Inaugural report of the Pacific Islands Region Ichthyoplankton Survey (PIRIS): Hawaiʻi Pae ʻĀina, 2023

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Executive Summary

This inaugural report details the findings of the 2023 Pacific Islands Region Ichthyoplankton Survey, the most geographically expansive survey of its kind in the Hawaiian Archipelago to date.

The study was conducted in collaboration with the Pacific Islands Fisheries Science Center‘s (PIFSC) Pelagic Research Program, PIFSC‘s Hawaiian Islands Cetacean and Ecosystem Assessment Survey (HICEAS), and members of the Papahānaumokuākea Native Hawaiian Cultural Working Group (CWG). The goal of this report is to characterize larval distributions for managed coastal and pelagic fish species.

The research integrates both Kānaka ʻŌiwi and Western science practices through identifying fish larvae, examining traditional ʻŌiwi names for these larval species, and in some cases, developing new Hawaiian names. Working with CWG members is part of building a long-term ethical and equitable partnership with Kānaka ʻŌiwi through reciprocity of knowledge exchange.

Ichthyoplankton collections were conducted during nighttime hours of the HICEAS expedition aboard NOAA Ship *Oscar Elton Sette* between July and November 2023, utilizing a 6-foot Isaacs-Kidd midwater trawl down to 50 m depth. A total of 78 high-quality samples were collected across the Hawaiʻi exclusive economic zone and the Papahānaumokuākea National Marine Sanctuary. The findings establish a baseline for a region-wide fishery-independent ichthyoplankton survey and will be helpful for developing tools, such as Species Distribution Models , to predict spawning locations and recruitment potential, enhancing the effectiveness of modern fisheries management in Hawaiʻi.

List of Terms

Fish Names

Binomial Latin Name	English Common Name	‘Inoa Hawai‘i	Non-adult lifestage names	Sources / Authorities
Acanthurus triostegus	Convict Surgeonfish	Manini, kala	Juvenile: ‘ōhua liko	Titcimb & Pukui, 1972; Pukui & Elbert, 1986
Polydactylus sexfilis	Sixfinger Threadfin; Threadfish	moi	Juvenile: moi li‘i	Pukui & Elbert, 1986
Thunnus albacares	Yellowfin Tuna	‘Ahi	Larva: ‘ahi hune	
Istiophoridae	Marlins	A‘u	Larva: A‘u maneo	Pukui & Elbert, 1986; CWG 2023
Etelinae	Jobfish	‘Ōpakapaka, onaga, gindai, ehu, lehi, kalekale		Main Hawaiian Islands deep sea bottomfish (NOAA Fisheries, 2024)
Coryphaena spp.	Dolphin fish, dorado, mahi	Mahimahi		Pukui & Elbert, 1986
Aprion virescens	Bluegreen jobfish	Uku		Pukui & Elbert, 1986
Katsuwonus pelamis	Skipjack tuna, bonito	Aku		Pukui & Elbert, 1986
Thunnus spp.	Yellow fin, albacore and big eye tunas	‘Ahi	‘ahi hune	Pukui & Elbert, 1986; CWG 2023
Acanthocybium solandri	Wahoo	Ono		Pukui & Elbert, 1986

Introduction

Historically, fisheries management rules (from juveniles through adults) in Hawaiʻi nei, were set by konohiki (stewards whose role included control of fishing rights) in accordance with the customs and observations of the fishers within their jurisdiction (Maly, 2003a; Lucas, 1995). This place-based and adaptive structure resulted in highly effective and sustainable fisheries management. However, a shift from traditional ahupuaʻa (a land division based on watershed boundaries) management, with konohiki enforcing kapu (restrictions), to largely Western management (Public Law 103-150) necessitates documenting the life history of fishes to understand their sensitivity to environmental variability and fishing pressure.

One of the earliest life history stages of are known in ʻŌlelo Hawaiʻi (the Hawaiian language) as pua iʻa (Pukui & Elbert 1986, p.345). Some pua iʻa were historically eaten in Hawaiʻi, such as ʻōhua liko (juvenile *Acanthurus triostegus*) on Hawaiʻi Island (Kauhi, 1996) and moi liʻi (juvenile *Polydactylus sexfilis*) on Kauaʻi (Maly, 2003a). Today, it is largely adult fishes that are harvested for food and thus our interaction and understanding of the early life stages has become limited.

A better understanding of the earliest larval stages of fish (ichthyoplankton) can provide insights into recruitment processes, productivity of important fish stocks, and spawning habitat (Auth & Brodeur, 2013). Ichthyoplankton surveys have been in existence for decades across NOAA Fisheries-managed regions, including the California Current (CalCOFI; Auth & Brodeur, 2013, Chen et al., 2025; Brodeur et al., 2008), Gulf of Alaska (Eco-FOCI; Marshall et al.,2019), the Southeast U.S. (SEAMAP; Lyczkowski-Shultz et al., 2004, SEFS 2022) and the Northeastern U.S. (EcoMon; Walsh et al., 2015; Morse et al., 2017). However, existing long-term ichthyoplankton surveys within the Pacific Islands region (PIR) are spatially limited. These early life stages are vital for the replenishment and health of fish stocks (Panprommin et al., 2020, 2021; Huang et al., 2022).

Many larval fish species rely on dynamic ocean currents as an important dispersal mechanism (e.g., Suca et al., 2025; Wren & Kobayashi 2016), thus, the timing and location of spawning can greatly influence larval settlement and recruitment locations.

Given the dynamic nature of pelagic ecosystems and the broad geographic ranges of many fish species, sampling across wide areas allows us to better understand how taxa respond to environmental variation (Thompson et al., 2014). One prominent example is the California Cooperative Oceanic Fisheries Investigations (CalCOFI) program. CalCOFI is a long-term NOAA Fisheries-supported effort that has sampled the southern California Current almost continuously since 1949 and has been instrumental in revealing the physical and biological drivers of fish production. In contrast, ichthyoplankton surveys in Hawai‘i have been comparatively sparse and geographically limited, with most sampling concentrated around O‘ahu and West Hawai‘i (e.g., Boehlert & Mundy, 1996; Kobayashi, 1989; Lobel et al., 1986; Whitney et al., 2021). These ichthyoplankton surveys are filling a unique gap in understanding fisheries biology in Hawai‘i.

In contrast to productive upwelling systems such as along the West Coast, the main Hawaiian Islands are characterized by oligotrophic waters within the North Pacific Subtropical Gyre. The islands and atolls themselves can contribute to localized increases in productivity through run-off, tidal flushing, and complex mesoscale dynamics caused by the abrupt bathymetry of the region (Gove et al., 2016).

Biophysical modelling of larval fish shows that wind patterns strongly affect where larvae end up, which in turn influences recruitment (Suca et al., 2025); furthermore, prevailing currents carry taxa from the main Hawaiian Islands to the Northwestern Hawaiian Islands (NWHI), highlighting the importance of directional flow (Wren et al., 2016) and oceanic features, such as eddies may also entrain larvae (Lindo-Atichati et al., 2020); however, this is somewhat controversial (Fox et al., 2012). Furthermore, highly migratory species such as ‘ahi, mahimahi, and a‘u seasonally occupy the waters of Hawai‘i, and the extent to which these taxa use the region for spawning remains poorly understood, despite their commercial and cultural importance.

Characterizing species-environment relationships, and their spatial and temporal components, is essential for understanding marine stock fluctuations (Tzanatos et al., 2014). Pairing ‘ike Hawai‘i (Native Hawaiian knowledge) regarding relationships between environmental changes and the timing of growth and reproduction and presence / absence of species with Western science will build a more holistic approach to managing these species. Kanaka ‘Ōiwi (Native Hawaiians) possess the longest record of environmental changes passed down through oral histories and living cultural practices that deepen relationships to our oceans. These practices are part of a living knowledge system driven by kilo (keen environmental observations) over time (Winter et al., 2020).

For example, Huli ‘ia is a kilo process documenting seasonal changes and shifts across entire landscapes, mauka (upland) to makai (sea) (Morishige et al., 2018; Andrade & Morishige, 2022). Developed by the non-profit organization Nā Maka Onaona, Huli ‘ia is a Kanaka ‘Ōiwi (Native Hawaiian) observational process documenting natural changes over time, identifies dominant cycles within certain species or occurrences (flowering, fruiting, presence / absence of flora / fauna, cloud formations, spawning, or recruiting of fish species, etc.) and assists in identifying correlations between species and / or occurrences as indicators of the other. This process guides best management practices that support a productive and thriving community (‘Āina Momona) allowing the flexibility needed to ensure the best times to allow areas or species to rest from cultivation and harvest.

Huli ‘ia stems from traditional management systems driven by an intimate understanding of the natural environment and the ability of communities to adjust and adapt their activities as best management practices to support these systems of nature (Andrade & Morishige, 2022) Ecological metrics such as water temperature, flow and ocean productivity that can be measured broadly by satellites and uncrewed systems (amongst other methods) can be correlated with certain species spawning events (Contreras et al., 2023), abundances (Smith et al., 2021), and predictors of recruitment success (Woodworth-Jefcoats & Wren, 2020). Larval fish ecology, as a combination of multiple knowledge systems is, therefore, central to sustaining Hawai‘i’s diverse fisheries today.

By identifying the ecological relationships that influence larval success, we can develop tools such as species distribution models (SDMs) to predict spawning locations and recruitment potential, which are key components of effective management for today's modern, commercialized fisheries.

To move towards a future where Indigenous and Western science are both meaningfully integrated in research and decision-making, it is first critical to acknowledge that Kānaka ‘Ōiwi have long stewarded these oceans, cultivating sophisticated resource management systems living in sync and sustainably with the island and ocean ecosystems for centuries. This is exemplified by traditional Hawaiian fishing practices where lawai‘a would only be permitted to fish after a fish species had a chance to reproduce for the year (Titcomb & Pukui, 1972; Wyban, 1992). In a recent publication, renowned Master lawai‘a and konohiki, Mac Poepoe, observed shifts in moi spawning seasons linked to habitat degradation and environmental stressors, suggesting that existing bans are insufficient to protect extended spawning periods. In response, he established Nā Kai ‘Ewalu, a collective of lawai‘a, to document and study these changes across islands (Poepoe et al., 2025).

In an effort to describe important fisheries taxa and environmental patterns across broader scales, the Pacific Islands Region Ichthyoplankton Survey (PIRIS) was established in 2023 to aid in better understanding the distribution, habitat, and early life history of larval fish populations. By partnering with core Pacific Islands Fisheries Science Center (PIFSC) missions, the survey has an expansive reach and strives to map larval fish distributions across the Pacific Islands under NOAA Fisheries’ jurisdiction.

