a report dated 14 June 2023.

In Period 2 of Phase 2 (this report), ensemble simulations were performed by releasing particles daily throughout the spawning seasons over a number of years in the Kona and Cross Seamount regions, with the goal to predict the most likely spawning grounds by capturing a range of flow patterns that influence larval dispersal.

A tool for tracking the movements of larval billfish

Ocean Parcels (https://oceanparcels.org) is a computer program for conducting particle tracking simulations, utilizing computationally efficient and highly accurate algorithms for spatial and temporal interpolation. 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 of particle dispersal, or backward in time to trace the possible origins of particle occurrences.

In this project, the particles of interest are larval billfish in their passive planktonic stage (i.e., freely drifting propagules by the flow environment before gaining any active behaviors such as directed swimming). The velocity fields generated by HYCOM provide the background flow environment. The placement of billfish larvae is based on field survey data. Backward tracking simulations are performed and the time period of tracking are concordant with the estimated ages of larvae at capture. The goal is to determine the most likely spawning origins of larval billfish.

Design of the ensemble simulations

Based on the database of Phase 1 on larval billfish capture locations and seasons around Hawaii, initial placement of particles (or "virtual larvae") is shown in Figure 1 (left).

Around Cross Seamount, young larvae of approximate age 5-14 days were found in 3 locations from 1950 and 1961, within a radius of 50 nautical miles from the summit. In Figure 1 (middle), they are represented by 3 clusters of 9 particles each, centered on the larval catch sites.

Off the west coast of the island of Hawaii (Kona), billfish larvae with approximate age ranging from days to weeks were collected during field surveys by NOAA in 1997-2017. NOAA survey cruises were confined mostly near land, approximately 3-25 nautical miles offshore. On the HYCOM grid (0.08° x 0.08°), particles closest to the Kona coast are placed 0.02° westward of the first velocity vector (Figure 1, right). The jagged stair-like representation of the Kona coastline in HYCOM is the result of the model's resolution.

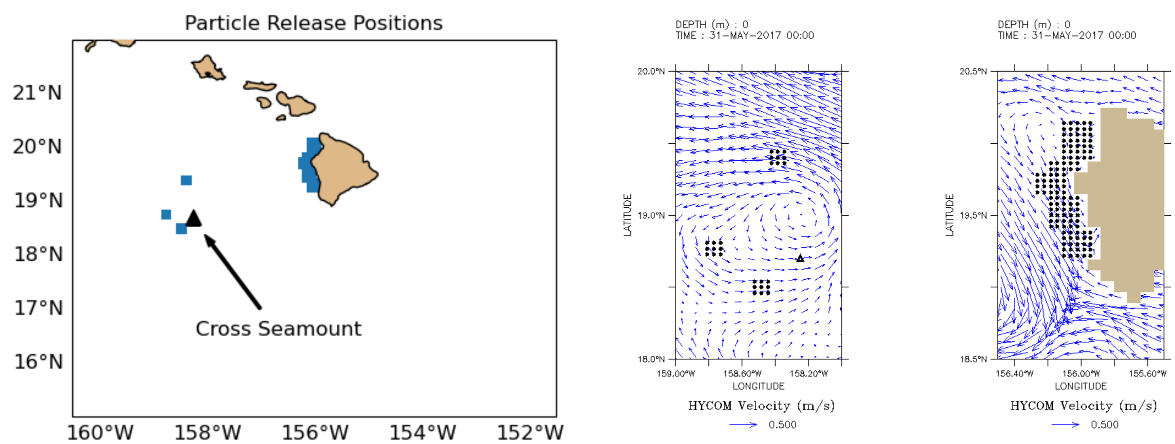

Figure 1. *Left panel*: placement of particles ("virtual larvae") at the start of each simulation (blue patches). *Middle & Right panels*: particle positions (black dots) on the HYCOM grid, with the surface flow vectors on 31 May 2017 at Cross Seamount (middle panel; black triangle marks the summit location) and off the Kona coast (right panel; color beige represents land cells in HYCOM).

Ensemble simulations consisted of daily release of particles from the sites (as defined above) during each of the spawning seasons (1 May - 30 September) of 2016, 2017 and 2018. Each particle was tracked backward in time for 15 days, the length of time over which larval billfish are assumed to remain in a passive planktonic state (i.e., pelagic larval duration).

