# FINAL REPORT

24 August 2023

## 1 AWARD INFORMATION

Purchase Order No. C11105 and C21732, State of Hawaii DLNR

Life History Information for Key Hawaii Coral Reef Fish Species

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Progress reporting period: 01 Sept 2022 – 01 March 2023

## 2 PROJECT SUMMARY

Size at maturity and spawning season were estimated for several species two Parupeneus goatfish species and five Kyphosid chub species, and the wet mount technique was compared to histology for microscopic assignment of maturity and oocyte stage. Fishes were collected from O‘ahu waters using spearfishing between 2020 and 2023, with a smaller number of samples coming from markets. Both freediving and closed circuit rebreather diving were used for sample collection. Macroscopic and microscopic methods of assigning maturity and reproductive stage were used for females, while a statistical assignment was used for males. L50 and L95 were successfully calculated for all species. Three of the kyphosid species can be distinguished only using x-rays so these three species were combined into a group for analysis. Wet mount maturity assignments were as accurate as histology when assigning maturity in female fish.

Key findings are as follows, all lengths are fork length:

| Species | L50 female | L50 male | L95 female | L95 male | Spawning season |
|---|---|---|---|---|---|
| Parupeneus insularis **Munu** | 186 mm (171, 196) | 239 mm (235, 243) | 244 mm (224, 271) | 252 mm (247, 257) | March-September |
| Parupeneus cyclostomus **Moano kea** | 246 mm (230, 261) | 300 mm (287, 304) | 295 mm (267, 324) | 323 mm (317, 339) | Year round |
| Kyphosus vaigiensis **Nenue (lowfin)** | 376 mm (364, 391) | 345 mm (324, 357) | 408 mm (388, 436) | 379 mm (348, 396) | Year round |
| Kyphosus cinerascens **Nenue (highfin)** | 346 mm (314, 373) | 340 mm (325, 353) | 431 mm (378, 481) | 384 mm (360, 408) | Year round |
| Kyphosus group | 302 mm (284, 327) | 332 mm (323, 343) | 386 mm (327, 452) | 380 mm (359, 406) | January-May |


Mano Marine
Marine Services and Research
Munu

| Species | L50 female | L50 male | L95 female | L95 male | Spawning season |
|---|---|---|---|---|---|
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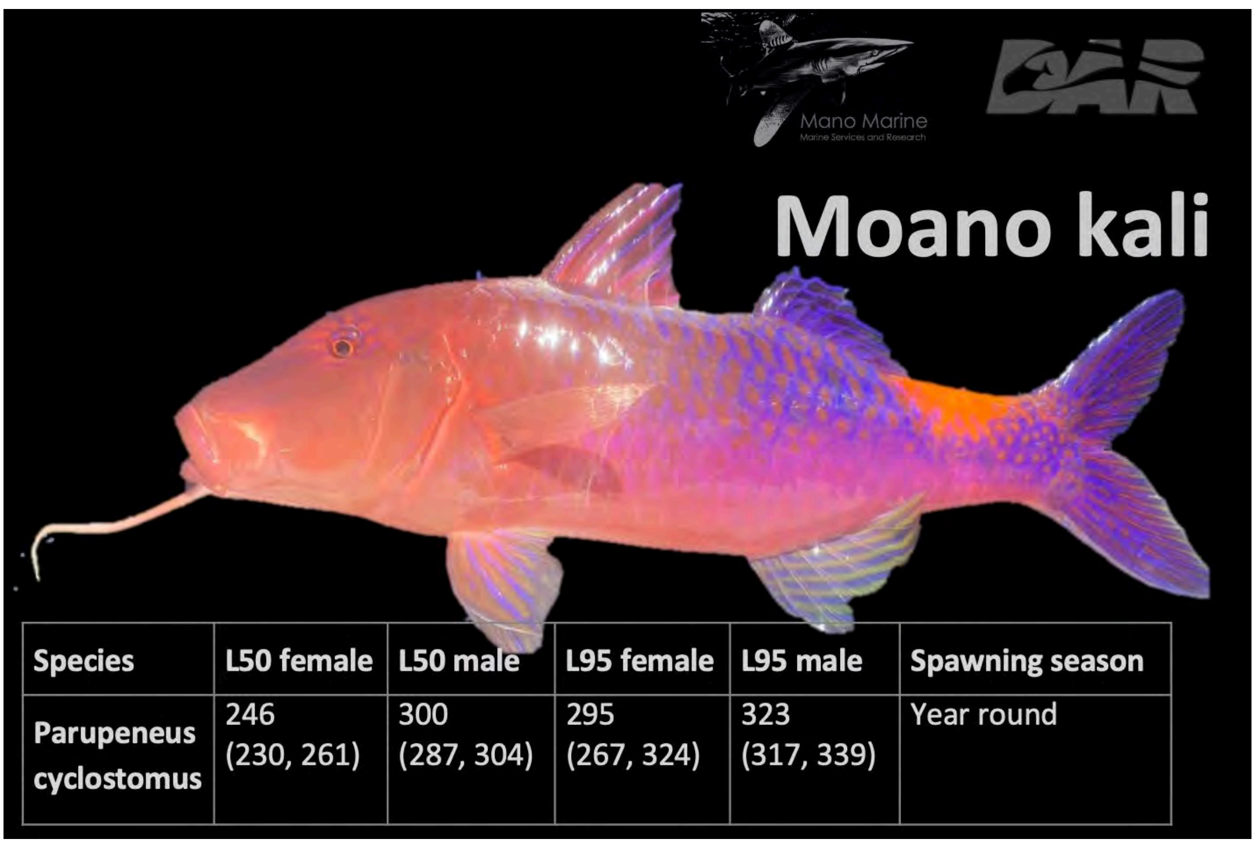
Mano Marine
Marine Services and Research
Moano kali

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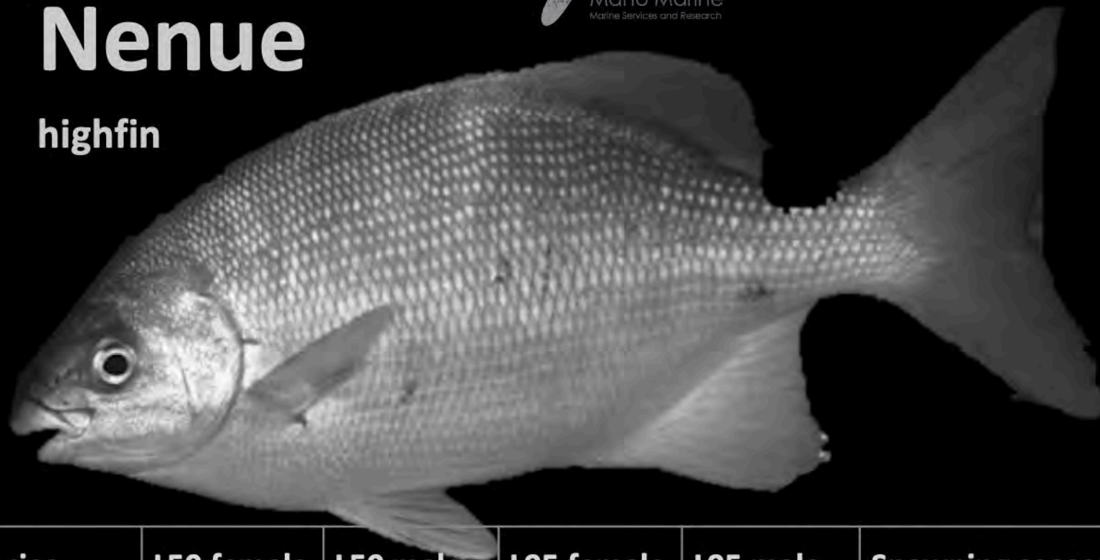
# Nenue

highfin



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| Species | L50 female | L50 male | L95 female | L95 male | Spawning season |
|---|---|---|---|---|---|
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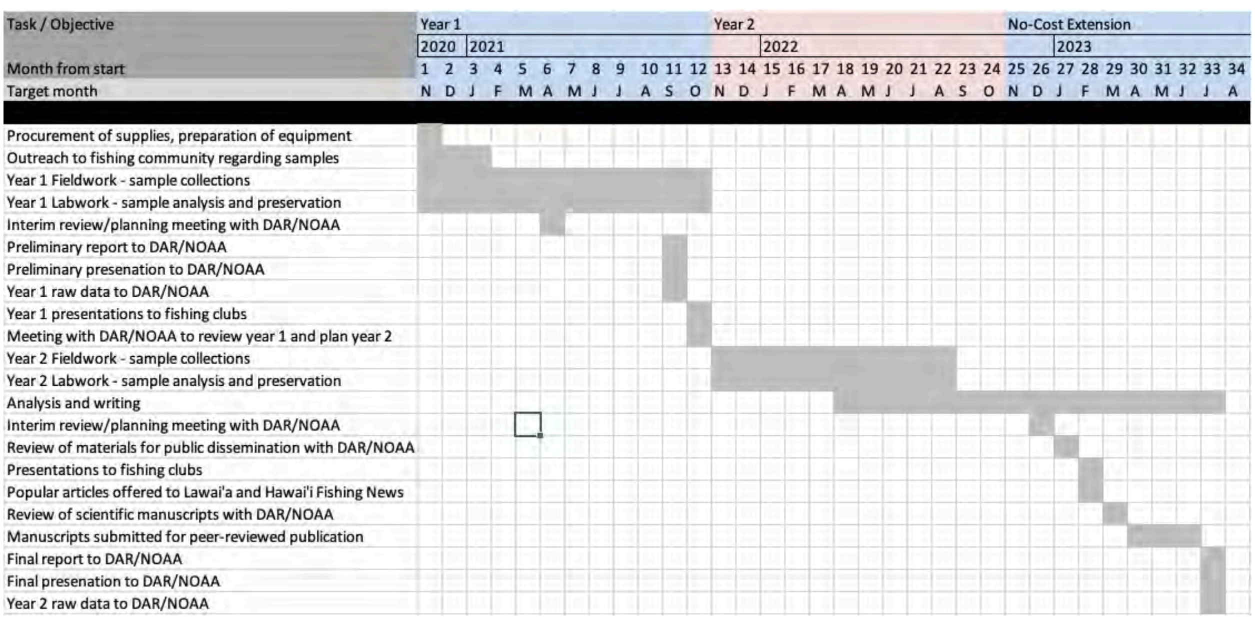
# 3 ACTIVITIES PLANNED