The first PIRIS expedition took place as a collaboration between PIFSC’s Pelagic Research Program, the Hawaiian Islands Cetacean and Ecosystem Assessment Survey

(HICEAS), and members of the Papahānaumokuākea Native Hawaiian Cultural Working Group (CWG) to conduct a comprehensive ichthyoplankton survey across Hawaiʻi Pae ʻĀina (Hawaiian Archipelago), spanning both the main Hawaiian Islands and Papahānaumokuākea National Marine Sanctuary (PNMN).

This work represents a continuation of long-term engagement with Native Hawaiian partners to co-mentor Native Hawaiian students and interns through multiple knowledge systems. Central to this effort is an ongoing commitment to building pilina (relationships) and engaging in an ethical, reciprocal, and respectful process of collaboration. Through this partnership, Kānaka ʻŌiwi knowledge, values, and practices are intentionally woven with institutional science to foster a more holistic understanding of ocean systems. Kūlana Noiʻi (Alegado et al., 2023) has provided crucial guidance to those involved in this partnership.

The goal of this research is to characterize larval habitat for management unit species (MUS) of coastal and pelagic fish (such as ʻahi *Thunnus* spp., mahimahi *Coryphaena spp.,* aku *Katsuwonus pelamis,* ono *Acanthocybium solandri,* uku *Aprion virescens* and aʻu (family Istiophoridae) across Hawaiʻi. This research also intends to establish a fishery-independent ichthyoplankton survey for the Pacific Islands region. In this report, we present the first results of the 2023 sampling effort. We hope that the resulting data will support both stock assessment efforts and the development of forecasting tools, such as SDMs and dispersal models, to predict spawning locations and recruitment potential.

Methods

Ichthyoplankton collections were conducted along transect lines during the nighttime hours of HICEAS 2023 expedition aboard *NOAA Ship Oscar Elton Sette* between daytime visual and acoustic cetacean surveys (Yano et al., 2025). Sampling was conducted across Hawaiʻi Pae ʻĀina between July and November, 2023 using a 6-foot Isaacs-Kidd midwater trawl (IKMT; Friedl, 1971) with 505 μm mesh. This marks the first sampling effort of the Pacific Islands Region Ichthyoplankton Survey (PIRIS), which is designed to be flexibly coupled with daytime oceanographic and ecosystem surveys across NOAA programs.

In its inaugural year, PIRIS was implemented in coordination with HICEAS, establishing a flexible framework intended for broader integration across a range of future survey efforts (including NOAA's Coral Reef Monitoring Program). The HICEAS survey follows set, parallel transect lines (spaced 42.5 nmi (85 km) apart) that encompass the entirety of the Hawaiʻi exclusive economic zone (EEZ) in West North West to East South East direction (Yano et al., 2025). This standardized survey area allows for quantitative statistics of cetacean observations (Yano et al., 2025; Bradford et al., 2017) and provided an ideal opportunity to sample ichthyoplankton in a standardized approach across the archipelago.

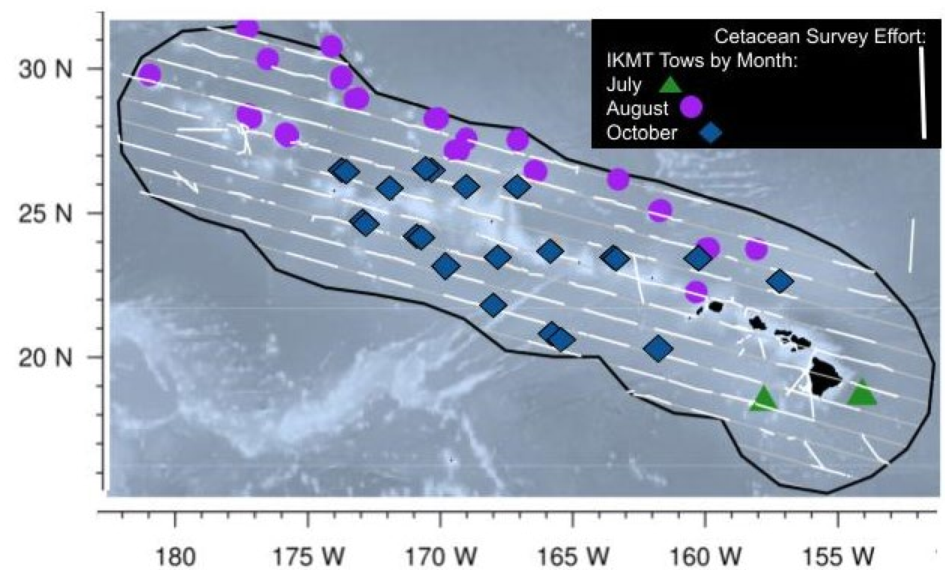

Figure 1. Map of the PIRIS ichthyoplankton sampling locations during the 2023 HICEAS effort across Hawaiʻi Pae ʻĀina. PIRIS participated in HICEAS cruises took place between July and November 2023, encompassing a wide geographical area across the Hawaiian Islands. The black shape around Hawaiʻi Pae ʻĀina denotes the boundaries of the United States EEZ.

Table 1. Summary of the Pacific Islands Region Ichthyoplankton Survey (PIRIS) field effort during the 2023 HICEAS Expedition. This table details the three cruise legs, including the 2023 date range, the number of tows conducted, and the approximate geographical extent (latitude/longitude) for each leg.

Cruise Leg	Date Range, in 2023	Number of Tows	Geographical Extent (Approx. Lat/Lon)
1	July 23–26	4	18.9°N–155.9°W to 19.0°–159.3°W
2	August 8–29	38	24.0°N–160.0°W to 31.6°N–178.8°W
4	October 13 – 1 November	39 (36 tows to 50 m depth, 3 neuston tows, 3 tows to 10 m only)	20.5°N–162.2°W to 26.9°N–171.7°W

Field Effort

We began each sampling night on the ship's bow with the oli (chant) “E hō mai” (E. Kanakaʻole, 2017). This oli was selected as a way to ask to be granted wisdom and knowledge before we collected marine organisms for research (Office of Hawaiian Affairs et al., 2021; Kealiikanakaoleohaililani et al., 2018; Alegado et al., 2023) within and outside of PNMN, which encompasses land and ocean is sacred to Kānaka ʻŌiwi (Kikiloi et al., 2017).

IKMT tows were conducted as three oscillations of the net (henceforth referred to as tow-yos) between the surface and 50 m depth (lasting approximately 45 minutes) at a ship speed of 2.5 kts and were spaced as evenly as possible within the allotted time for sampling (Habtes et al., 2014). Sampling occurred between dawn and dusk during the periods of full dark. Tows only occurred in sea states less than a Beaufort 7. Due to operational constraints on the August and October legs, the sampling window was often only four hours, limiting the spacing between tows to only ~5 nmi and a maximum of four tows per night. Additionally, each night we engaged in the practice of kilo (Morishige et al., 2018, Winter et al., 2020, Andrade & Morishige 2022), where we observed (and recorded) moon phase, weather and ocean conditions, clouds, and other environmental occurrences. Two flow meters were attached to the mouth of the net in order to calculate an average water volume filtered (in m^3) per tow to standardize ichthyoplankton densities (See Appendix for equation). Two temperature depth recorders (TDRs) were attached to the headrope and footrope of the net’s mouth opening to continuously record temperature and depth throughout the deployments.

Sample Processing

After recovery of the net, a seawater hose was used to rinse biological material caught on the panels of the net into the cod end. The cod end was placed in a bucket, then brought into the ship's wet lab. Cod-end contents were poured through a 500 µm mesh sieve and preserved in 95% ethanol.

In the laboratory, fish larvae and other taxa of interest were pulled from the bulk sample under a microscope. Taxa of interest were removed from the bulk sample, identified to the designated level of interest, and kept in separate scintillation vials in 95% ethanol. For management unit species (MUS) such as ʻahi, mahimahi, aku, ono, uku, and aʻu larvae were identified to the lowest taxonomic level possible.

The snappers in the subfamily etelinae, *Pristipomoides sp.* and *Aphareus sp.* are nearly morphologically indistinguishable at the larval stage in the sizes observed, while *A. virescens* is distinct from all other etelines. For this reason, all non-*Aprion* etelinae larvae were grouped at the subfamily level for consistency. Non-MUS fish are discussed briefly in the Appendix; they will be the subject of their own publication(s) in the future. Larval *Thunnus albacares* and Istiophoridae were also examined through a biocultural lens and names for the early life history stages were developed after the process described in Pihana & Lorenzo-Elarco (2022). One example is the ʻahi hune (tiny ʻahi), which is the name subsequently used in this paper.

For stations with ten or fewer individuals of a particular species of interest, all were counted and standard length (SL) was measured to the nearest whole millimeter; larvae smaller than 2 mm were excluded from the final dataset (*n*=5). For stations with more than ten individual MUS, all were counted and of these up to ten were randomly selected to be measured for SL. For stations where more than 10 individuals of a given taxon were collected, we randomly selected and measured 10 individuals, then measured an additional 10 individuals spanning the full size range from the smallest to the largest collected. Members of the family Istiophoridae, were only identified to family level but the measuring procedure was the same as for the aforementioned taxa. Larval developmental stage was noted for each taxa identified. The working definitions we used for these stages (preflexion, flexion, postflexion) were interpreted from Kendall et al. (1984), acknowledging that sizes associated with a particular stage vary across taxonomic groups.

Data

Data summaries and visualizations were created using R (Version 4.5.1, "Great Square Root," R Core Team, 2025) within the tidyverse package (Wickham et al., 2019).

Bathymetric data was obtained from the *marmap* package (Pante et al. 2025), Hawaiʻi Pae ʻĀina maps were generated using the *rnaturalearth* (Massicotte & South, 2025) and *TSP* packages (Hahsler & Hornik 2025), and the sampling map with the cetacean survey efforts was created using *CruzPlot* v1.4.9 (Woodman & Gerrodette 2024). Simple environmental relationships with the presence or absence of taxa are also explored. Environmental variables were pulled from multiple publicly available sources and paired with larval data. Daily sea surface temperature (SST) data were obtained from NOAA Coastwatch using the *rerdapp* (Chamberlain, 2017) and *rerddapXtracto* (Mendelssohn, 2025) packages in R from Coral Reef Watch (v3) and daily gap-filled chlorophyll-α concentration (chl-a) was obtained from Copernicus-Glob Colour (BGC L4).