Positions of the particles after being tracked for 7 days (young larvae) and 14 days (older larvae but assumed still in the planktonic stage) were gathered to generate particle density maps in terms of the number of particles per unit area for the given ages (days), providing a quantitative measure of probability for a specific region as billfish spawning habitat. Density maps were created and examined for particles released from different regions as shown below.

Results from the ensemble simulations

Particles released from Kona back-tracked for 7 days

Figure 2 shows the density maps generated from the positions of particles back-tracked for 7 days after their release from Kona for all the days during the spawning seasons of 2016-2018, and separately for each year. The redder the area, the higher the probability as an origin of billfish spawning. The area just off the Kona coast emerges as the most favorable spawning ground but yearly variation suggests, for example, the highest density area in 2018 was further west from Kona and closer to Cross Seamount. The region south of the island is another high density area for 2016 and 2018.

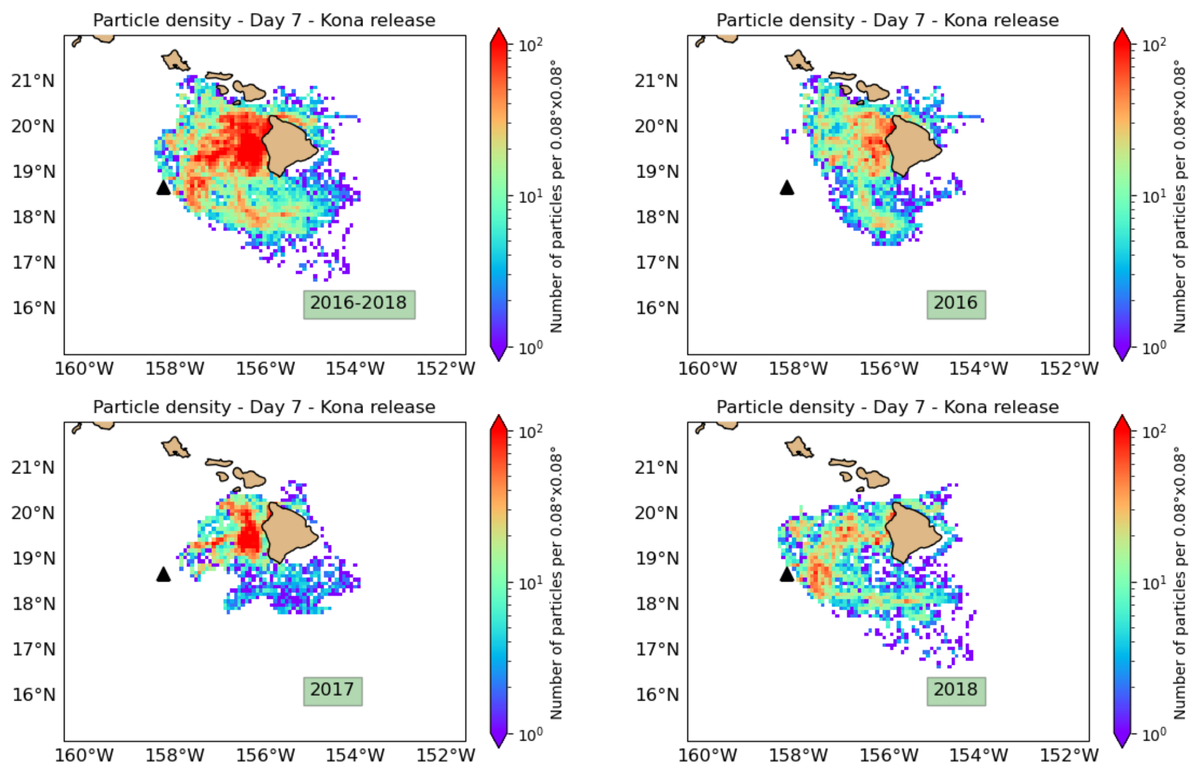

Figure 2. Density maps generated from the positions of particles back-tracked for 7 days after their release from Kona during the spawning seasons in the years as indicated, showing the possible spawning grounds of larvae age 7 days. The black triangle represents the summit of Cross Seamount.