## 4 PROGRESS AND OUTCOMES

| Task / Objective | Status |
|---|---|
| Procurement of supplies, preparation of equipment | Complete |
| Outreach to fishing community regarding samples | Complete |
| Year 1 Fieldwork - sample collections | Complete |
| Year 1 Labwork - sample analysis and preservation | Complete |
| Interim review/planning meeting with DAR/NOAA | Complete |
| Preliminary report to DAR/NOAA | Complete |
| Preliminary presenation to DAR/NOAA | Complete |
| Year 1 raw data to DAR/NOAA | Given to DAR on USB storage drive. Archived on google drive, sharable with DAR/NOAA |
| Year 1 presentations to fishing clubs | We attended fishing tournaments and put up posters to share our work |
| Meeting with DAR/NOAA to review year 1 and plan year 2 | Complete |
| Year 2 Fieldwork - sample collections | Complete |
| Year 2 Labwork - sample analysis and preservation | Complete |
| Analysis and writing | Complete |
| Interim review/planning meeting with DAR/NOAA | Complete |
| Review of materials for public dissemination with DAR/NOAA | Pending responses from magazine publishers |
| Presentations to fishing clubs | We attended fishing tournaments and put up posters to share our work |
| Popular articles offered to Lawai'a and Hawai'i Fishing News | Lawai'a has agreed to publish an article. Articles also offered to Hawai'I Fishing News, Hawai'I Skin Diver, Hawaiian Airlines Magazine. |
| Review of scientific manuscripts with DAR/NOAA | Manuscripts in preparation |
| Manuscripts submitted for peer-reviewed publication | Manuscripts in preparation |
| Final report to DAR/NOAA | Final report submitted |
| Final presenation to DAR/NOAA | Final presentation conducted on 22 August 2023 |
| Year 2 raw data to DAR/NOAA | Given to DAR on USB storage drive. Archived on google drive, sharable with DAR/NOAA |

### 4.1 Management of small scale fisheries

Fisheries management in tropical/subtropical reef zones occurs in biodiverse systems where management budgets are spread across many species (Costello et al. 2012). Data-driven management of the style that occurs for large-volume temperate fisheries is not appropriate in such systems. Instead, management based on life history data can be used to set size limits, e.g., based on the L50 (Nadon et al., 2015). If life history data are lacking for a species, then science-based size limits cannot be established. Some of the highly targeted goatfish species are in this category and as such were selected for this research project.

In Hawai'i reef fishes are harvested in subsistence, recreational and commercial fisheries that use a variety of methods and gear types. Data on these fisheries is incomplete but has been estimated at 1.2 million kg/year (McCoy et al., 2018). Reef fishes are harvested using a variety of gear including monofilament gillnets, surround net, pole and line, and spear, including SCUBA spearing and night SCUBA spearing.

To ensure that a fishery remains sustainable and productive, fisheries managers can regulate the number, size, and time of year of harvest for fish populations. These decisions require knowing the fish's life cycle and developmental trends, as well as trends in the fishery and harvest. In a data-rich fishery, regulations are established by modeling the growth and changes in the population (Prince and Hordyk, 2019). These models use predictions of annual recruitment, the number of fish that will be added to the population in a year, as well as the size and structure of the population to adjust the regulations as needed. Data limited fisheries cannot used such models (Costello et al. 2012) and instead rely on knowledge life history, particularly seasonality and size at maturity data, to set two major types of regulations - fishing seasons and size limits. Size limits set a minimum or maximum allowable size for a catch (Hilborn et al., 2020). Minimum size limits ensure that fish are not harvested before they have reached maturity and contribute to the population, while maximum size limits are used to protect the most fecund females (Hixon et al., 2014). These limits may vary by sex and are generally driven by the fish species' reproductive strategy. Seasonal limits are generally used to protect a population during peak spawning periods, and managers can adjust the opening and closing date of a fishery to compensate for trends in the fishery (Sass et al., 2014).

Life history is the set of traits that govern growth and reproduction for a species based on their strategy for surviving in their habitat. Every species employs a different life history strategy to adapt to their environment and maximize their fitness. The variation in traits that influence life history is often described in terms of time functions - common traits include growth rate, time until maturity, and lifespan (Gaillard et al., 2016). These traits are highly variable in fish species; species with slow growth rates and long times until maturity are impacted more by commercial harvest, whereas those with rapid growth rates and short times until maturity can be fished more sustainably (Law, 2000). Understanding life history is therefore essential for management. For a fishery, crucial traits include the growth rate, reproductive output, and the time between hatching and reproductive maturity. This information is sufficient to set basic regulations and improve the health of a fish population. However, smaller fisheries may not have the resources needed to obtain this information for all species, especially as these life history traits can vary widely in tropical regions (Winemiller, 2005). This has led to a paucity of information for species in smaller tropical fisheries with high biodiversity and more complex reproductive schemes; the term data-poor fishery management is used to describe the basic elements of their fishery models.

## 4.2 Determination of maturity

To determine the size at maturity and the seasonality of an organism, researchers examine the reproductive characteristics of the population throughout the year. Size at maturity is usually described with the length at which 50 and 95 percent of fish are expected to be mature (L50 and L95). This is shown on a growth curve ogive, which describes the estimated proportion of mature fish at each length. Fish with greater length are more likely to be engaged in reproduction during their spawning period.

Fish currently engaged in reproduction will have enlarged gonads with larger, more developed reproductive tissues, leading to a higher ratio of gonad mass to somatic tissue mass. The gonadosomatic index, or GSI, is the preferred measure of reproductive investment. GSI is the percentage of gonad mass in relation to total mass in an individual. A high average GSI indicates a spawning period for a population, often linked to a date range or season, or other environmental factors, such as water temperature and the phase of the moon. While GSI is easily measured, and sometimes used as a metric of maturity, it is not always an accurate measure of maturity (Flores et al., 2019; Winemiller, 2005). High GSI is indicative of a mature fish, but low GSI is not indicative of an immature fish, especially when considering seasonality. A mature fish with a large enough body mass will have a smaller relative change in gonad mass, vs a smaller fish that will have greater fluctuations in GSI. The magnitude of changes in GSI are also dependent on sex and individual health. Since both body mass and gonad mass are highly variable, GSI-based methodologies have lower signal - noise-ratio, especially at the beginning and end of a spawning season. Managers may use GSI as a faster and cheaper method in fisheries, but this requires larger sample sizes due to the lower signal-to-noise ratio from GSI. Direct measurement of reproductive stages continues to be the gold standard for resource managers (Brown-Peterson et al., 2011).

Reproductive stages can be identified using a variety of techniques, either with microscopy or macroscopic analysis. Maturity can be assigned using macroscopic and microscopic morphological traits consistent with ontogenetic development. Depending on their sex and reproductive status, fish can have visibly different appearances, proportions, and reproductive or somatic organs, which researchers can use to assign maturity macroscopically. A juvenile fish can be visually distinct from a mature and reproducing fish based on the appearance of its gonads alone. In many species, researchers are able to assign maturity with visual cues during initial processing in the field or lab (Flores et al., 2019; Vitale et al., 2006). However, macroscopic maturity assessment is less effective than microscopic methods at assigning maturity, as it cannot identify specific spawning stages. Without specific information on oocyte stages, a developing fish may appear identical to a regenerating fish in an asynchronous spawning population. In addition, visual signs of maturity are species-specific and may require more training. As such, macroscopic assignment is usually less accurate than microscopic methods (Vitale et al., 2006).

Due to the difference in concentration, size, and opacity of egg stages, the undeveloped oocytes in an ovary are visually distinct from mature oocytes in a standard compound microscope. This allows for rapid, simple assessment of maturity without fixatives or stains, and is accurate enough to identify maturity stages in ovaries. Wet mount is a quick, inexpensive alternative to histology that provides detailed images of tissue structures such as eggs, simply by placing a small amount of tissue on a microscope slide and viewing it immediately (without chemical processing, slicing and other steps that are used for histology). While wet mounts are effective at assigning maturity and reproductive stage for females, they cannot assess prior history of spawning via post ovulatory follicles, and they cannot identify reproductive stages for testes. As a result, the most common method of assignment is histology (Brown-Peterson et al., 2011).