Results

A total of 82 IKMT tows (5, 38, and 39 on each expedition leg, respectively) were successfully conducted down to 50 m depth. After filtering for quality control factors such as maximum depth reached (deeper than 30 m), 80 out of these 82 IKMT tows were deemed appropriate for further statistical analysis. During the HICEAS 2023 surveys, mean sea surface temperatures (SST) exhibited a distinct spatial gradient, with cooler waters observed to the northeast (windward of Hawaiʻi Pae ʻĀina) and warmer waters concentrated to the southwest (leeward of Hawaiʻi Pae ʻĀina; Figure 2A, B) in August. However, by October, warmer waters extended further north of the archipelago. Mean chlorophyll-α concentrations were higher overall in August compared to October (Figure 2C, D). The highest concentrations of chlorophyll-α were consistently observed in close proximity to the islands and atolls. These concentrations are displayed on a log scale to account for order-of-magnitude differences in productivity across the region.

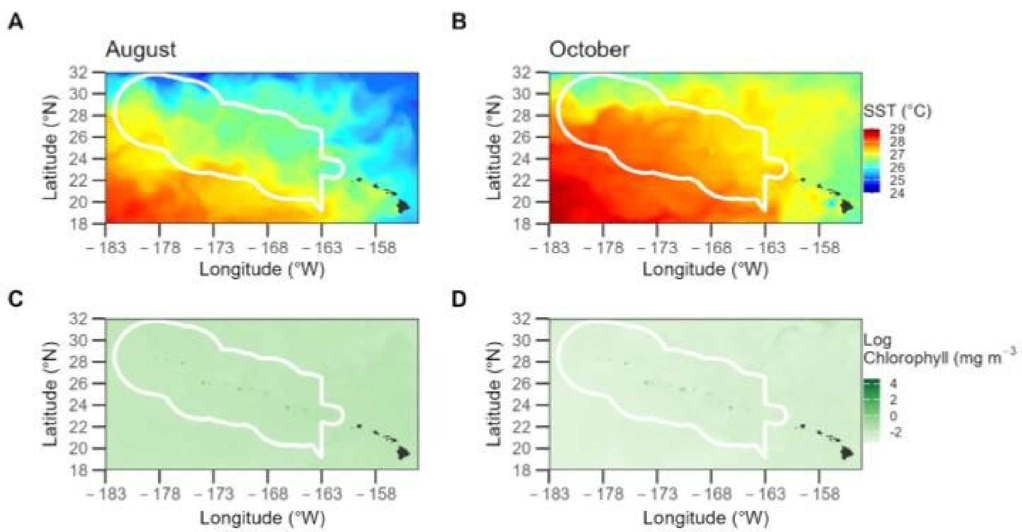

Figure 2. Spatial distribution of mean environmental variables across the Hawaiʻi Pae ʻĀina during the HICEAS 2023 Ichthyoplankton Survey. Lower sea surface temperatures were observed in the same areas as higher chlorophyll-α concentrations over the course of the study period. A & B) Mean Sea Surface Temperature (SST) for August and October 2023, respectively. C & D) Mean chlorophyll-α concentration for August and October 2023, respectively. The white shape around Hawaiʻi Pae ʻĀina in each panel denotes the boundaries of the United States EEZ.

Table 2. Summary table of observed ranges of standard length, SST, and chlorophyll-α for taxa of interest.

Local Name	Taxa	N stations where taxa were found	N larvae found across survey	Size rage (mm)	SST rage (°C)	Chlorophyll α (mg/m^3)
A'u	Istiophoridae	22	42	2–18	26.3–27.7	0.038–0.073
'Ōpakapaka, onaga, gindai, ehu, lehi, kalekale	Etelinae	15	104	2–18	26.7–27.7	0.038–0.093
Mahimahi	*Coryphaena spp.*	47	180	2–19	26.3–28	0.038–0.093
Uku	*Aprion virescens*	9	45	2–12	26.7–27.6	0.038–0.064
Aku	*Katsuwonus pelamis.*	47	1,208	2–18	26.4–28	0.038–0.093
'Ahi	*Thunnus spp.*	55	1,790	2–13	26.2–28	0.038–0.093
Ono	*Acanthocybium solandri*	16	30	2–13	26.3–27.6	0.038–0.066

Taxon specific density distributions

Spatial and temporal summary statistics are provided below for priority fish taxa collected during the 2023 expeditions. Below we describe taxon-specific distributions of larval occurrence, density, size, phenology, and environmental associations.

Mahimahi, Coryphaenidae, Coryphaena spp.

Larval mahimahi were observed across the entirety of Hawai'i Pae 'Āina but exhibited higher densities to the north of the main Hawaiian Islands and around the central part of Papahanāumokuākea National Marine Sanctuary (PNMS) (Figure 3A). Overall, mahimahi larvae were found between 31.07°N and 18.73°N. The maximum number of individual mahimahi larvae observed across the 51 stations where present was 17 (with a mean of 0.014 fish per 1000 m^3, range 0.001–0.041 fish per 1000 m^3). Mahimahi were observed at greater densities in October than in August (Figure 3B). The first occurrence was in late July (July 24, day-of-year 205) and the latest was in late October (Oct. 31, day-of-year 304) with a mean in mid-September (Sept. 13, day-of-year 256). The mean length of mahimahi caught was 5.8 mm SL (range: 2–19 mm SL; Figure 3C). The mean sea surface temperature and chlorophyll-α concentration where mahimahi were collected were 27.1°C and 0.057 mg/m^3 respectively (Figure 3D, E).

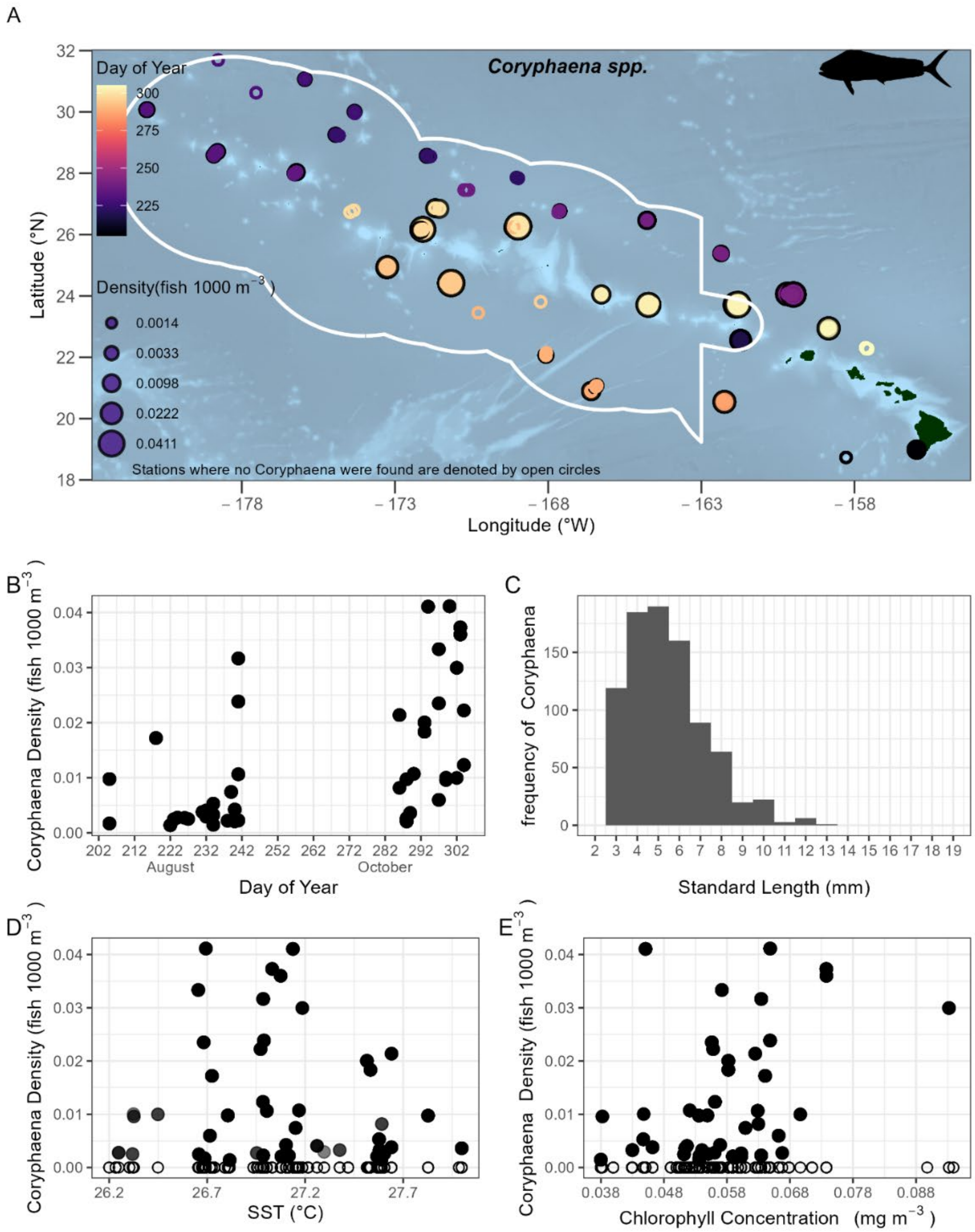

Figure 3. Map of Hawai'i Pae 'Āina with a silhouette of an adult mahimahi in the top right corner and the boundaries of the United States EEZ denoted by the white line. The map shows A) the spatial distribution and density (fish per 1000 m^3) of mahimahi, *Coryphaena* spp. larvae across; B) Density (fish per 1000 m^3) of *Coryphaena* spp. larvae plotted against Day of Year (DOY), indicating higher densities in October compared to August; C) Histogram of standard length (mm) measurements; D) Larval density plotted against daily sea surface temperature (SST, °C); E) Larval density plotted against chlorophyll-α concentration (mg/m^3); Dates that included sampling but where the target taxa were not found are denoted by open circles; E) Larval density plotted against chlorophyll-α concentration (mg/m^3). Dates that included sampling but where the target taxa were not found are denoted by open circles.

Scombridae

Co-occurrence of multiple Scombrid taxa were frequently observed in the same tow. Larvae belonging to the family Scombridae were identified in 84% of all sampled stations (67 out of 80 stations).

Aku; Katsuwonus pelamis

Aku were observed throughout the majority of Hawai‘i Pae ’Āina, with the highest densities recorded on the southern sides of the islands and atolls of PNMS compared to other areas (Figure 4A). The furthest north aku larvae were found was 30.07°N and the furthest south was 18.73°N. The maximum number of individual larval aku observed at any given station was 213 individuals (0.211 fish per 1000 m^3, range 0.002–1.954 fish per 1000 m^3). The greatest densities of aku were observed in October (Figure 4B). The earliest occurrence was in late July (July 25, day-of-year 206), the latest was in early November (Nov. 1, day-of-year 305) and the mean was in mid-September (Sept. 19, day-of-year 262). The average aku length was 5.6 mm (range: 2–18 mm SL; Figure 4C). The mean SST and chlorophyll-α concentration where aku were collected were 27.2°C and 0.055 mg/m^3 respectively (Table 2).