Particles released from Kona back-tracked for 14 days

For older larvae back-tracked for 14 days after their release, Kona and the region south of the island can still be considered as the most likely spawning origins (Figure 3) despite the expanded spatial range of particle dispersal from tracking over a longer length of time in a variable flow environment.

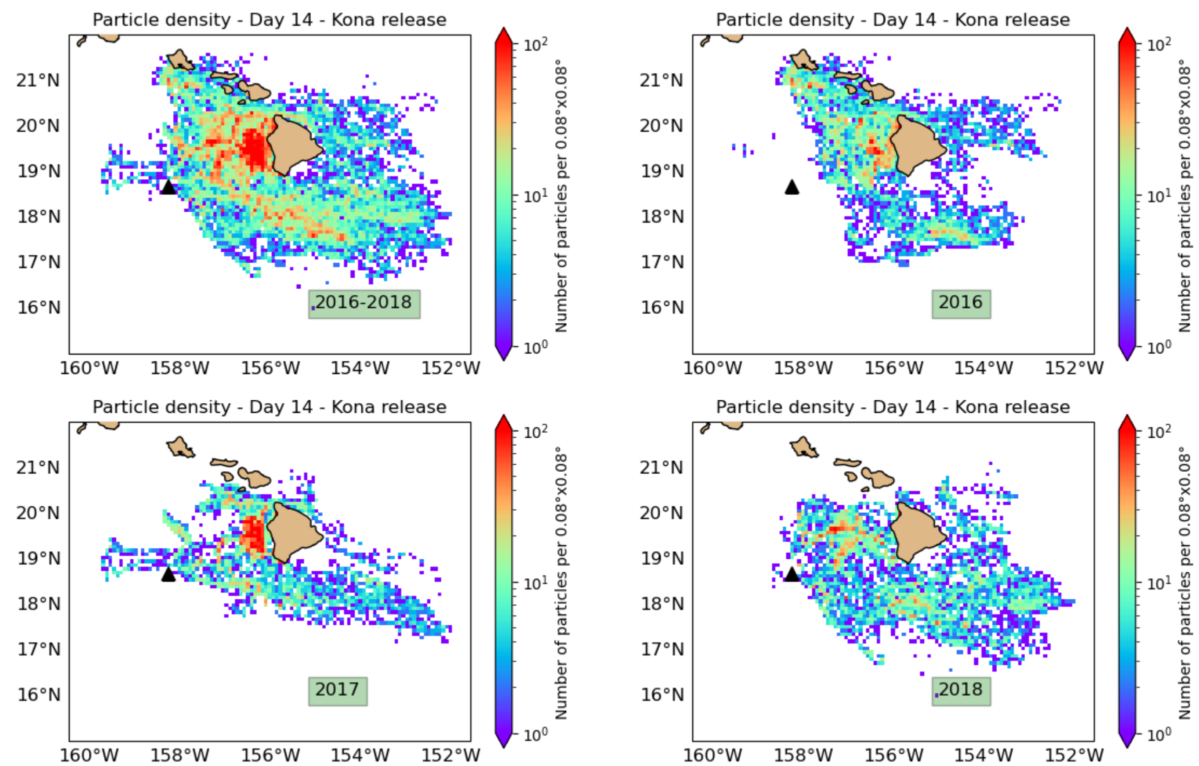

Figure 3. Density maps generated from the positions of particles back-tracked for 14 days after their release from Kona during the spawning seasons in the years as indicated, showing the possible spawning grounds of larvae. The black triangle represents the summit of Cross Seamount.

Particles released from a survey region in 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 approximate area of the tows is shown in Figure 4. Numerous larval samples including istiophorids were collected. Figure 5 shows the likely spawning origins of larvae age 7 and 14 days. The density maps for particles released from this survey region show similar distributions to those for particles released from the whole Kona region (panels for 2017 in Figures 2 and 3), identifying the region off the Kona coast as the most favorable spawning ground.