Histology is the most labor and resource-intensive method, but offers more depth of information than wet mounts or macroscopic assignment. Histologists can identify not only maturity and stage but also evidence of prior spawning and specialized tissue characteristics. This provides the most information per sample and maximizes both precision and accuracy (Brown-Peterson et al., 2011). Histology is generally selected for studies with adequate funding, whereas GSI is typically used for large sample sizes and studies without the resources to pay for histological processing. Wet mounts are less represented in the literature, but do provide a less resource intensive alternative for assigning maturity. Wet mount requires only a microscope, whereas histology requires specialized lab facilities and uses toxic chemicals. Wet mount can provide oocyte stage data for maturity assignment and other life history questions at very low cost.

### 4.3 Spawning season

Fish in temperate or arctic environments generally have well-described seasonal reproductive patterns, with annual changes in physiology and behavior at certain times of year. Due to the more consistent climate, tropical and subtropical fishes often use alternative reproductive schemes. Many species in tropical environments have partially or completely asynchronous spawning occurring with various degrees of seasonal specificity (Brown-Peterson et al., 2011). In a temperate species, a mature fish out of season will have undeveloped gonads and immature germ cells that resemble an immature fish. However, in a tropical species without synchronous spawning, reproduction can occur throughout the year, so a mature fish could be spawning capable or in non-capable stages during any particular month.

Life history analysis must determine the seasonal patterns for a species and account for seasonal differences during sampling, or else the data collected may be inaccurate. In the spawning season, the gonads of mature fish should be significantly larger and demonstrate clear differences in gonad morphology (Winemiller, 2005). Life history analysis must sample year round to determine if and when a species' spawning season occurs. In a temperate environment, life history analysis will usually find a consistent spawning season in a specific date range. That season can be used to set catch seasons and determine sampling dates. However, tropical species may or may not be seasonal.

### 4.4 Species studied

| **Latin** | **Hawaiian** | **Common** | **NOAA** |
|---|---|---|---|
| *Parupeneus insularis* | Munu | Doublebar goatfish | PAIN |
| *Parupeneus cyclostomus* | Moano kea, moano kali | Blue goatfish, Yellowsaddle goatfish | PACY |
| *Kyphosus vaigiensis* | Nenue, Enenue | Lowfin chub | KYVA |
| *Kyphosus cinerascens* | Nenue, Enenue | Highfin chub | KYCI |
| *Kyphosus hawaiiensis* | Nenue, Enenue | Hawaiian chub (endemic) | KYHA |
| *Kyphosus elegans* | Nenue, Enenue | Pacific chub | KYEL |
| *Kyphosus sectatrix* | Nenue, Enenue | Bermuda chub | KYSE |

The number of Kyphosids occuring in Hawai'i is generally considered to be four species (Kyphosus vaigiensis, Kyphosus cinerascens, Kyphosus hawaiiensis, Kyphosus elegans). K. cinerascens is easily identified by the square fins, while K. vaigiensis has distinct stripes and coloration. The other species are difficult to distinguish. During the course of the project we communicated with the authors of a taxonomic reorganization of the Kyphosidae , and they advised us that Kyphosus sectatrix also occurs here. We sought advice on species identification and were advised that it was necessary to x-ray each specimen to get accurate counts of skeletal structures. Since this was beyond the scope of this project we discussed the issue with DAR and agreed that Kyphosus hawaiiensis, Kyphosus elegans and Kyphosus sectatrix would be combined into a group. Since these species are difficult to distinguish, it is not possible to use separately regulations, and as such they will be managed as a single 'species'.

## 4.5 Parupeneus goatfishes

Goatfish are a diverse clade found around the world in tropical and subtropical reefs, and a significant subsistence and recreational fishery in the Hawaiian islands (Echreshavi et al., 2022). They are benthopelagic carnivores that forage on sand flats and corals using a specialized set of barbels to sense prey (Gosline, 1984). The Parupeneus genus is endemic to the Indo-Pacific and contains 27 species, including several unique to the reefs of Hawaiʻi. Several species of goatfish in Hawaiʻi are considered understudied, making regulation of the fishery challenging, since data is needed for each species.

Prior studies of the *Parupeneus* genus show the species are normally smaller and faster growing. Most species reach a maximum size in the 20 - 30 centimeter range, live for five or more years, reach maturity within a year of hatching, and do not show strong seasonal trends in reproduction (Reed and Taylor, 2020). These studies can be helpful for predicting traits in other species in the genus, but reef fish ontogenetics are extremely variable. The *Parupeneus* genus exhibits gonochoristic reproduction (two sexes determined during embryonic stages) with only one species known to exhibit hermaphroditism. Two species, *P. multifasciatus* and *P. porphyreus* are regulated statewide at 7 and 10 inches total length respectively, and a size limit has been set for all goatfish on the island of Maui at 8 inches total length (20 cm). *P. insularis* does not have an L50-based size limit due to the lack of life history data for the species.

The potential for sexual dimorphism was of interest since this may be important from a management perspective. If fishers target larger individuals, the catch may be skewed to one sex or another.

*Parupeneus insularis*, called the Two Saddle Goatfish or the Munu, is a small species of goatfish that occurs in the Eastern Central Pacific from Hawaii, French Polynesia, and Pitcairn Islands to the Marshall, Mariana, Phoenix, and Samoa islands (Randall and Myers, 2002). No life history analysis has been conducted for the species (Echreshavi et al., 2022), and no seasonal or size limits have been set at this time. It is generally dark red, with a white band on the tail, and found as deep as 80 meters. It reaches a maximum of around 30 cm and a maximum weight of around 1.4 kilograms (Randall and Myers, 2002).

*Parupeneus cyclostomus* is an Indo-Pacific species occurring from the Red Sea and east coast of Africa south to Durban, South Africa, east to the Hawaiian Islands, islands of French Polynesia and the Pitcairn Islands, north to the Ryukyu Islands and Ogasawara Islands, Japan south to Australia (Farrag et al., 2018).

## 4.6 Kyphosids (chubs, rudderfishes)

The Kyphosids are a tropical to temperate group of herbivorous fishes living in shallow waters, associated with rocky reefs or floating objects at sea (Knudsen and Clements, 2016). Due to high morphological similarity between species the taxonomy of the group has only recently been established (Knudsen and Clements, 2013). Kyphosids may represent a significant portion of the total fish biomass in some area and are major consumers of macroalgae (Knudsen and Clements, 2016), so they are of interest in the management of coral-algal competition and benthic/ecosystem health. A study in Japan found that spawning season extends from June to October for Kyphosus bigibbus, and that L50 was 284 mm for males and 360 mm for females (Yamaguchi et al., 2011).

# 5 METHODS

## 5.1 Sample collection

Sampling for fish biology projects frequently occurs by visiting fish markets and purchasing the species of interest. However, this method frequently results in strong size bias since very small individuals often do not occur in fish markets. Furthermore, for species that are rarely captured and sold, fish markets may yield a very small sample size. Therefore we elected to collect samples via spearfishing (Figure 2). Fish were collected between 2020 and 2023 from a number of reef sites around O‘ahu, Hawai‘i. Although the majority of fishing was done via freediving, some samples were collected using SCUBA or closed-circuit rebreather to increase the efficiency and depth of sampling. Local fishermen allowed us to sample gonads from the fish they caught.

Figure 1. P. insularis sampled on 11 January 2021

## 5.2 Sampling and measurement

Total length (TL) and fork length (FL) were measured to the nearest millimeter, the total mass was recorded to the nearest gram, and specimens were photographed. Length will refer to fork length unless otherwise noted. The gonads were removed and weighed to the nearest milligram, photographed and a cross sectional sample taken for histology. For future analysis, various samples were collected but not analyzed: The sagittal otoliths for estimating age, a pectoral fin clip for genetic / genomic analysis, and the digestive tract for diet. Gonadosomatic index (GSI) was calculated as

$(\frac{Gonad\ Mass}{Total\ Mass} * 100)$.

## 5.3 Macroscopic maturity assignment

Maturity was estimated using macroscopic characteristics of the fish and gonads. General assignment of maturity was performed according to the ICES Report on the Workshop on Sexual Maturity Sampling (ICES, 2007).

Oocytes were usually visible inside a mature gonad beyond the early developing stage. If gonads were small, difficult to locate, dense and rubbery, or dark red, they were considered reproductively immature. When ovaries in this state were located and wet mounted or examined histologically, these fish only had primary growth oocytes. These gonads could be described as "threadlike" or "stringy", and could have a very small cross-section diameter. Smaller fish with particularly small gonads were considered immature, while larger fish with larger inactive gonads were considered mature but inactive.

Goatfish testes have a triangular cross-section, while female ovaries have a circular or oval cross-section. Mature ovaries generally have an opaque yellowish color with a distinct texture and are always larger than immature gonads. However, a mature fish not currently spawning could have gonads similar to an immature fish. A fish was classified as mature macroscopically if the gonads were enlarged, visibly similar to other mature gonads, or if eggs or semen were visible during processing.

In the event that a very small fish did not have gonads, it was classified as immature.