‘Ahi (yellowfin)*, ‘ahi po‘onui* (bigeye)*, ‘ahi pālaha* (albacore) tunas*, Thunnus* spp.

‘Ahi larvae were distinguished to species level where possible. Those that were identified morphologically were ‘ahi (at 23 stations), ‘ahi pālaha (at 26 stations), suspected T. obesus (bigeye, at 12 stations; pending genetic confirmation) while some larvae were only identified to genus. All *Thunnus* larvae were grouped at the genus level for consistency in this analysis, as has been done in other ichthyoplankton studies in the region (Boehlert & Mundy, 1994).

‘Ahi larvae were observed throughout the Hawaiian Archipelago. The furthest north ‘ahi larvaewere found was 31.7°N and the furthest south was 18.73°N (Figure 5A). Higher densities of larvae were collected in October compared to August or July (Figure 5B). The earliest occurrence was in late July (July 24, day-of-year 205), the latest was in early November (Nov. 1, day-of-year 305) and the mean occurrence was late September (Sept. 22, day-of-year 265). ‘Ahi hune were found in 55 stations with a maximum of 177 individuals (0.146 fish per 1000 m^3, range 0.001–1.27 fish per 1000 m^3). The mean length of‘ahi larvae. was 5.5 mm SL (range 1-13 mm SL, Figure 5C). The mean SST and chlorophyll-α where ‘ahi larvae were collected were 27.2 °C and 0.053 mg/m^3 respectively.

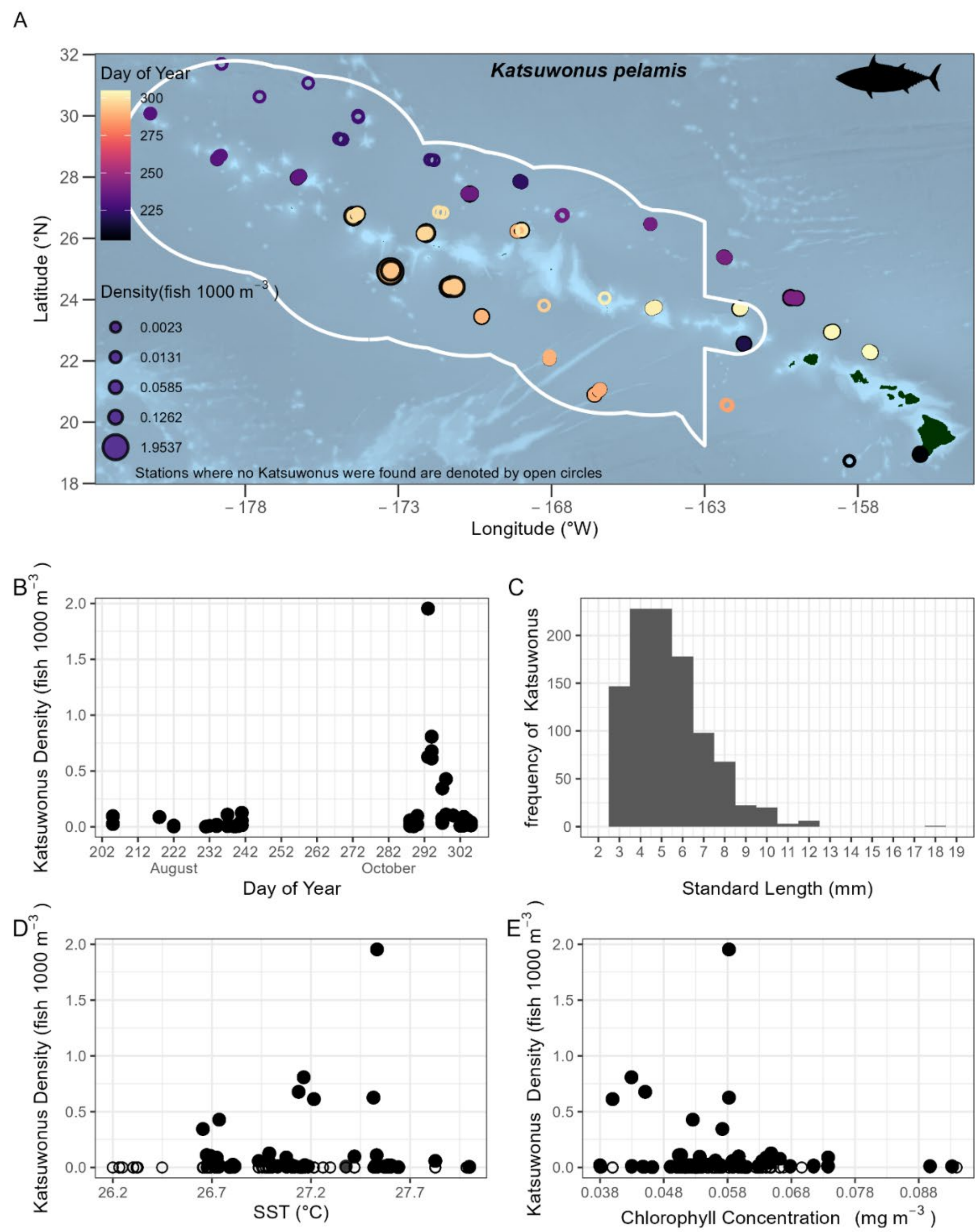

Figure 4. Map of Hawaiʻi Pae ʻĀina with a silhouette of an adult aku in the top right corner and the boundaries of the United States EEZ denoted by the white line. The map shows showing A) the spatial distribution and density (fish per 1000 m^3) of aku, *Katsuwonus pelamis* larvae across Hawaiʻi Pae ʻĀina; B) Density (fish per 1000 m^3) of Katsuwonus pelamis larvae plotted against Day of Year (DOY), indicating higher densities in October compared to August. C) Histogram of standard length (mm) measurements; D) Scatterplot of larval density against daily sea surface temperature (SST, °C); E) Larval density plotted against chlorophyll-α concentration (mg/ m^3). Dates that included sampling but where the target taxa were not found are denoted by open circles.

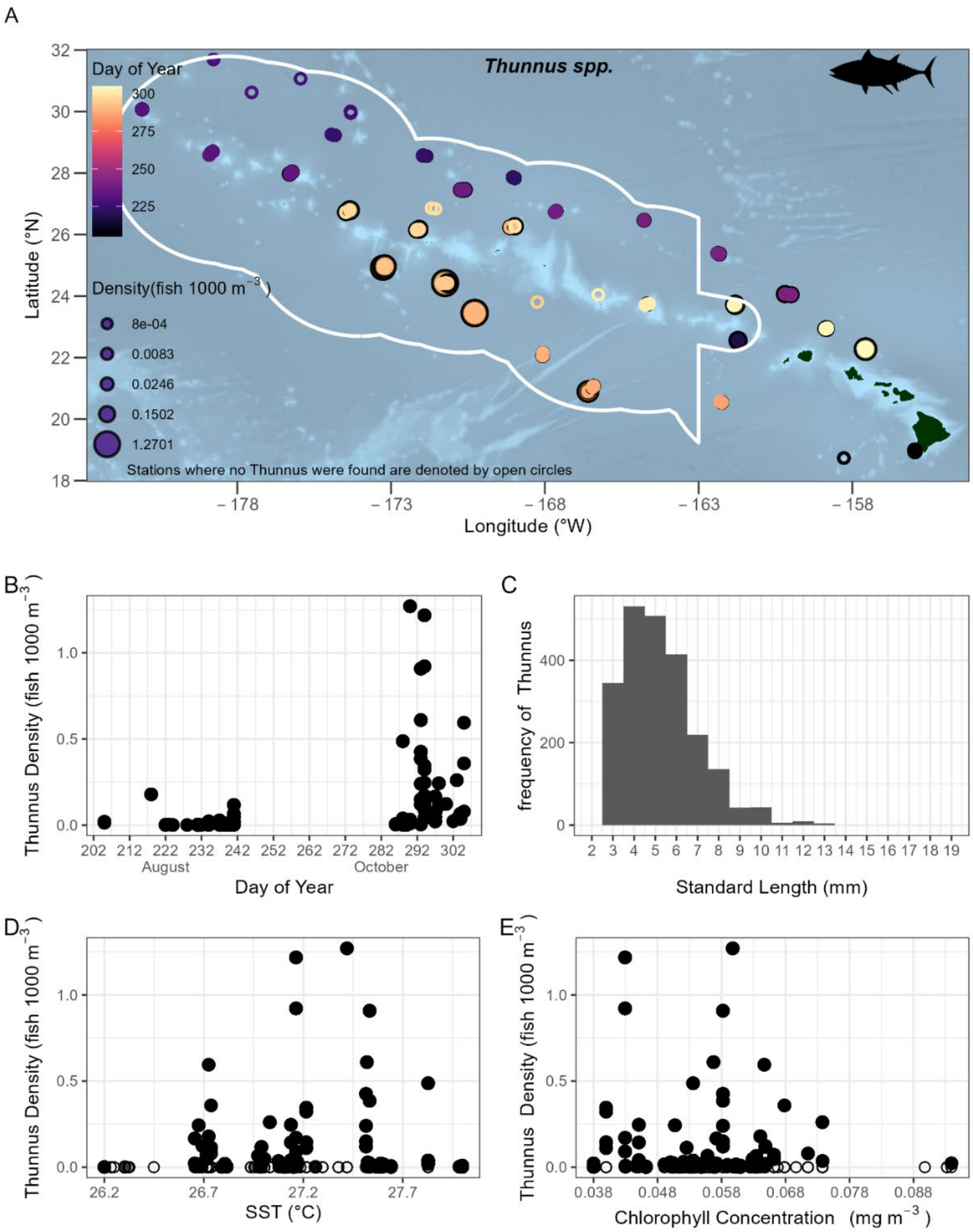

Figure 5. Map of Hawai'i Pae 'Āina with a silhouette of an adult 'ahi in the top right corner and the boundaries of the United States EEZ denoted by the white line. The map shows showing A) the spatial distribution and density (fish per 1000 m^3) of 'ahi *Thunnus spp.* larvae across Hawai'i Pae 'Āina; B) Density (fish per 1000 m^3) of *Thunnus* spp. larvae plotted against day of year (DOY), indicating higher densities in October compared to August; C) Histogram of standard length (mm) measurements; D) Larval density plotted against daily sea surface temperature (SST, °C); E) Larval density plotted against chlorophyll-α concentration (mg/m^3). Dates that included sampling but where the target taxa were not found are denoted by open circles.