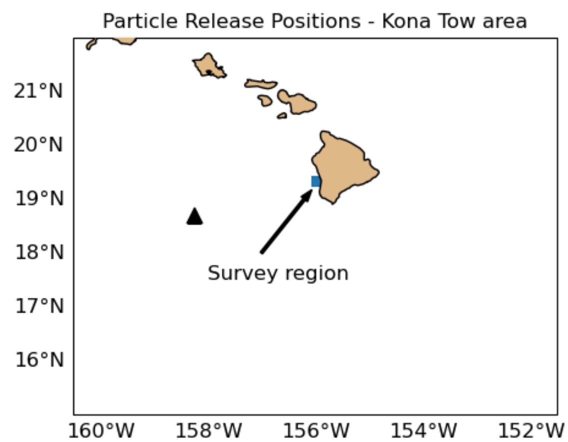

Figure 4. Approximate area of 16 NOAA cruise tows in 2017 (blue rectangle). The black triangle represents the summit of Cross Seamount.

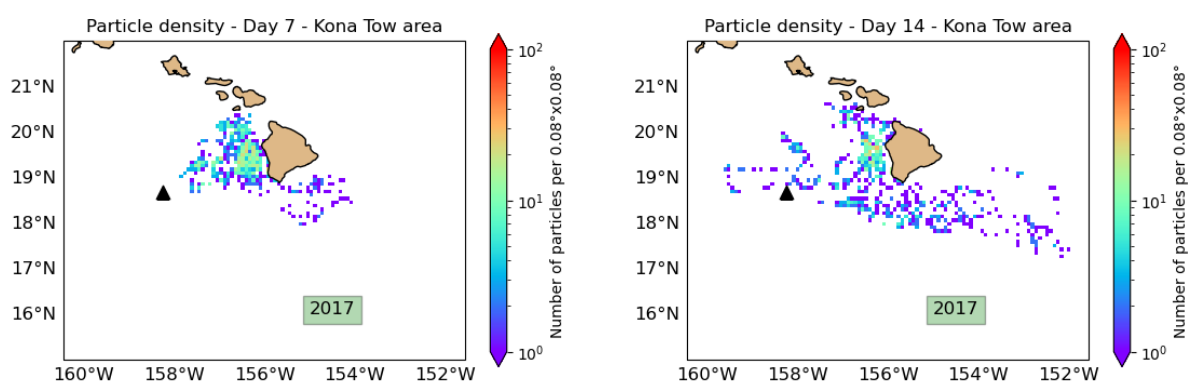

Figure 5. Density maps generated from the positions of particles back-tracked for 7 and 14 days after their release from the survey region indicated in Figure 4 during the spawning season in 2017, showing the possible spawning grounds of larvae age 7 and 14 days. The black triangle represents the summit of Cross Seamount.

Particles released around Cross Seamount back-tracked for 7 days

For particles released around Cross Seamount, it appears that young larvae (< 7 days) are likely spawned near their capture locations (Figure 6). The possibility of Kona as the spawning origin is very low (i.e., size and ages of larvae do not correlate for a Kona spawning origin even under unrealistic conditions such as linear travel with a speed of 0.5 m/s). Except for a weak connectivity between Kona and Cross Seamount in 2018, the connection is basically non-existent in 2016 and 2017.