## 5.4 Wet mount assignment of reproductive stage

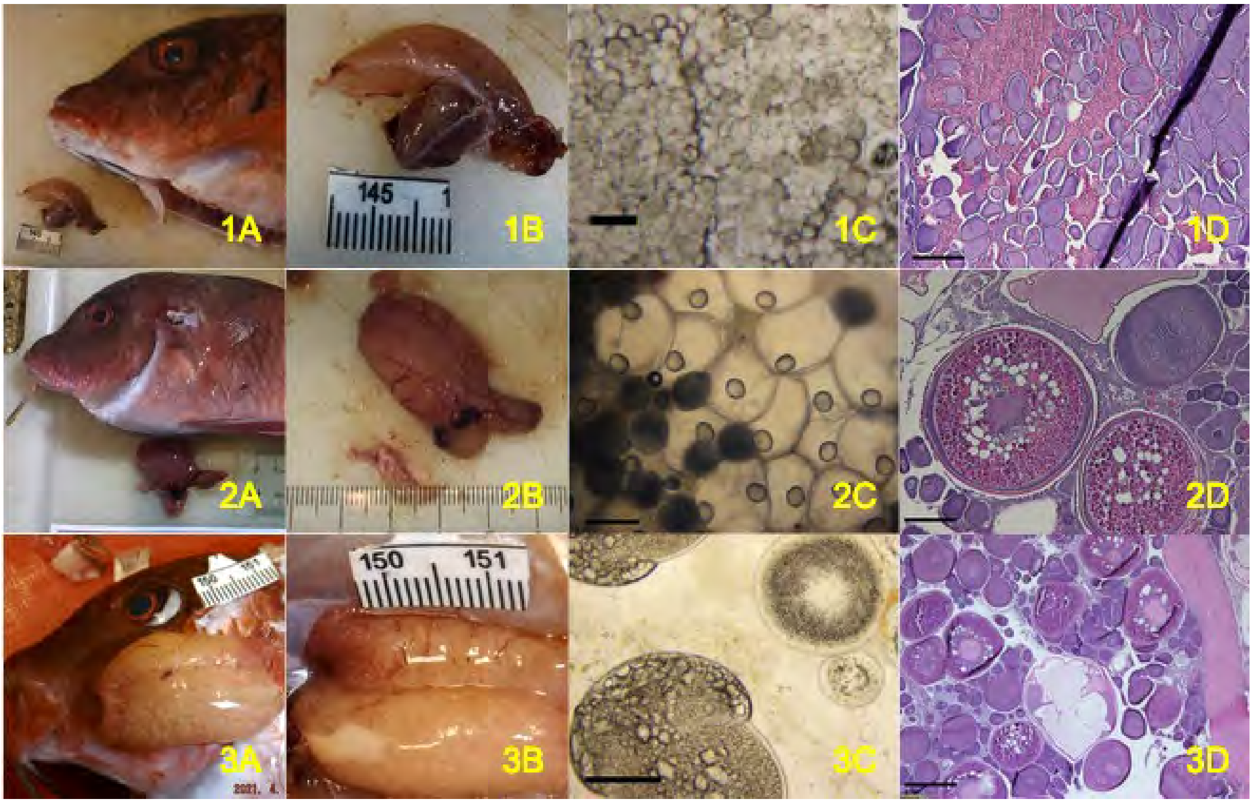
Wet mount slides were prepared by removing a small section of eggs from the center of an ovary with a scalpel and placing it onto a microscope slide, diluted with saline, and covered with a cover slip. Photographs of wet mounts were taken using a Canon camera mounted onto a Meiji compound microscope at 4X and 10x magnifications.

Wet mount slides were prepared and reviewed without reviewing assigned macroscopic maturity. Slides or images of slides were assigned maturity using a modified version of the Brown - Peterson series (Brown-Peterson et al., 2011). The presence or absence of large hydrated eggs, the size of the eggs, and the opacity of the eggs were all used as visual cues for the stage of oogenesis. Primary growth eggs would be dense, clear, and extremely small in a wet mount slide, whereas vitellogenic stage eggs appear larger and grainy. Since wet mount views the entire sphere of the egg, the granulation of vitellogenic eggs blocks most of the transmitted light, causing them to appear dark. Fully hydrated eggs were clear, round, and had distinct oil-drop yolks.

Without stains or fixative, wet mounts could not reliably identify atresia, post-ovulatory follicles, cortical alveolar eggs, or tissue structures. In addition, hydrated or late stage vitellogenic eggs could lyse during the mounting process due to mechanical damage by the scalpel or the application of the cover slip; However, the wet mount method could reliably differentiate between primary growth, different vitellogenic stage eggs, and hydrated eggs, which was sufficient to assign maturity. Although post-ovulatory follicles and hydrated eggs can be confused during wet mount analysis, both provide evidence of maturity. Slides were not preserved or fixed, but images were taken of all wet mount slides, and verified between different researchers. Although the macroscopic and microscopic analysis was conducted separately, comparisons of immature and mature fish using both microscopic and macroscopic images were used to train researchers.

### 5.5 Histology

While histological analysis was not included in the DAR project, we obtained additional funding and included this analysis in the project. Cross sectional gonad samples were placed in histology cassettes and fixed in 10% neutral buffered formalin. Gonads were mounted and stained using H&E stain by the Histology Core at the John A. Burns School of Medicine, University of Hawai‘i (NIH U54MD007601). Histology slides were analyzed and staged at the Virginia Institute of Marine Science using the protocols described by Brown-Peterson et al (2011) and a staging guide developed for this project.




Reproductive stages of P. insularis. Examples of macroscopic ovary images, wet mounts, and histology images for assigning maturity. All samples are *P. insularis*, scale bars represent 100 microns. Each row is a single individual fish. Column A shows the fish with whole gonad, column B shows the whole gonad for macroscopic assignment, column C shows wet mount microscope image, and column D shows histology image. Row 1 is an immature fish of 224 mm fork length and 229 grams, with a GSI of 0.55. Row 2 is a mature fish of 241 mm fork length, 344 grams, with a GSI of 1.44. Row 3 is a mature fish of 196 mm fork length, 179 grams, with a GSI of 1.96. Columns A and B show macroscopic staging information. 1A and 1B shows small red gonads are visibly underdeveloped, with no eggs visible inside. 2A and 2B shows gonads with more visible texture - the pebbly or cloudy texture inside indicates eggs. 3A and 3B, the yellow color, engorged size, pillowy shape, and cloudy opacity indicate hydrated eggs. Column C shows wet mount slide images: 1C shows tiny eggs that are densely packed, while 2C shows large eggs with visible yolks, and 3C shows several large, dense eggs with oil droplets forming. These are are tertiary stage vitellogenic eggs. Column D shows histology for the same gonads. 1D is densely packed with small eggs, these are cortical alveolar or primary growth eggs, indicative of an immature fish. 2D shows two large vitellogenic eggs, which are late-stage eggs preparing to hydrate and be released. 3D shows a mixture of late-stage eggs at various stages of development. Organisms with patterns similar to 2 or 3 in columns B, C, and D are clearly mature; however, while 3A is visibly mature, 2A is not.

Slides were selected randomly and assessed without knowing the size of the fish or prior estimations of maturity; this helped blind the observer to potential bias but was not a fully blinded process. Mature fish were fish for which there were multiple vitellogenic or higher-stage eggs or histological evidence of prior reproduction (i.e., Stage 2 of the Brown - Peterson scale).

The size at maturity was calculated using the L50, the proportion of mature fish for a given size class. L50 and L95 analysis was performed using the Aquatic Life History package (version 1.0.4) by Jonathan Smart (Smart et al, 2016). This uses a GLM to predict the likelihood of a fish being mature at a given size using histology and wet mount data and graphed against fork length in a logistic regression. Similar calculations were performed to establish a mass at 50% maturity. The maturity of the fish was established using macroscopic and microscopic staging. When available, histology was used to assign maturity, and otherwise, wet mounts were used. If no microscopic assignment was available, maturity was assessed using macroscopic and GSI methods. Stages were used to assign mature or immature based on stage 2 in the Brown-Peterson Scale (Brown-Peterson et al., 2011).

Wet mount and GSI / macroscopic maturity assignment methods were compared to histology to assess the effectiveness of different methods. All statistical analysis was conducted in R (version 1.3.959).

### 5.6 Spawning season

Analysis of seasonality, the annual timing of reproduction in the population, was performed using GSI, the ratio of gonad mass to total mass for an individual versus month.

## 6 RESULTS

The sample dataset was as follows:

| Total Collections | Abbreviation | Female | Male | Unknown | Total |
|---|---|---|---|---|---|
| Parupeneus cyclostomus | PACY | 43 | 65 | 7 | 115 |
| Parupeneus insularis | PAIN | 117 | 128 | 9 | 254 |
| Kyphosids pooled | KYSP | 88 | 162 | 6 | 256 |
| Kyphosus vaigiensis | KYVA | 46 | 50 | 4 | 100 |
| Kyphosus cinerascens | KYCI | 33 | 44 | 3 | 80 |
| | | | | | 805 |
| | | | | | |
| | | | | | |
| Kyphosus hawaiiensis | KYHA | 41 | 80 | 3 | 124 |
| Kyphosus elegans | KYEL | 6 | 4 | 0 | 10 |
| Kyphosus sectatrix | KYSE | 37 | 70 | 2 | 109 |
| | KYSP | 4 | 8 | 1 | 13 |
| | | 88 | 162 | 6 | 256 |

### 6.1 Performance of wet mount vs histology

Histology slides were assessed for 51 female *P. insularis* samples and a wet mount maturity assessment was conducted for 117 female or indeterminate samples. Of the female samples analyzed using the wet mount method, 56 were immature, and 70 were immature. Of the 51 ovary cross-sections were analyzed histologically, 30 specimens were mature and 21 were immature. Histology is considered the most reliable method for maturity assignment, and there was 100% agreement between histology and wet mount methods.