Ono, Acanthocybium solandri

Ono larvae were predominantly observed windward (N/NE) of the archipelago (Figure 6A). The furthest north ono larvae were found was 30.36°N and the furthest south was 18.73°N. Ono were collected at 17 stations with a maximum of 13 individuals (0.003 fish per 1000 m^3, range of 0.001–0.011 fish per 1000 m^3). Ono larvae were most frequently captured in August, although the highest density catch occurred in October, north of Oʻahu (Figure 6A–B). The earliest for capture was in late July (July 24, day-of-year 205), the latest was in late October (Oct. 31, day-of-year 304), with a mean of mid-August (Aug. 14, day-of-year 226) (Figure 6B). The mean SL was 6.4 mm (range 2–13 mm SL (Figure 6C). The mean SST and chlorophyll-α where ono were collected were 26.9 °C and 0.052 mg/m^3, respectively.

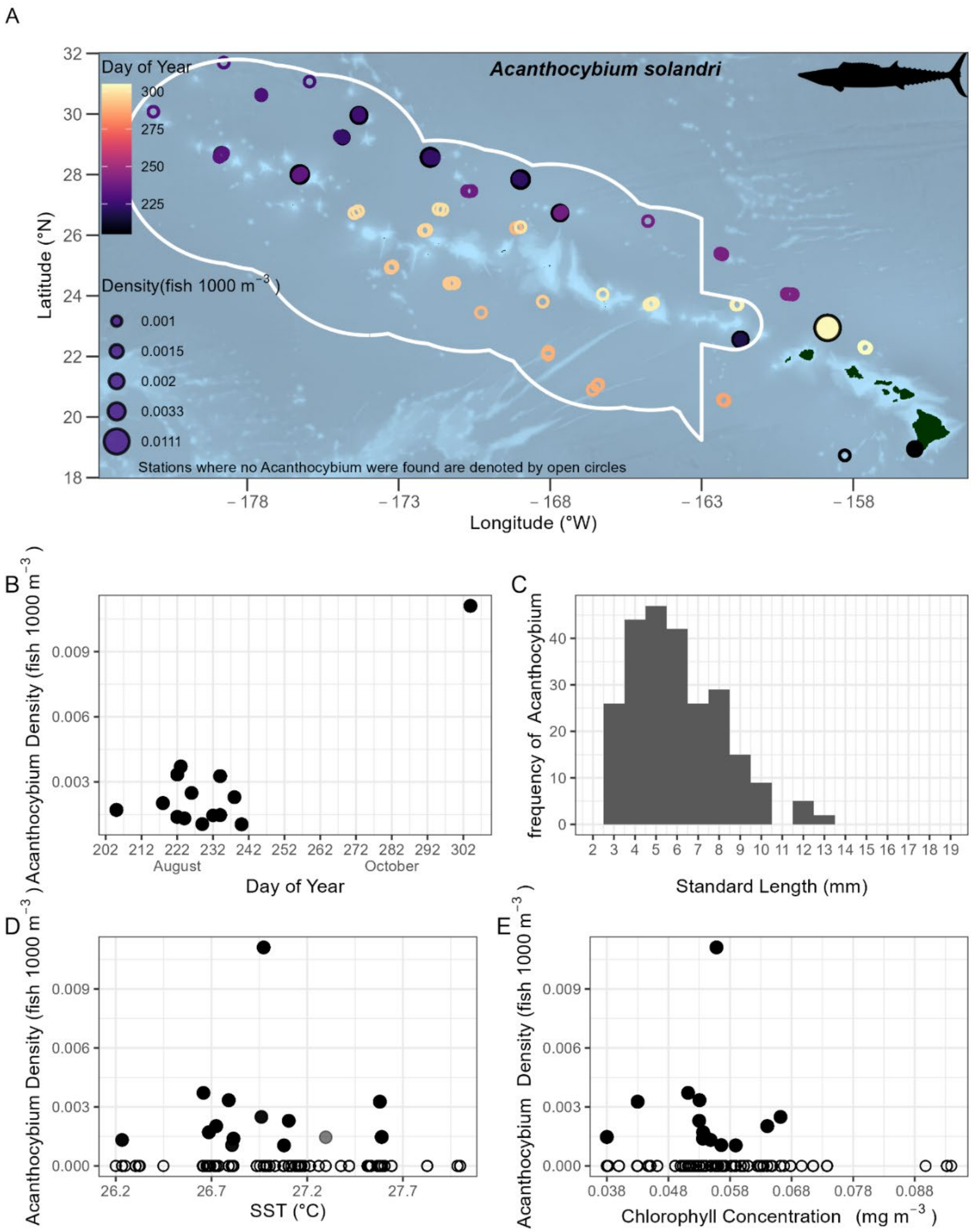

Figure 6. Map of Hawai‘i Pae ‘Āina with a silhouette of an adult ono in the top right corner and the boundaries of the United States EEZ denoted by the white line. The map shows showing A) the spatial distribution and density (fish per 1000 m^3) of ono larvae across Hawai‘i Pae ‘Āina; B) Density (fish per 1000 m^3) of *Acanthocybium solandri* larvae plotted against day of year (DOY), indicating higher densities in October compared to August; C) Histogram of standard length (mm) measurements; D) Larval density plotted against daily sea surface temperature (SST, °C); E) Larval density plotted against chlorophyll-α concentration (mg/m^3). Dates that included sampling but where the target taxa were not found are denoted by open circles.

Lutjanidae

Non-Etelinae Lutjanids were also identified. These are of particular interest due to the prevalence of to‘ao, an invasive species in Hawai‘i (Appendix). For reporting purposes, only a subset of genera within the subfamily Etelinae, which are relevant to active fisheries, will be included in this report.

Etelinae

Larvae were predominantly observed on the northern side of the archipelago with higher densities nearer to shore (Figure 7A). The furthest north Eteline snapper larvae were found was 30.63°N and the furthest south was 18.95°N. Although the subfamily Etelinae includes several genera, the only two identified here were the genera, *Pristipomoides sp.* and *Aphareus sp*. These two represent a suite of species including ‘ōpakapaka, gindai, lehi, and kalekale. The next section includes further information about *Aprion virescens*.

Eteline snapper larvae were found in 13 stations with a maximum of 57 individuals at a given station (0.011 fish per 1000 m^3, range of 0.001–0.084 fish per 1000 m^3). The highest density of larvae was recorded in August followed by October. The earliest for detection was in late July (July 24, day-of-year 205), the latest was in late October (Oct. 31, day-of-year 304), and the mean was late August (Aug. 21, day-of-year 234; Figure 7B). The mean SL was 5.43 mm (range of 2–18 mm SL; Figure 7C). The mean SST and chlorophyll-α where Eteline larvae were collected were 27 °C and 0.057 mg/m^3, respectively.

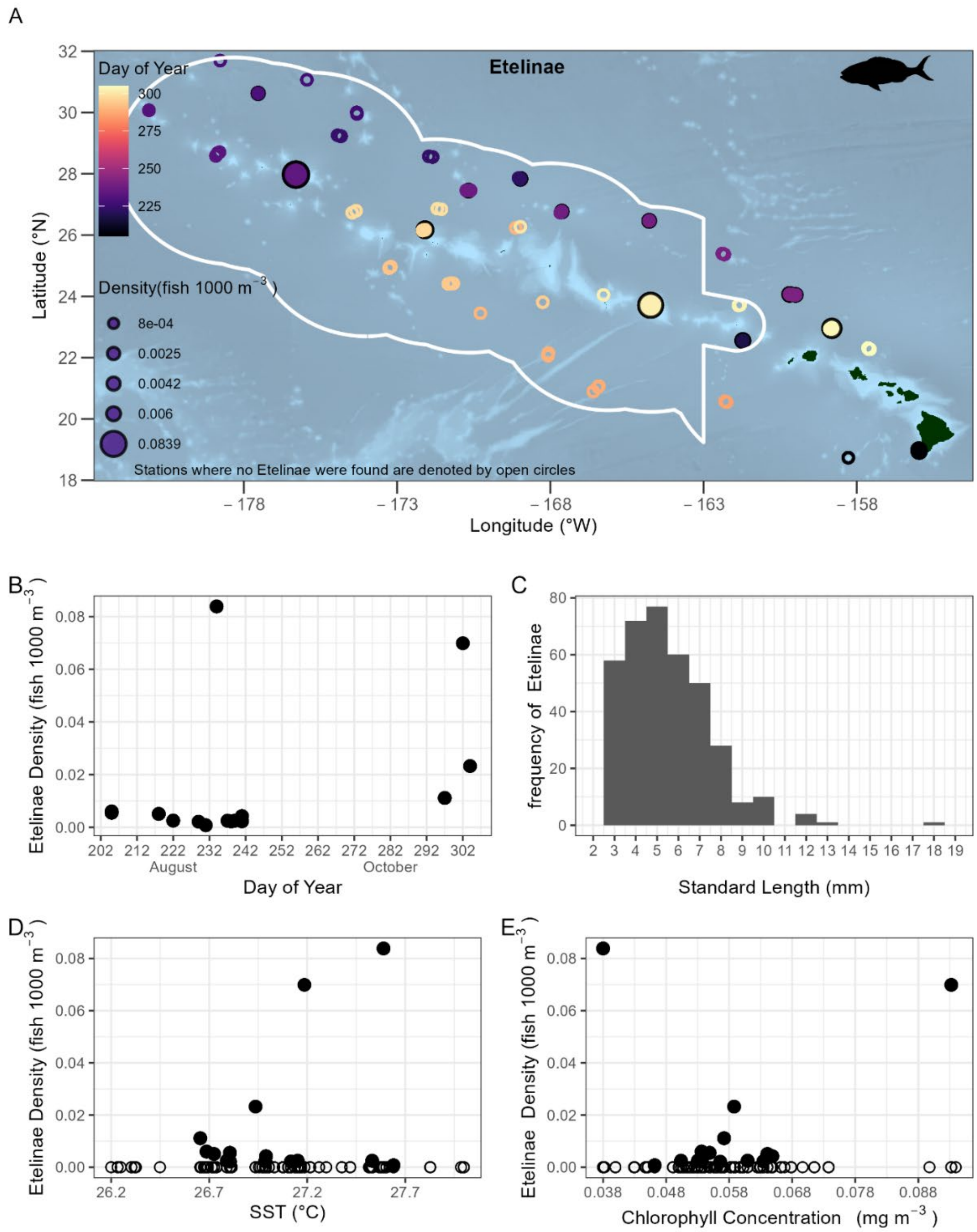

Figure 7. Map of Hawaiʻi Pae ʻĀina with a silhouette of an adult ʻōpakapaka in the top right corner and the boundaries of the United States EEZ denoted by the white line. The map shows showing A) the spatial distribution and density (fish per 1000 m^3) of non-eteline snappers, larvae in the subfamily Etelinae across Hawaiʻi Pae ʻĀina; B) Density (fish per 1000 m^3) of Etelinae larvae plotted against Day of Year (DOY), indicating higher densities in October compared to August; C) Histogram of standard length (mm) measurements; D) Larval density plotted against daily sea surface temperature (SST, °C); E) Larval density plotted against chlorophyll-α concentration (mg/m^3). Dates that included sampling but where the target taxa were not found are denoted by open circles.