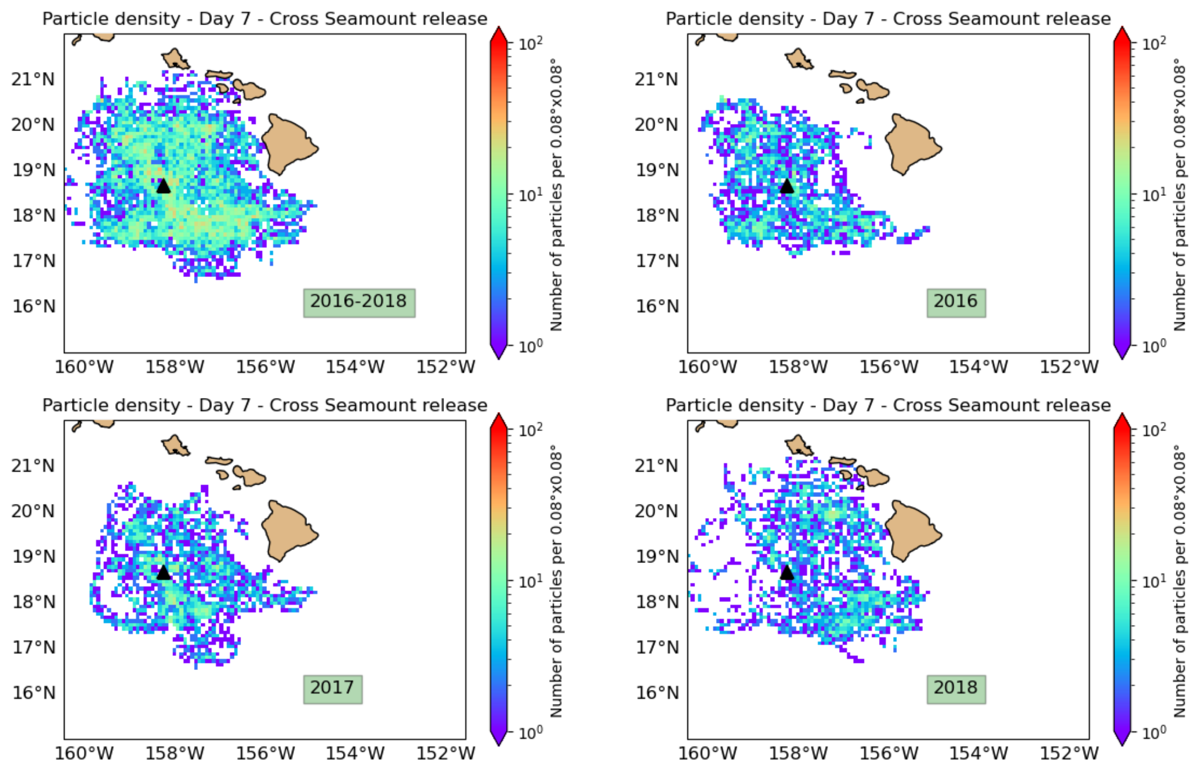

Figure 6. Density maps generated from the positions of particles back-tracked for 7 days after their release around Cross Seamount (black triangle) during the spawning seasons in the years as indicated, showing the possible spawning grounds of larvae age 7 days.

Particles released around Cross Seamount back-tracked for 14 days

For a spawning hypothesis at Cross Seamount, patterns of older larvae (e.g., 14 days) suggest the possibility of a Kona origin, with the region south of the island as an additional possibility (Figure 7, upper-left panel). However, due to small and unrepresentative sample sizes from the historical collections, this possible scenario must be accepted with caution. A relatively large ensemble analysis is needed to reveal distinct patterns because when viewing the years separately, particles are too thinly spread out to do so.