Agreement between histology and wet mount methods for maturity assignment. Left column is the 'true' condition determined by histology. Middle and right columns show number of instances in which wet mount made correct or wrong assignments.

| Histology Stage | Immature (Wet Mount) | Mature (Wet Mount) |
| --- | --- | --- |
| 1 or 2 (Immature) | 39 (correct) | 0 (wrong) |
| 3, 4, or 5 (Mature) | 0 (wrong) | 55 (correct) |

## 6.2 Munu, Doublebar Goatfish, Parupeneus insularis

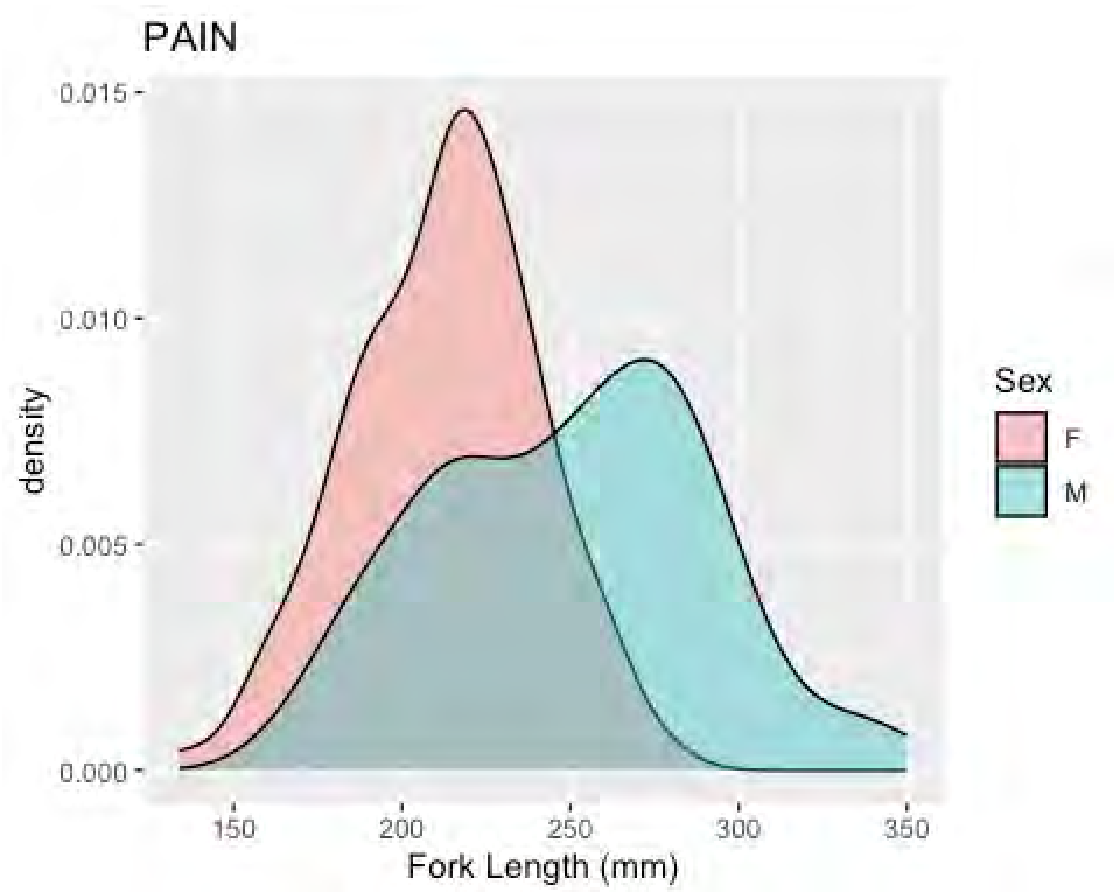
P. insularis photographed in waters off the fire station at Pupukea, O'ahu. Photo: K Weng.

The *P. insularis* sample pool used 235 samples collected between November 2020 and March 2023. Of these fish, 118 were identified macroscopically as males (50.8%, Figure 4) and 117 as females (49.2%, Figure 5), nine fish at the smallest end of the size range were indeterminate as gonads could not be recovered. These fish were too small to be reproductively mature, and are included as immature for analysis.


Figure 2. A male P. insularis, PAIN20230305_01. Upper pane shows forehead bump and mostly black barbels characteristic of males. Lower right shows testes in anatomical position within the body cavity. Lower right shows a wet mount microscope image of a small piece of testis tissue, in which the elongate structure of spermatophores can be seen. For smaller individuals, it was not possible to assign sex macroscopically, but wet mount microscopic inspection could clearly distinguish male and female gonads tissue.


Figure 3. A female P. insularis, PAIN20220806_03. Upper pane shows smooth forehead characteristic of females. Lower left shows ovaries in anatomical position within body cavity. Lower right shows wet mount image containing larger vitellogenic eggs nearing hydration along with smaller early vitellogenic and primary oocytes.

The size distribution for females and males was as follows:




### 6.2.1 PAIN Females

In the table below, Length = Fork Length, Total = Total Length. Maturity was assigned based on oocyte stages (microscopic assignment) and appearance of ovaries (macroscopic assignment). 1 = mature, 0 = immature. Scatterplots are shown for the change in GSI with length, and the change in GSI with season of year.

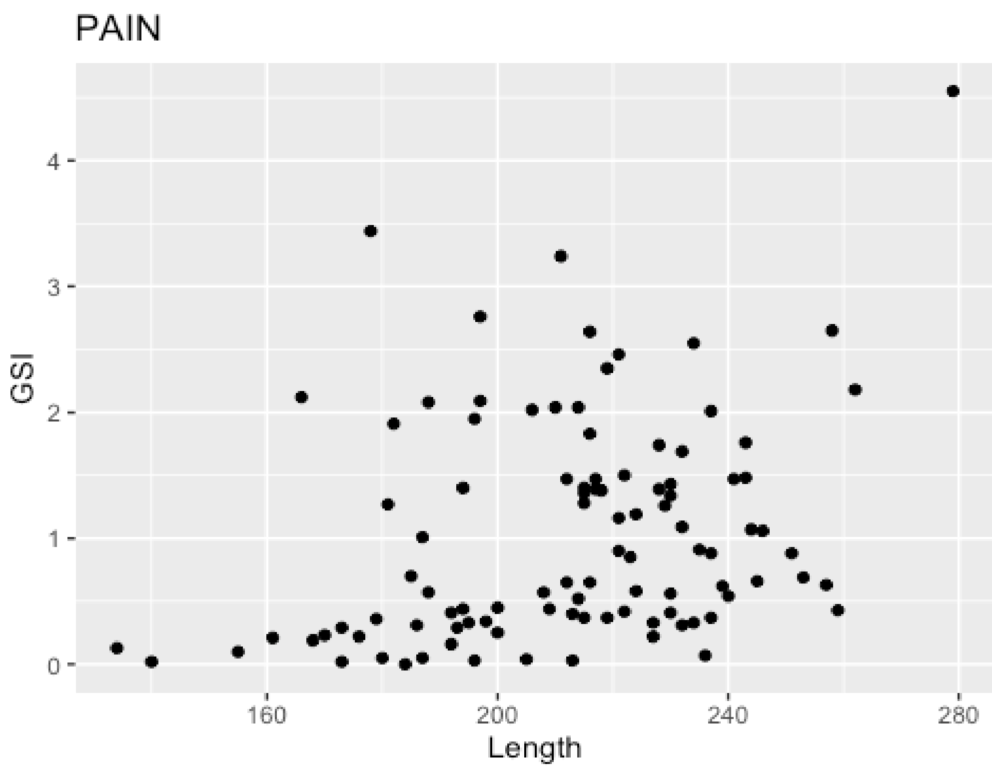
| | Month | Location | Species | Length | Total | Sex | Mass | GonadMass | GSI | Maturity |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 8 | Rabbit Island | PAIN | 134 | 155.0000 | F | 53 | 0.0680 | 0.1300 | 0 |
| 2 | 9 | Makapuu | PAIN | 155 | 176.0000 | F | 81 | 0.0780 | 0.1000 | 0 |
| 5 | 4 | Waikiki | PAIN | 161 | 194.0000 | F | 125 | 0.2630 | 0.2100 | 0 |
| 7 | 5 | Moku Manu | PAIN | 166 | 183.0000 | F | 100 | 2.1150 | 2.1200 | 1 |
| 8 | 2 | Alan Davis | PAIN | 168 | 194.0000 | F | 101 | 0.1960 | 0.1900 | 0 |
| 9 | 5 | Mokuleia | PAIN | 170 | 194.0000 | F | 120 | 0.2740 | 0.2300 | 0 |
| 10 | 2 | Alan Davis | PAIN | 173 | 200.0000 | F | 115 | 0.3370 | 0.2900 | 0 |
| 11 | 3 | Rabbit | PAIN | 176 | 203.0000 | F | 122 | 0.2660 | 0.2200 | 0 |
| 12 | 6 | Moku Manu | PAIN | 178 | 229.0000 | F | 182 | 6.2580 | 3.4400 | 1 |
| 13 | 3 | Rabbit | PAIN | 179 | 206.0000 | F | 125 | 0.4540 | 0.3600 | 0 |