Uku, Aprion virescens

Uku larvae were only collected in late July and August with patchy spatial distribution. Larvae were only observed windward of the archipelago and more frequently within the boundaries of PNMS, with a mean observed density of 0.005 fish per 1000 m^3 (range of 0.001–0.016 fish per 1000 m^3; Figure 8A). Uku larvae were found in 10 stations with a maximum of 39 individuals at a given station. The furthest north uku larvae were found was 27.97°N and the furthest south was 18.95°N. The earliest uku larva was caught in late July (July 24, day-of-year 205), the latest in late August (Aug. 29, day-of-year 241) with a mean of mid-August (Aug. 14, day-of-year 226). The mean uku length was 6.3 mm SL (range 2– 12 mm SL; Figure 8C). The mean SST and chlorophyll-α where uku larvae were collected were 27°C (Figure 8D) and 0.056 mg/m^3 (Figure 8E), respectively.

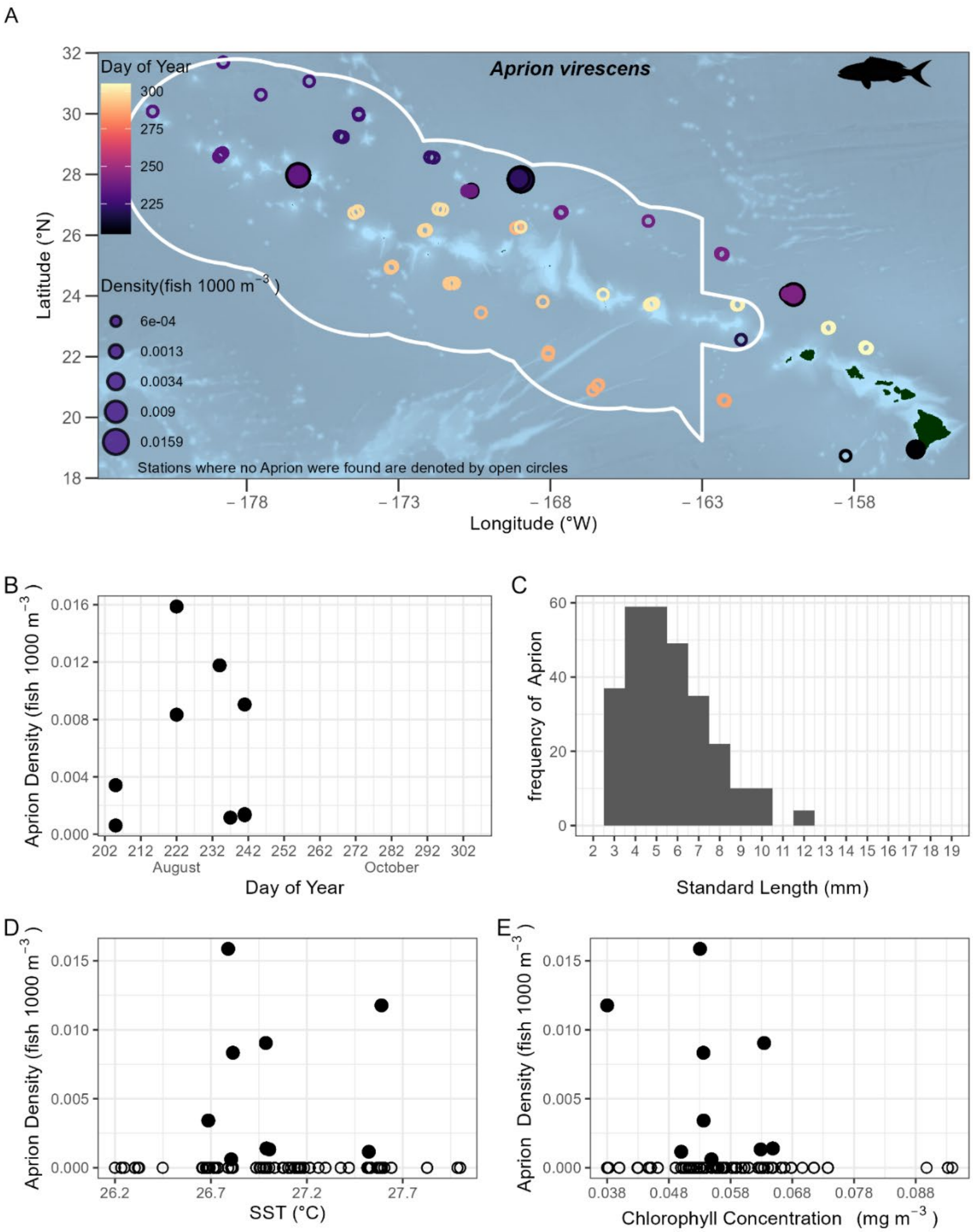

Figure 8. Map of Hawai'i Pae 'Āina with a silhouette of an adult uku in the top right corner and the boundaries of the United States EEZ denoted by the white line. The map shows A) the spatial distribution and density (fish per 1000 m^3) of uku, *Aprion virescens* larvae across Hawai'i Pae 'Āina; B) Density (fish per 1000 m^3) of *Aprion virescens* larvae plotted against Day of Year (DOY), indicating higher densities in October compared to August; C) Histogram of standard length (mm) measurements; D) Larval density plotted against daily sea surface temperature (SST, °C); E) Larval density plotted against chlorophyll-α concentration (mg/m^3). Dates that included sampling but where the target taxa were not found are denoted by open circles.

A‘u, Istiophoridae

Billfish larvae (a‘u mane‘o) were caught throughout Hawai‘i Pae ’Āina, the furthest north a‘u larvae were found was 29.26°N and the furthest south was 18.73°N (Figure 9A). Of the 22 stations where a‘u larvae were found, counts ranged from 1 to 8 larvae at a given station with a mean of 2.4 larvae per station. Of the management unit taxa considered in this study, Istiophoridae had the lowest abundances at any given station. The mean density of a‘u mane‘o at a given station was 0.006 fish per 1000 m^3 seawater; range of 0.001–0.025 fish per 1000 m^3 seawater). The earliest billfish was caught in late July (July 24, day-of-year 205), the latest in late October (Oct. 31, day-of-year 304) with a mean in early September (Sept. 6, day-of-year 249; Figure 8B). The mean a‘u mane‘o length was 5.8 mm SL (range 2–8 mm SL; Figure 9C). The mean SST and chlorophyll-α where a‘u mane‘o were collected were 27.1°C (Figure 9D) and 0.055 mg/m^3 (Figure 9E), respectively.

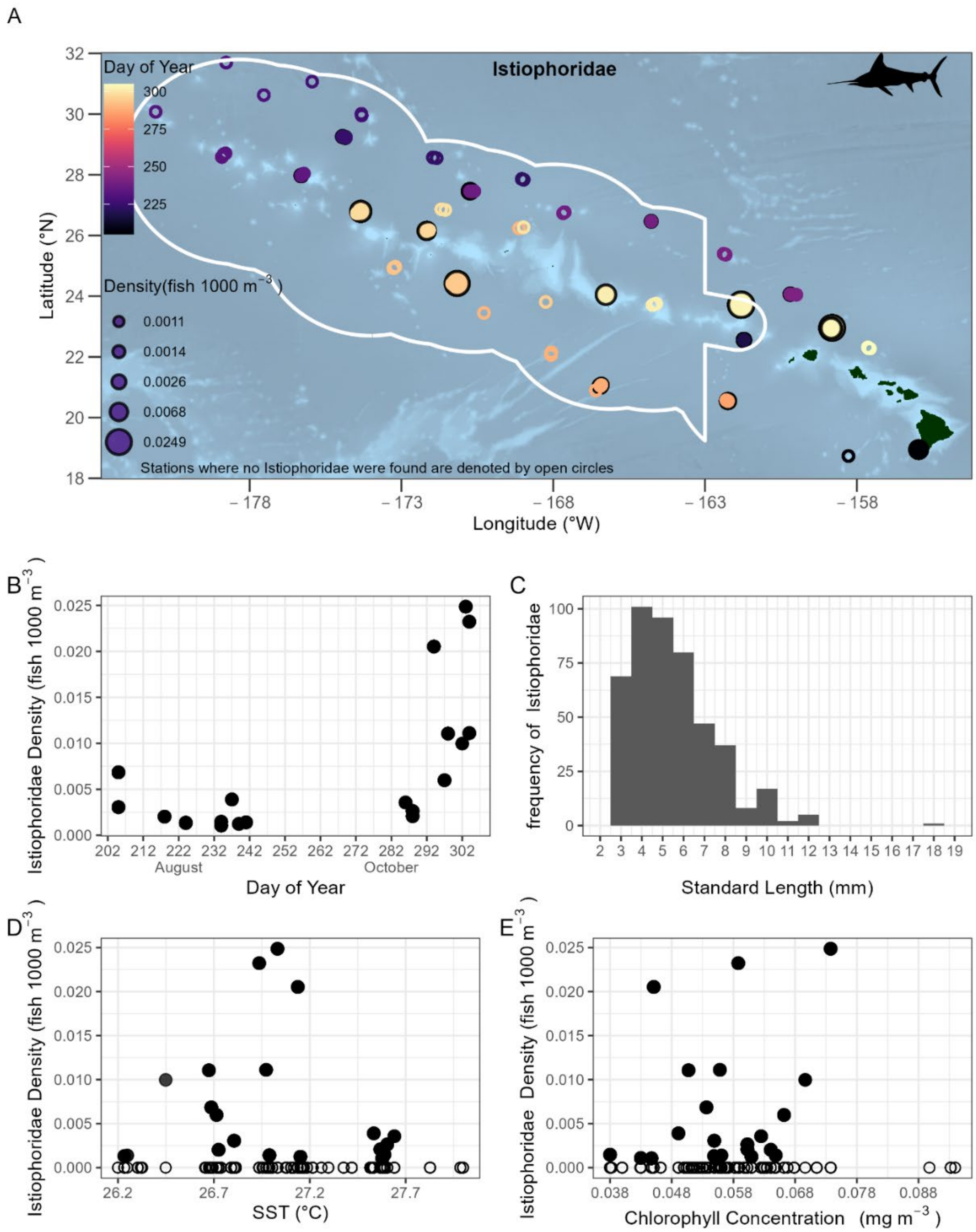

Figure 9. Map of Hawaiʻi Pae ʻĀina with a silhouette of an adult aʻu in the top right corner and the boundaries of the United States EEZ denoted by the white line. The map shows showing A) the spatial distribution and density (fish per 1000 m^3) of aʻu maneʻo, larvae in the Family Istiophoridae, across Hawaiʻi Pae ʻĀina; B) Density (fish per 1000 m^3) of aʻu maneʻo plotted against Day of Year (DOY), indicates higher densities in October compared to August; C) Histogram of standard length (mm) measurements; D) Larval density plotted against daily sea surface temperature (SST, °C); E) Larval density plotted against chlorophyll-α concentration (mg/m^3). Dates that included sampling but where the target taxa were not found are denoted by open circles.