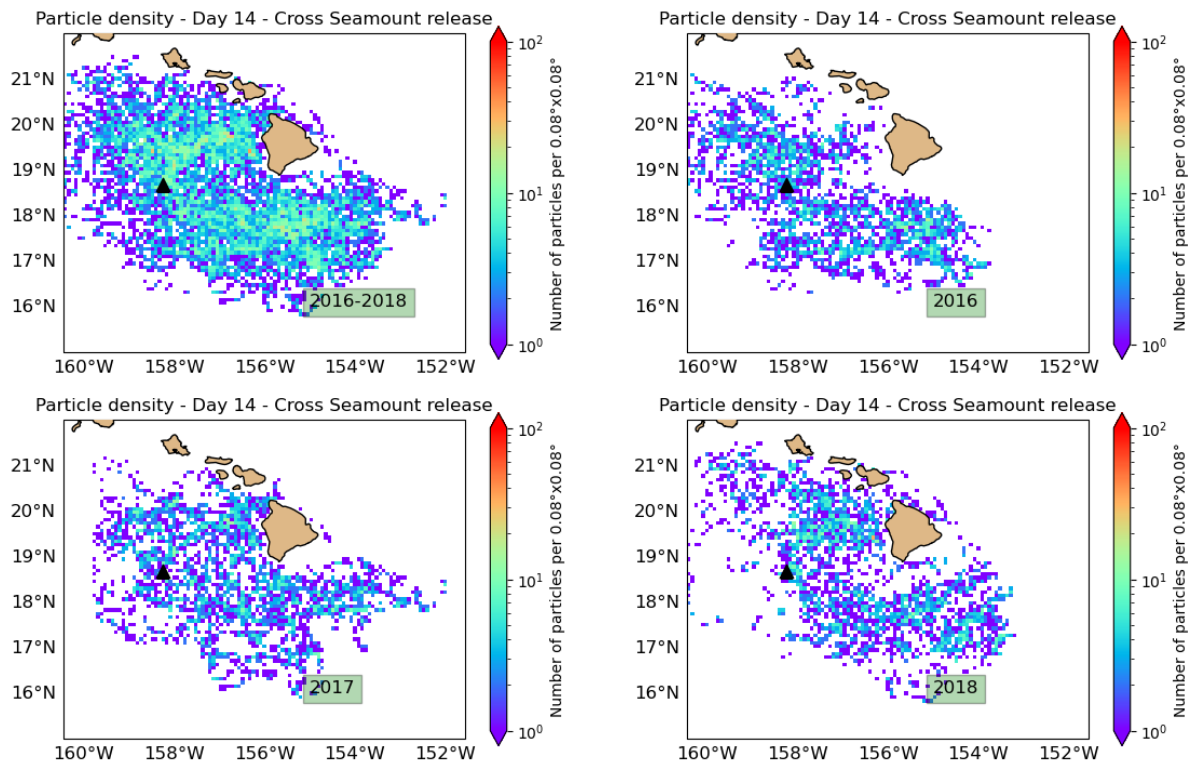

Figure 7. Density maps generated from the positions of particles back-tracked for 14 days after their release around Cross Seamount (black triangle) during the spawning seasons in the years as indicated, showing the possible spawning grounds of larvae age 14 days.

The background flow environment

The patterns of density maps are consistent with the circulation patterns that are prevalent in the spawning seasons of the years examined. Kona is a region where cyclonic and anticyclonic eddies of varying strength are continuously spun up in the northern and southern sectors, respectively (Fig. 8). In 2016 and 2017, the region west of the Kona coast was dominated by a cyclonic circulation with a northward flow along the coast that was fed by the southeastward flow further west. In 2018, the along-shore flow was also northward but was fed by an eastward flow which was the northern sector of an anticyclonic eddy situated to the southwest of Kona.