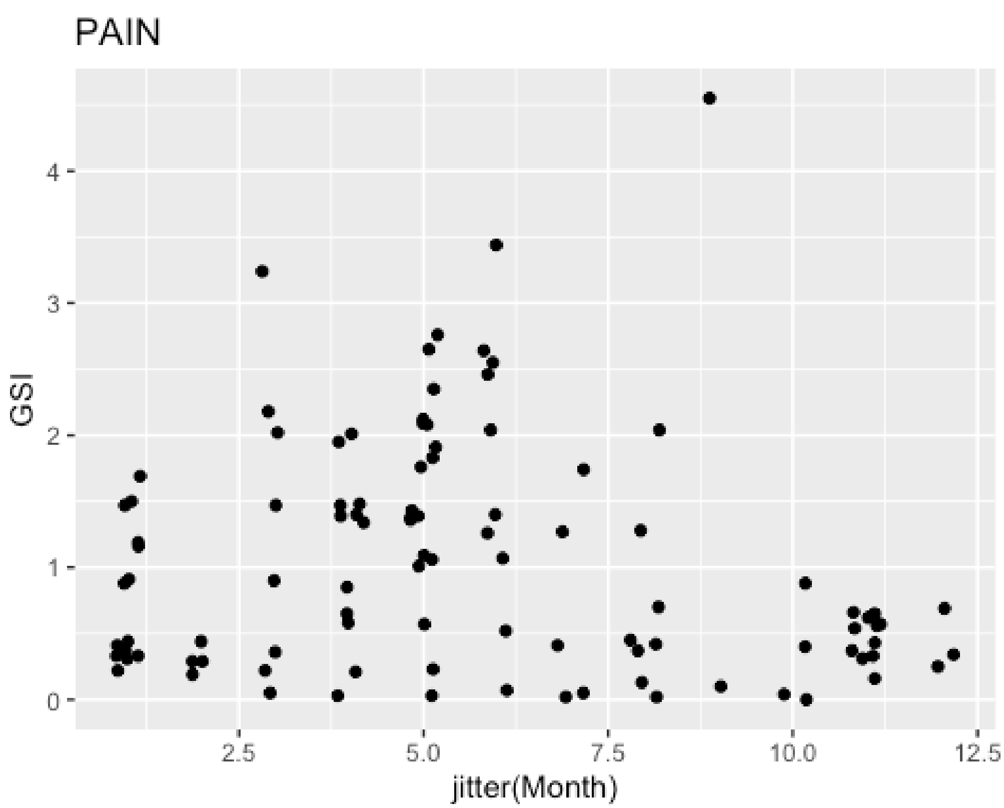
| | Month | Location | Species | Length | Total | Sex | Mass | GonadMass | GSI | Maturity |
|---|---|---|---|---|---|---|---|---|---|---|
| 14 | 7 | K Bay | PAIN | 180 | 211.0000 | F | 128 | 0.0650 | 0.0500 | 0 |
| 15 | 7 | Market | PAIN | 181 | 210.0000 | F | 145 | 1.8460 | 1.2700 | 1 |
| 17 | 5 | Moku Manu | PAIN | 182 | 217.0000 | F | 161 | 3.0730 | 1.9100 | 1 |
| 19 | 8 | Moku Manu | PAIN | 185 | 214.0000 | F | 172 | 1.2110 | 0.7000 | 1 |
| 20 | 11 | LANAI LOOKOUT | PAIN | 186 | 227.0000 | F | 171 | 0.5380 | 0.3100 | 1 |
| 21 | 3 | Rabbit Island | PAIN | 187 | 219.0000 | F | 187 | 0.1020 | 0.0500 | 0 |
| 22 | 5 | Moku Manu | PAIN | 187 | 216.0000 | F | 164 | 1.6610 | 1.0100 | 1 |
| 23 | 5 | Moku Manu | PAIN | 188 | 219.0000 | F | 151 | 0.8540 | 0.5700 | 0 |
| 24 | 5 | Moku Manu | PAIN | 188 | 218.0000 | F | 164 | 3.4170 | 2.0800 | 1 |
| 26 | 11 | BARBERS | PAIN | 192 | 220.0000 | F | 155 | 0.2500 | 0.1600 | 0 |
| 28 | 7 | Kaena W | PAIN | 192 | 222.0000 | F | 164 | 0.6790 | 0.4100 | 1 |
| 29 | 2 | Alan Davis | PAIN | 193 | 222.0000 | F | 172 | 0.4970 | 0.2900 | 1 |
| 30 | 2 | Alan Davis | PAIN | 194 | 221.0000 | F | 159 | 0.7030 | 0.4400 | 1 |
| 31 | 4 | Waikiki | PAIN | 194 | 223.0000 | F | 157 | 2.1980 | 1.4000 | 1 |
| 32 | 1 | Hanauma Point S | PAIN | 195 | 220.0000 | F | 154 | 0.5020 | 0.3300 | 1 |
| 33 | 5 | Moku Manu | PAIN | 196 | 225.0000 | F | 181 | 0.0510 | 0.0300 | 0 |
| 34 | 4 | Rabbit | PAIN | 196 | 229.0000 | F | 179 | 3.4890 | 1.9500 | 1 |
| 35 | 5 | Makapuu | PAIN | 197 | 231.0000 | F | 205 | 5.6640 | 2.7600 | 1 |
| 36 | 5 | Moku Manu | PAIN | 197 | 230.0000 | F | 191 | 4.0000 | 2.0900 | 1 |
| 37 | 12 | Kahala Barge | PAIN | 198 | 228.3614 | F | 167 | 0.5750 | 0.3400 | 0 |
| 38 | 12 | Outside K-Bay | PAIN | 200 | 230.6418 | F | 171 | 0.4220 | 0.2500 | 0 |
| 39 | 8 | Moku Manu | PAIN | 200 | 231.0000 | F | 192 | 0.8670 | 0.4500 | 1 |
| 43 | 10 | Moku Manu | PAIN | 205 | 234.0000 | F | 145 | 0.0550 | 0.0400 | 0 |
| 44 | 3 | Rabbit Island | PAIN | 206 | 233.0000 | F | 235 | 4.7530 | 2.0200 | 1 |
| 46 | 11 | LANAI LOOKOUT | PAIN | 208 | 245.0000 | F | 243 | 1.3890 | 0.5700 | 1 |
| 47 | 1 | Alan Davis | PAIN | 209 | 239.0000 | F | 220 | 0.9620 | 0.4400 | 0 |
| 48 | 6 | Moku Manu | PAIN | 210 | 239.0000 | F | 206 | 4.1960 | 2.0400 | 1 |

| | Month | Location | Species | Length | Total | Sex | Mass | GonadMass | GSI | Maturity |
|---|---|---|---|---|---|---|---|---|---|---|
| 49 | 3 | Rabbit Island | PAIN | 211 | 242.0000 | F | 234 | 7.5820 | 3.2400 | 1 |
| 50 | 3 | Rabbit | PAIN | 212 | 249.0000 | F | 241 | 3.5520 | 1.4700 | 1 |
| 51 | 11 | LANAI LOOKOUT | PAIN | 212 | 242.0000 | F | 209 | 1.3650 | 0.6500 | 1 |
| 53 | 4 | Waikiki | PAIN | 213 | 245.0000 | F | 221 | 0.0650 | 0.0300 | 0 |
| 54 | 10 | Moku Manu | PAIN | 213 | 244.0000 | F | 214 | 0.8580 | 0.4000 | 1 |
| 55 | 6 | Moku Manu | PAIN | 214 | 247.0000 | F | 212 | 1.0920 | 0.5200 | 0 |
| 56 | 8 | Moku Manu | PAIN | 214 | 247.0000 | F | 252 | 5.1390 | 2.0400 | 1 |
| 57 | 8 | Moku Manu | PAIN | 215 | 247.0000 | F | 204 | 0.7450 | 0.3700 | 1 |
| 58 | 8 | Rabbit Island | PAIN | 215 | 246.0000 | F | 233 | 2.9790 | 1.2800 | 1 |
| 59 | 5 | Moku Manu | PAIN | 215 | 247.0000 | F | 218 | 2.9710 | 1.3600 | 1 |
| 60 | 6 | Moku Manu | PAIN | 215 | 243.0000 | F | 217 | 3.0320 | 1.4000 | 1 |
| 62 | 4 | Moku Manu | PAIN | 216 | 247.0000 | F | 237 | 1.5320 | 0.6500 | 1 |
| 63 | 5 | Moku Manu | PAIN | 216 | 248.0000 | F | 204 | 3.7400 | 1.8300 | 1 |
| 64 | 6 | Moku Manu | PAIN | 216 | 243.0000 | F | 240 | 6.3240 | 2.6400 | 1 |
| 65 | 4 | Waikiki | PAIN | 217 | 249.0000 | F | 235 | 3.4470 | 1.4700 | 1 |
| 66 | 4 | Lanai Lookout | PAIN | 217 | 248.0000 | F | 228 | 3.1580 | 1.3900 | 1 |
| 67 | 5 | Moku Manu | PAIN | 218 | 245.0000 | F | 215 | 2.9750 | 1.3800 | 1 |
| 68 | 1 | Hanauma Point S | PAIN | 219 | 252.0000 | F | 222 | 0.8250 | 0.3700 | 0 |
| 69 | 5 | Mokuleia | PAIN | 219 | 250.0000 | F | 264 | 6.1940 | 2.3500 | 1 |
| 70 | 1 | Waimanalo | PAIN | 221 | 257.0000 | F | 274 | 3.1770 | 1.1600 | 1 |
| 71 | 3 | Moku Manu | PAIN | 221 | 252.0000 | F | 247 | 2.2220 | 0.9000 | 1 |
| 72 | 6 | Moku Manu | PAIN | 221 | 260.0000 | F | 275 | 6.7580 | 2.4600 | 1 |
| 74 | 1 | Moku Manu | PAIN | 222 | 252.0000 | F | 264 | 3.9650 | 1.5000 | 1 |
| 75 | 8 | North Shore | PAIN | 222 | 259.0000 | F | 292 | 1.2220 | 0.4200 | 1 |
| 76 | 4 | Rabbit | PAIN | 223 | 256.0000 | F | 269 | 2.2930 | 0.8500 | 1 |
| 77 | 1 | Waimanalo | PAIN | 224 | 256.0000 | F | 254 | 3.0220 | 1.1900 | 1 |