Discussion

The 2023 PIRIS effort represents the most geographically expansive survey of larval fishes conducted across Hawaiʻi Pae ʻĀina to date. Historically, sampling in the region has been geographically limited within the main Hawaiian Islands, but by mapping larval fish distributions across both the main Hawaiian Islands and PNMS, PIRIS aims to comprehensively enhance our understanding of pelagic larval habitats throughout the Pacific Islands. This technical memorandum provides an overview of the distributions of selected fish taxa of management interest observed around Hawaiʻi Pae ʻĀina in 2023 and introduces a comprehensive larval fish dataset at various taxonomic resolutions for public use.

These samples provide the first large-scale characterization of ichthyoplankton distributions across Hawaiʻi Pae ʻĀina, spanning gradients in SST and chlorophyll-α concentration. These ichthyoplankton distributions can further our understanding of spawning patterns across this domain. Possible age ranges are discussed for various taxa based on existing length-age research, but ongoing and future work will confirm the age ranges of these fishes.

The environmental conditions encountered during the survey provide a first-pass characterization of larval habitat space for focal management unit taxa. Observed ranges of SST and chlorophyll-α (Table 2) provide some empirical bounds on the environments where larvae were detected during this study period. All sampling was conducted during the season of kau (summer; Pukui & Elbert, 1986), specifically within the months of Hilinama and Ikuwa (time spans overlapping with August and October; Malo, 1898; Handy et al.,1972).

The observation of higher productivity and distinct thermal boundaries in August aligns with traditional Hawaiian seasonal calendars, which categorize this period as the season where currents are consistent; it is also the peak season for aku fishing (Kahāʻulelio, 2006). The transition observed in October, where warmer waters moved northward, corresponds with the shift toward the rainy months, a period traditionally noted for “zigzagging” currents and a shift in deep-sea fishing focus (Kahāʻulelio, 2006; Maly, 2003).

Temperature and chlorophyll-α concentration were selected as primary environmental variables due to their roles in potentially explaining species ranges (Hsieh et al., 2009), growth rates (Stieglitz et al., 2017), and serving as proxies for ichthyoplankton prey availability (Woodworth-Jefcoats & Wren, 2020), respectively. Additionally, temperature acts as a detectable cue for adult spawning (Stieglitz et al., 2017; Schaefer, 1998). It is worth noting, however, that the temperature and chlorophyll values reported here are both from the surface, while specimen collection ranged from the surface down to 50 m, where conditions certainly differed (Fujieki et al., 2026).

Although depth and temperature data are available for each net tow, chlorophyll-ɑ concentration was not. For maximum agreement between variables, we present only surface variables (temperature and chlorophyll-ɑ) in this report. While these variables, along with sea surface height (SSH), can indicate the presence of eddies or other oceanographic features, the specific effects of such features were not analyzed in this product. Although global ocean temperatures were the warmest on record (NCEI, 2023), the trends displayed here for August and October around Hawaiʻi Pae ʻĀina in 2023 are relatively consistent with data collected in Hawai'i from the last 15 years (Fujieki et al., 2026).

Fish Taxa

The following discussion elaborates on each taxon's larval distribution. We acknowledge that these data represent a single, limited timeframe, but they contribute to the current understanding of spawning time and geographic windows by comparing our observations to published research on adult reproductive windows and previous larval occurrences in Hawaiʻi.

Mahimahi, Coryphaenidae, Coryphaena spp.

The observed mahimahi occurrence window in this survey, with the highest densities in October, suggests that while mahimahi cohorts spawned in July are the most likely to survive to adulthood (Kraul, 1999), this is not the only window in which mahimahi spawn around Hawaiʻi. It is widely thought that mahimahi caught in Hawaiian waters spawn year-round, as local fishers note that females are nearly always ripe with eggs (Hawaiʻi small boat fishers, [personal communication with Hawaiʻi small boat fishers, 2026]).

Unlike other taxa discussed, the authors were not able to find publicly available cultural information regarding mahimahi at the larval life stage. Larval mahimahi caught in this study ranged from 2–19 mm SL (Figure 3C). Based on previous research that estimated larvae between 6- and 9- mm SL were 5–13 days old (Bignami et al., 2014), some of the larvae in our study are likely within this 5-to-13-day age range. Future otolith and gut content analyses can reveal the specific ages and feeding behaviors of the mahimahi collected in this survey.

The mean SST and chlorophyll-ɑ where mahimahi were collected were 27.1°C and 0.057 mg/m^3 respectively. These observations correspond well with research finding Hawaiʻi-caught captive mahimahi spawn in water temperatures from 19°C to 31°C

(Stieglitz et al., 2017) and exhibit rapid embryonic development at temperatures greater than 25°C (Ostrowski & Divakaran 1990). Although more data are necessary to better understand mahimahi larval distributions in relation to environmental conditions, the attempts at mahimahi aquaculture in the 1980s and 1990s provided significant environmental context for the ichthyoplankton sampling presented here.

Scombridae

Overall, the SST and chlorophyll-α ranges where Scombrids were observed were similar for all taxa except for ono, which occurred within a much more restricted range of these conditions.

Aku; Katsuwonus pelamis

The observed aku occurrence window in this survey, with higher densities in October compared to August, suggests a potential expansion of the spawning window previously described for Hawaiʻi. Historically, adult females were presumed to have mature eggs between March and September (Brock, 1952). In addition to possibly expanding the spawning window our results also align with more recent surveys, such as a study off the Kona coast that captured over 300 aku larvae in September (Paine et al., 2008) and another that caught 126 aku off Oʻahu (Boehlert & Mundy, 1994). These publications support the idea that spawning continues into the autumn.

This biological timing corresponds with traditional Hawaiian fishing practices, where the kapu protecting spawning aku was lifted at the start of the Makahiki season, often in late October (Titcomb & Pukui, 1972; Pukui and Elbert, 1986). Larval aku in our study reached lengths of approximately 8–10 mm SL, which likely correspond to an age of at least 10–11 days post-hatch, suggesting these individuals originated from spawning events within the month of October (Ashida et al., 2018).

The largest larvae in our study approached the size range reported for juveniles (11.4–54.8 mm SL) collected near Japan, and given that metamorphosis is reported to occur around 10 days post-hatch, our larger larvae were likely on the cusp of transformation. The mean SST and chlorophyll-α where aku were collected were 27.2°C and 0.055 mg/m^3, respectively. While specific environmental thresholds for these larvae are still being refined, these conditions represent the window in which active transformation into the juvenile stage occurs in the south Pacific (Tanabe, 2001).

Ahi: ʻahi hune (yellowfin)*, ʻahi pālaha* (albacore) and *ʻahi poʻonui* (bigeye) tunas*, Thunnus* spp.

The observed ʻahi. occurrence window in this survey, with higher densities in October compared to August or July, overlaps with the expected spawning windows for this genus. In parts of the Pacific Ocean north of 20°N, spawning primarily occurs from July through December (Schaefer, 1998; June, 1953). Our temporal results align with previous work off Kona in September 2004, where 392 ʻahi hune *T. albacares*, 43 ʻahi pālaha *T. alalunga*, and a single ʻahi poʻonui *T. obesus* larva were caught (Paine et al., 2008). Indeed, the *Thunnus* larvae we identified to species, ʻahi hune, ʻahi poʻonui, and ʻahi pālaha, had similar counts per station compared to the aforementioned study. ʻAhi larvae in our study ranged from 2–10 mm SL with estimated ages between 1 to 21 days after hatch based on growth rate data for *T. albacares* from Okinawa, Japan (Kaji et al., 1999) and the Mississippi River Delta (Lang et al., 1994).

Larval growth rates differ between species; however, we were unable to locate species-specific information for ʻahi poʻonui or ʻahi pālaha, so future analyses should seek to incorporate these data as they become available. ʻAhi poʻonui is not expected to spawn around Hawaiʻi (Yuen, 1955). These facts make our identifications here surprising but not impossible, since other studies around the main Hawaiian Islands have also found these larvae in low numbers using morphological (Boehlert & Mundy, 1994) and genetic methods (Paine, 2008), respectively, to confirm identities.

Adult ʻahi poʻonui have been known to spawn within temperature ranges (24- 29°C, Sun et al., 2013) present in the waters around Hawaiʻi nei. Throughout the study, sea surface temperatures indicated that conditions were consistently above the minimum thermal threshold (25°C) for spawning, as reported by Schaefer (1998). Although these temperature values are slightly lower than the optimal range of 26°C to 31°C reported for *ʻ*ahi hune the Panama Bight (Wexler et al., 2011), they seem consistent with those reported for ʻahi (24–26.5 °C) by Boehlert & Mundy (1994).

Ono, Acanthocybium solandri

The observed ono occurrence window in this survey, with larvae captured most frequently in August and the highest density catch in October, aligns with research on adult specimens suggesting a spawning season that begins in June and extends through at least September (Uchiyama & Boggs, 2006). These observations are further supported by studies in the western and central Pacific Ocean, where mature-active adults were observed over a five-month period peaking in November (Gao et al., 2020).

Our results also track with previous larval surveys; for instance, Paine et al. (2008) caught two ono larvae during the day offshore from Kona in late September. In the current study, ono were found at only 17 stations with relatively low absolute numbers, where the maximum number of ono larvae collected at any given station was four. These relatively low densities, especially when compared to some stations where over 200 aku were observed, perhaps reflect a similar pattern to that seen in adult ono, which unlike ʻahi, do not form large schools (Titcomb & Pukui, 1972). Larvae in this study ranged from 2–13 mm SL (Figure 6C) and size-at-age cannot be estimated, since data for ono larvae does not yet exist in the literature (Uchiyama & Boggs, 2006; Matsumoto, 1967; Strasburg, 1964). The mean SST and chlorophyll-α where ono were collected were 26.9°C and 0.052 mg/m^3, respectively.