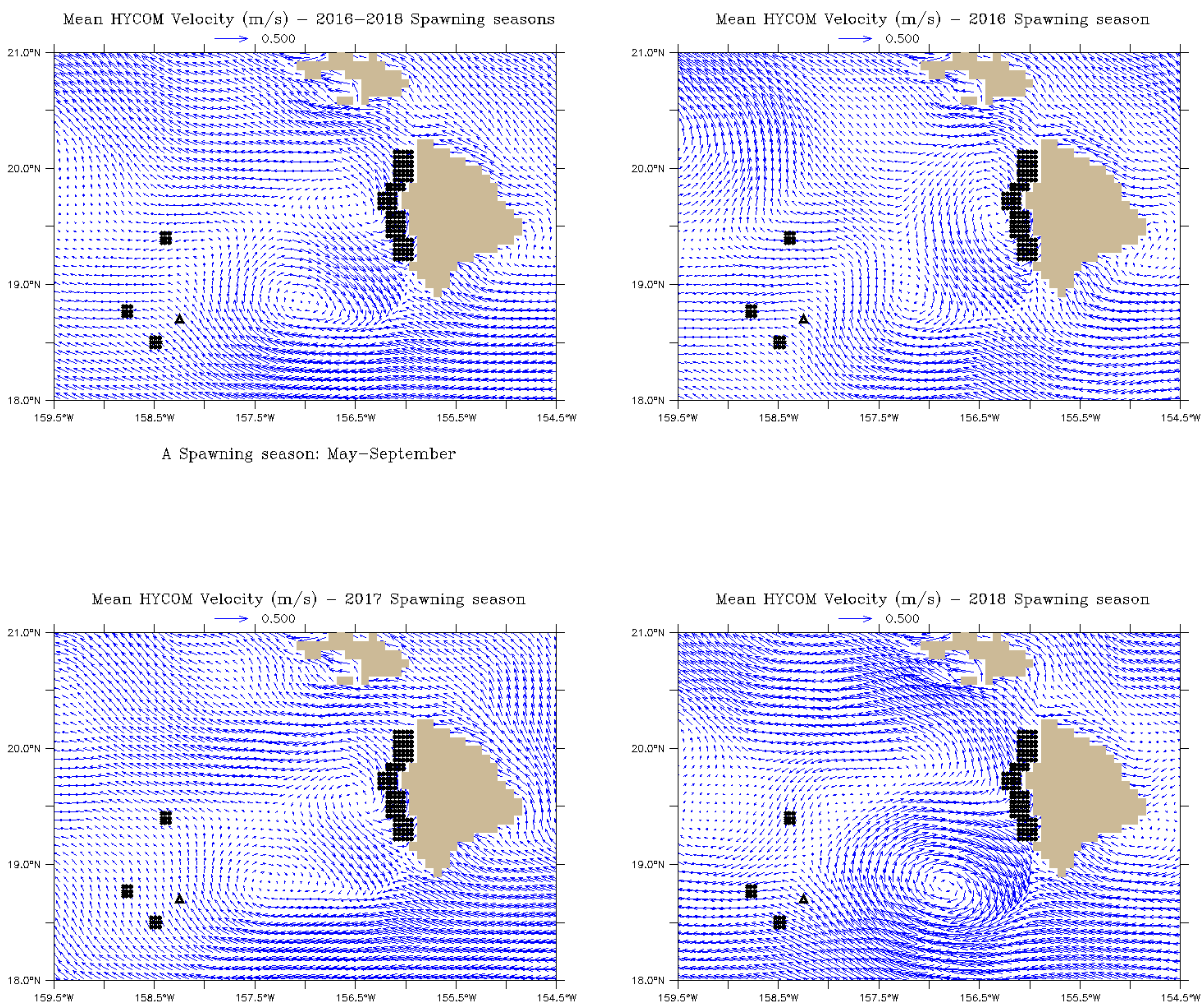

Figure 8. HYCOM velocity vectors averaged over the spawning seasons as indicated. Black triangle: summit of Cross Seamount. Black dots: particle release sites.

Discussion

In an ideal situation where larval capture location and time and the history of the background flow are accurately measured, then the end location after tracking backward for a length of time that is equal to the estimated age of the larva would be the spawning origin. The reality, however, is far from being ideal. The background flow is usually not well known, especially on the spatial and temporal scales of larval movements. Additionally, larval collections tend to be sparse with unequal effort and the results based on a few samples may not fully reflect spawning areas.

The ensemble simulations predict a wide spatial range of possible spawning grounds for larval billfish, and as the age of the larvae increases, the range increases. This inextricable result is expected and by design since the ensemble simulations assume that spawning takes place on each day of the spawning seasons in 2016-2018 in a highly variable flow environment. In a situation where the spawning activity of larval billfish is unclear, the region with a high particle density may be considered the most probable spawning ground for a given age of larvae.

Records from the literature and past surface net tow operations off the Kona coast conducted by NOAA collected both billfish eggs and larvae of a range of sizes (ages), suggesting that the region is both a spawning ground and a nursey habitat. The prediction from the ensemble simulations that the Kona region is the most likely spawning origin for young larvae (< 15 days) is consistent with past field surveys and historical records from the literature. This agreement also serves as a confirmation of the importance of the physical flow environment in the dispersal of larvae during their planktonic stage.

Recommendations

Next steps in the exploration of billfish spawning origins:

- Prepare a manuscript on the findings from Phase 2 for a peer-reviewed literature.
- Conduct field surveys to collect larval samples during spawning season with locations guided by model predictions (Phase 3 of the project). Alternatively, larval traps could be placed on a systematic grid and samples retrieved on a regular basis. And in turn, the survey data can be used by the tracking model to update predictions.
- Search for higher resolution velocity fields that also include tidal motions to test the sensitivity of larval trajectories. It is important to establish how critical it is to resolve the Kona coastline that includes both open coasts and semi-enclosed bays.
- Explore the oceanographic and environmental characteristics of predicted putative spawning grounds (e.g., geographic features, background flow variability, temperature ranges, salinity, dissolved oxygen, etc.) to gain insights into billfish reproductive preferences.
- Based on the overall findings, develop an index of larval abundance.