| | Month | Location | Species | Length | Total | Sex | Mass | GonadMass | GSI | Maturity |
|---|---|---|---|---|---|---|---|---|---|---|
| 78 | 4 | Lanai Lookout | PAIN | 224 | 255.0000 | F | 229 | 1.3250 | 0.5800 | 1 |
| 79 | 1 | Hanauma Point S | PAIN | 227 | 258.0000 | F | 243 | 0.5420 | 0.2200 | 0 |
| 80 | 11 | MOKU MANU | PAIN | 227 | 261.0000 | F | 284 | 0.9250 | 0.3300 | 1 |
| 81 | 7 | Market | PAIN | 228 | 267.0000 | F | 299 | 5.1940 | 1.7400 | 1 |
| 82 | 5 | Moku Manu | PAIN | 228 | 258.0000 | F | 262 | 3.6370 | 1.3900 | 1 |
| 83 | 6 | Moku Manu | PAIN | 229 | 262.0000 | F | 257 | 3.2320 | 1.2600 | 1 |
| 84 | 1 | Hanauma Point S | PAIN | 230 | 265.0000 | F | 283 | 1.1740 | 0.4100 | 0 |
| 85 | 4 | Lanai Lookout | PAIN | 230 | 272.0000 | F | 295 | 3.9460 | 1.3400 | 1 |
| 86 | 11 | LANAI LOOKOUT | PAIN | 230 | 264.0000 | F | 267 | 1.4990 | 0.5600 | 1 |
| 88 | 5 | Moku Manu | PAIN | 230 | 260.0000 | F | 271 | 3.8800 | 1.4300 | 1 |
| 89 | 1 | Waimanalo | PAIN | 232 | 270.0000 | F | 326 | 5.5090 | 1.6900 | 1 |
| 90 | 1 | Makapuu Wall | PAIN | 232 | 269.0000 | F | 266 | 0.8120 | 0.3100 | 1 |
| 91 | 5 | Moku Manu | PAIN | 232 | 267.0000 | F | 297 | 3.2450 | 1.0900 | 1 |
| 92 | 1 | Hanauma Point S | PAIN | 234 | 268.0000 | F | 301 | 0.9890 | 0.3300 | 0 |
| 93 | 6 | Kaaawa | PAIN | 234 | 267.0000 | F | 288 | 7.3570 | 2.5500 | 1 |
| 94 | 1 | Waimanalo | PAIN | 235 | 265.0000 | F | 300 | 2.7440 | 0.9100 | 1 |
| 95 | 1 | Waimanalo | PAIN | 237 | 270.0000 | F | 323 | 2.8470 | 0.8800 | 1 |
| 96 | 4 | Lanai Lookout | PAIN | 237 | 270.0000 | F | 285 | 5.7410 | 2.0100 | 1 |
| 97 | 11 | LANAI LOOKOUT | PAIN | 237 | 271.0000 | F | 284 | 1.0480 | 0.3700 | 1 |
| 98 | 11 | BARBERS | PAIN | 239 | 274.0000 | F | 314 | 1.9510 | 0.6200 | 1 |
| 99 | 11 | Reef Runway | PAIN | 240 | 276.2498 | F | 308 | 1.6610 | 0.5400 | 1 |
| 100 | 1 | Waimanalo | PAIN | 241 | 280.0000 | F | 344 | 5.0480 | 1.4700 | 1 |
| 101 | 4 | Lanai Lookout | PAIN | 243 | 282.0000 | F | 302 | 4.4670 | 1.4800 | 1 |
| 102 | 5 | Turtle Bay | PAIN | 243 | 280.0000 | F | 348 | 6.1340 | 1.7600 | 1 |
| 104 | 6 | Kaaawa | PAIN | 244 | 275.0000 | F | 318 | 3.4100 | 1.0700 | 1 |
| 105 | 11 | Reef Runway | PAIN | 245 | 281.9508 | F | 302 | 1.9910 | 0.6600 | 1 |
| 106 | 5 | Moku Manu | PAIN | 246 | 279.0000 | F | 313 | 3.3140 | 1.0600 | 1 |

| | Month | Location | Species | Length | Total | Sex | Mass | GonadMass | GSI | Maturity |
|---|---|---|---|---|---|---|---|---|---|---|
| 108 | 10 | Rabbit | PAIN | 251 | 283.0000 | F | 344 | 3.0310 | 0.8800 | 1 |
| 109 | 12 | Moku Manu | PAIN | 253 | 305.0000 | F | 463 | 3.1920 | 0.6900 | 1 |
| 110 | 11 | MOLOKAI | PAIN | 257 | 296.0000 | F | 408 | 2.5810 | 0.6300 | 1 |
| 111 | 5 | Kahala | PAIN | 258 | 295.0000 | F | 414 | 10.9590 | 2.6500 | 1 |
| 113 | 11 | MOKU MANU | PAIN | 259 | 291.0000 | F | 394 | 1.6880 | 0.4300 | 1 |
| 114 | 3 | Hauula | PAIN | 262 | 296.0000 | F | 360 | 7.8390 | 2.1800 | 1 |
| 117 | 9 | Kaaawa | PAIN | 279 | 315.0000 | F | 550 | 25.0000 | 4.5500 | 1 |
| 118 | 8 | Rabbit Island | PAIN | 140 | 162.0000 | U | 57 | 0.0140 | 0.0200 | 0 |
| 121 | 7 | Rabbit Island | PAIN | 173 | 201.0000 | U | 124 | 0.0230 | 0.0200 | 0 |
| 124 | 10 | Moku Manu | PAIN | 184 | 212.0000 | U | 149 | 0.0001 | 0.0001 | 0 |
| 126 | 6 | Kaaawa | PAIN | 236 | 268.0000 | U | 340 | 0.2270 | 0.0700 | 0 |

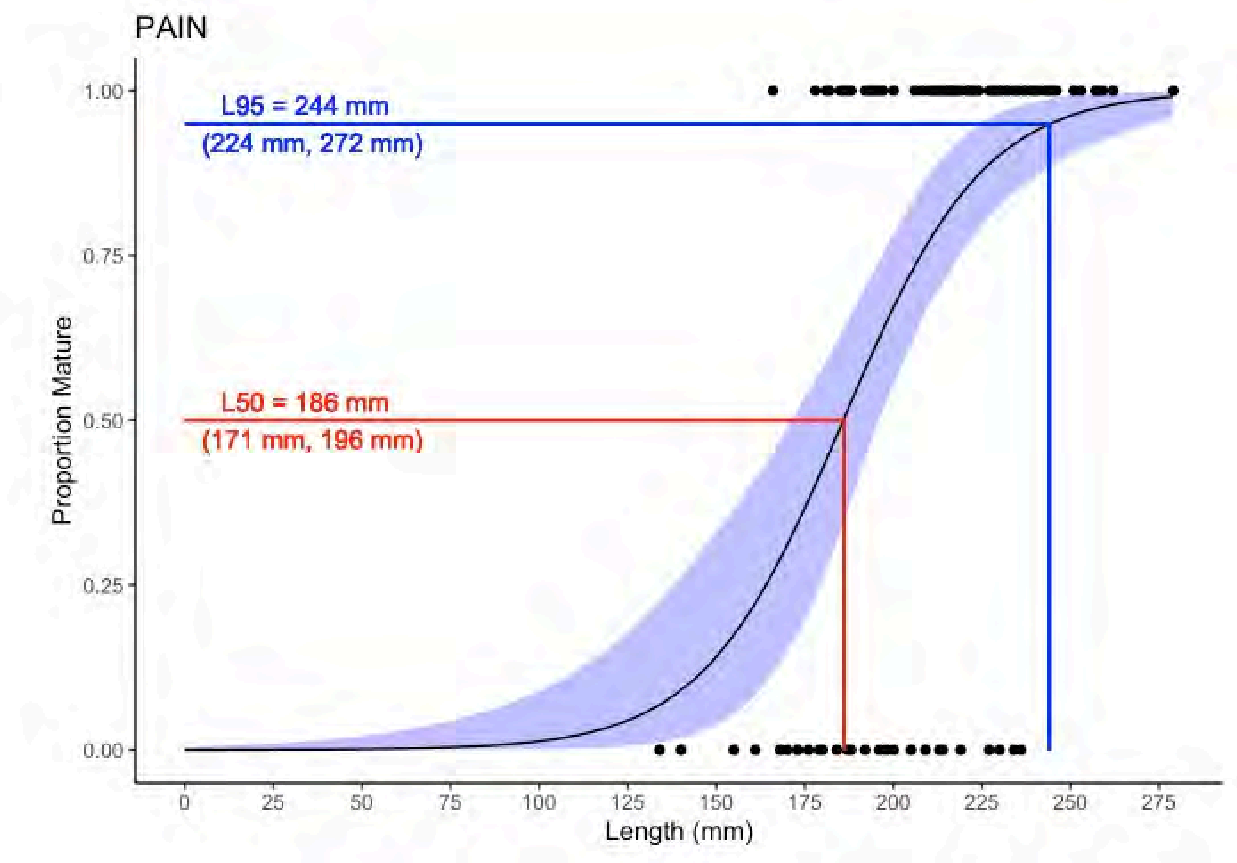

PAIN
GSI
0
1
2
3
4
160
200
240
280
Length


PAIN
GSI
0
1
2
3
4
2.5
5.0
7.5
10.0
12.5
jitter(Month)