Lutjanidae: Etelinae

The observed eteline snapper occurrence window in this survey, with the highest densities in August and detections spanning from late July to late October, aligns with expected regional spawning peaks. If spawning periods for these taxa are similar to those of onaga, spawning would begin in July and peak in October (Everson et al., 1989). This biological timing corresponds with traditional observations where deep-sea fishing was permitted during the winter months, a period when eteline snappers should be finished with their spawning (Titcomb & Pukui, 1972; Everson et al., 1989).

In the larval stage, eteline snappers present identification challenges, making it difficult to morphologically distinguish between *Pristipomoides* and *Aphareus* genera (Leis & Lee, 1994). These genera represent a suite of culturally and commercially important species including lehi, and ʻōpakapaka, gindai / ʻulaʻula, and kalekale. The mean standard length of our larvae was 5.2 mm SL (range 2–13 mm SL), suggesting these fish are at the very start of their pelagic larval duration (PLD).

Previous research highlights a potential for broad dispersal, with some species remaining pelagic until reaching at least 54 mm (Leis & Lee, 1994). PLD estimates vary significantly across the subfamily, ranging from approximately 40 days for *P. multidens* (Ovenden et al., 2004) to as many as 60–180 days for ʻōpakapaka (Gaither et al., 2011; DeMartini et al., 1994). For comparison, other members of the subfamily (in the genus *Etelis*) such as ehu and onaga remain pelagic until reaching at least 51 mm and 22 mm, respectively (Leis & Lee, 1994).

Uku, Aprion virescens

The observed uku occurrence window in this survey, primarily in August, aligns with published spawning records for the species; adult uku spawn from May to October with a peak in June (Everson et al., 1989). Unlike the other eteline species discussed, uku are morphologically distinguishable as larvae, occupy a broader habitat depth range during adulthood (Asher et al., 2017; Allen, 1985), and are more sought after as food fish (Titcomb & Pukui, 1972). Larval uku caught in this study ranged from 3–7 mm SL and are estimated to be less than a week old, based on previous research indicating that larvae 3–6 mm are in their first week of life (Schmidt et al., 2023).

Previous records indicate that most uku larvae are caught within the upper 40 m, which largely overlaps with the depth range sampled (Schmidt et al., 2023). The highest density of uku larvae was observed near 26.5°C, consistent with the historical mean surface temperature of 26.4°C reported for larval uku catches (Schmidt et al., 2023). While the PLD for uku is unknown, a recent modeling study (Suca et al., 2025) utilized a range of 27–45 days based on existing records for the PLD of other eteline snappers (Ovenden et al., 2004) and the maximum age at which pelagic uku larvae have been found, after which point it is assumed they transform and settle out into their adult habitat (Schmidt et al., 2023).

Aʻu, Istiophoridae

Overall, aʻu maneʻo (prickly aʻu), a newly developed name for larval istiophorids, were found at lower densities in this study than the other taxa reported here. These larvae represent several species identified in this region, including *Makaira nigricans*, *Tetrapturus angustirostris*, and *Kajikia audax* (Hyde et al., 2005; Hyde et al., 2006). Due to the difficulty in morphologically identifying billfish to species at these sizes, we present these data at the family level, though historical records highlight their cultural importance as aʻu (Titcomb & Pukui, 1972).

Larval aʻu maneʻo in this study reached a mean length of 5.3 mm SL (range 2–8 mm SL). Ages of aʻu maneʻo (*M. nigricans*, *T. angustirostris*) caught near Cross Seamount have been estimated utilizing particle back tracking. Although these studies were based on collection data from five larvae caught in the 1950s, they suggest that our larvae could range between just hatched and two weeks old (Musyl et al., 2024). The relatively low densities observed may be a result of our tow-yo sampling method. Historically, istiophorid sampling conducted by PIFSC has occurred strictly at the surface (e.g., Whitney et al., 2021; Humphreys, 2000), and while our method included surface sampling between intervals, it may have captured fewer individuals than tows conducted entirely at the surface.

The mean SST and chlorophyll-α where aʻu maneʻo were collected were 27.1°C and 0.055 mg/m^3 respectively. These temperatures are notably lower than those observed in surveys off the Gulf of California, where *K. audax* larvae catch was highest between 27.7°C and 31.5°C (Armas et al., 1999). Similar to *M. nigricans*, the temperatures where our highest larval densities were recorded remain lower than those typically reported for these taxa in other oceanic regions.

Summary and Next Steps

The PIRIS effort underscores the value of collaborative research and ship time utilization across diverse primary research projects, providing a model for broad-scale, regular sampling efforts. This collaborative effort is exemplified by the biocultural lens applied to naming practices, such as aʻu maneʻo for larval Istiophoridae, which intentionally weaves Kānaka ʻŌiwi knowledge with Western science practices. This intentional co-design connects modern fisheries research to the effective, place-based management once enforced by konohiki, providing a more holistic and culturally informed path toward sustaining Hawaiʻi's fish stocks today.

The resulting dataset not only supports existing regional studies but also expands current knowledge of the early life stages of commercially and ecologically important taxa. While preliminary length data has been reported here, the archived larvae offer further potential for age determination via analysis of their otoliths. Coupling this age data with dispersal modeling would allow for the back-calculation of larval trajectories, providing valuable insights into the timing and location of adult spawning events. The associated environmental conditions reported here, particularly sea surface temperature and chlorophyll-α, represent a first-pass characterization of larval habitat indicators for our focal management taxa in this region. The observed ranges of these variables provide empirical bounds on thermal and productivity environments that can inform region-specific parameterization of larval species distribution models and related habitat-based analyses.

Together, these results advance our understanding of spawning patterns across the domain and establish a foundation for future modeling and synthesis efforts. Ongoing research will delve deeper into the environmental drivers of larval distributions across broad geographic regions, examining how such factors as lunar phase can affect larval distributions and occurrences. For example, the Hoku and Māhealani, or full moons (Malo, 1898; Handy et al., 1972) have been associated with plankton staying deep as a predator avoidance strategy (Handy et al., 1972; Shima et al., 2022) and currents run shoreward pushing larval fish with them (Maly, 2003; Handy et al., 1972).

Understanding these and other environmental drivers could better inform fisheries science, as oceanographic conditions are known to affect larval growth and survival (Fennie et al., 2023). Ongoing PIRIS surveys have evolved to include on-net instrumentation such as a FastCAT CTD, which enables more precise and real-time measurements of sampling depth and oceanographic conditions. This work serves to introduce this significant dataset to the broader scientific community, paving the way for future comprehensive studies.

Data Availability

Metadata for the HICEAS Ichthyoplankton Survey will be publicly available on NOAA Fisheries' InPort (GUID: 76822). The R code utilized for generating the environmental data plots and maps will be posted in a public repository named HICEAS Ecosystem on GitHub. This study has been conducted using E.U. Copernicus Marine Service Information; daily (gap filled) and monthly chlorophyll-α from the Global Ocean Colour (Copernicus-GlobColour); and Bio-Geo-Chemical, L4 (monthly and interpolated) from Satellite Observations (1997-ongoing) dataset.

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Appendix

Flowmeter formula

((difference in counts* rotor constant)/999999)*area of net opening, where rotor constant for Flowmeter manufacturer was given as 26873.

Previous ichthyoplankton survey efforts between 1984 and 2018

Figure A1. Previous ichthyoplankton survey efforts between 1984 and 2018 as conducted by PIFSC/ the Honolulu Lab of the SWFSC.

Non-MUS Fish

Reef fish of the families Mullidae, Acanthuridae and Labridae: Tribe Scarini were identified to the lowest taxonomic level possible but not measured. All other reef fish taxa were grouped together as “miscellaneous reef fish”, and non-target, non-reef taxa were grouped together as “miscellaneous fish”. For samples with large numbers (500+) of *Encrascholina punctifer,* henceforth referred to as nehu (oceanic), all other taxa were treated normally while only a quantitative split of the whole sample had nehu tabulated.

Nonfish Distributions

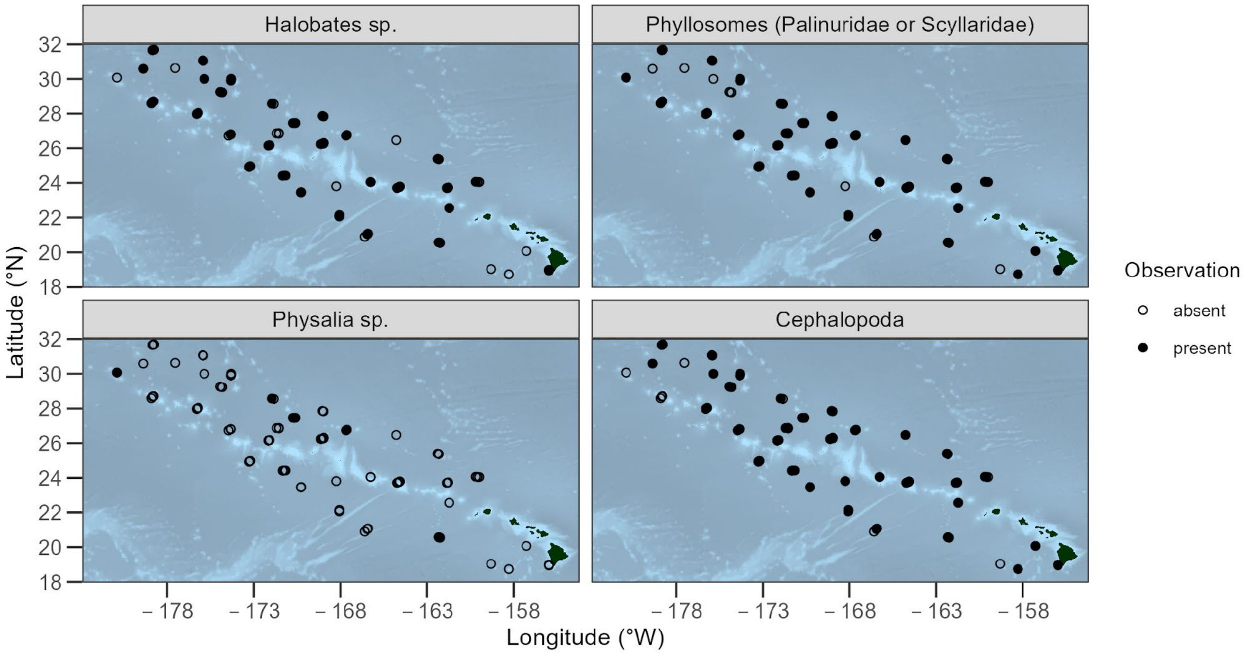

Figure A2. Maps showing the spatial distribution (presence/absence) of four non-fish taxa.