Once the maturity assignment is made for each individual, a logistic function is used to estimate size at maturity. The dataset is run through a general linear model with binomial error structure, using Length as the explanatory variable, and GSI as the response variable (R package: AquaticLifeHistory, Jonathan Smart).

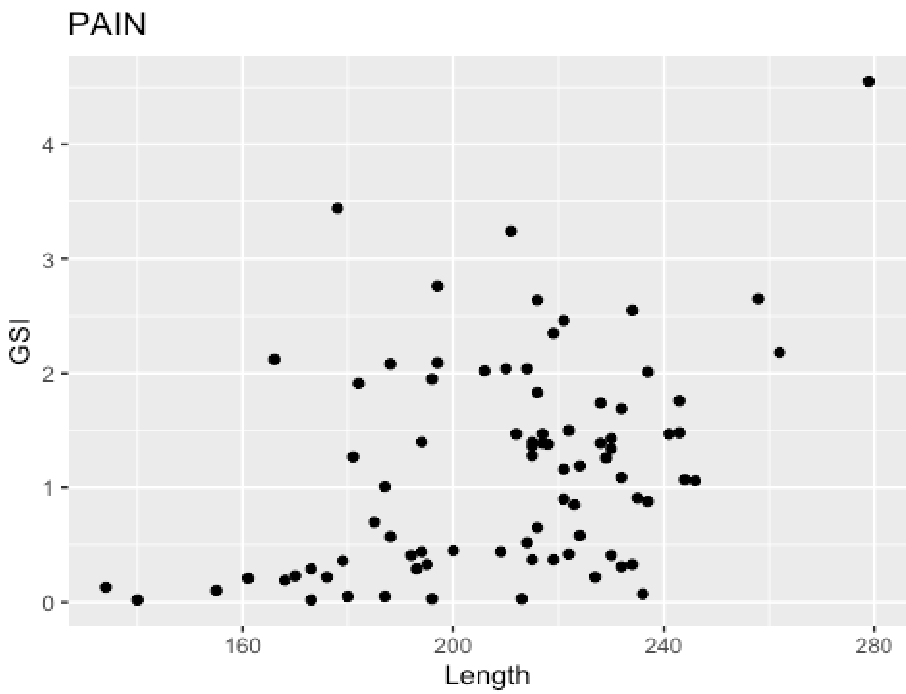
Smart J, Chin A, Tobin A, Simpfendorfer C (2016). "Multimodel approaches in shark and ray growth studies: strengths, weaknesses and the future." Fish and Fisheries, 17, 955–971.

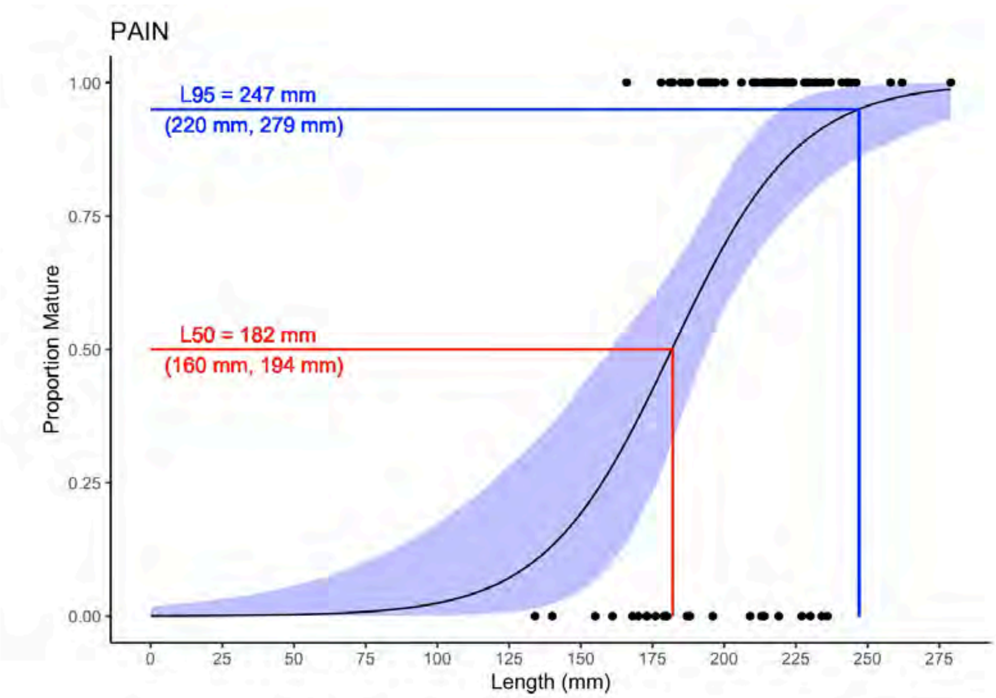
The maturity ogive for all females is shown below. Black line is the logistic estimate of the proportion of the population that as reached maturity at each fork length. Purple shading shows the 95% confidence envelope. Red line shows the length where 50% of the population is mature (L50), with the 95% confidence range of values given in parentheses. Blue line shows the same information for the L95. Black dots show each individual fish used for the input dataset.




In temperate zones, fish typically have a short spawning season. This means that during the off season, large mature fish have small gonads and may not have developing and advanced stage oocytes. Therefore, estimates of size at maturity are generally conducted after excluding individuals connected during the off season. This means that any fish included in the analysis was collected during a month when investment in gonads and oocyte development was expected. In tropical and subtropical zones there may be less of a season effect on fish reproduction. In order to determine if there is a strong effect of season, we can look at a plot of GSI vs month. Those months with high GSI would be considered the spawning season, while low GSI months would be considered the off season. Off season months can be excluded, being months before 1 and after 9.

The maturity ogive for females from spawning months is:



### 6.2.2 PAIN Males

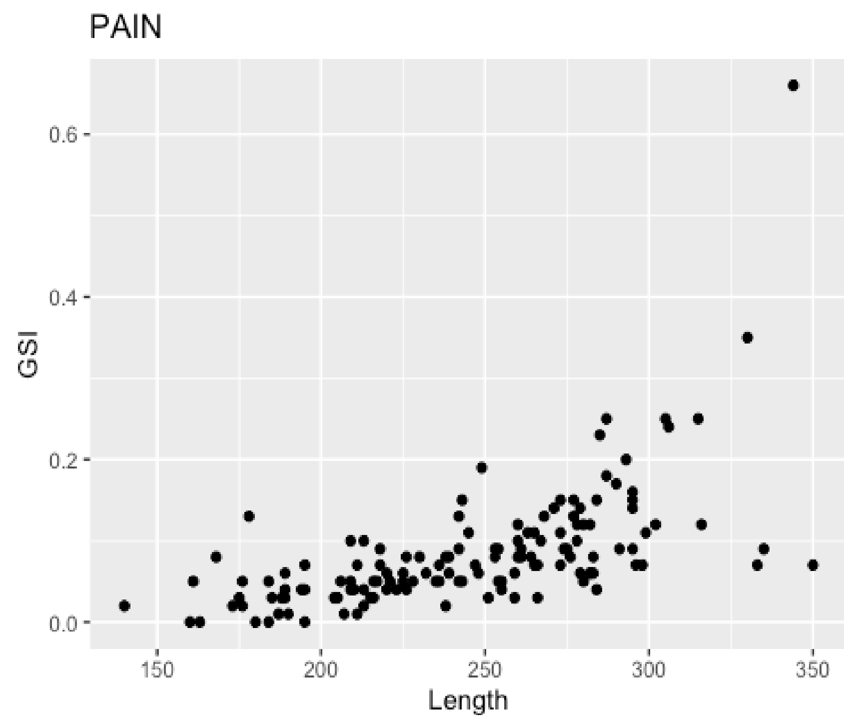
In the table below, Length = Fork Length, Total = Total Length. For males it was not possible to conduct micro and macroscopic maturity assignment; histology would be necessary for this purpose. Therefore, maturity is assigned using a statistical approach, described below. Scatterplots are shown for the change in GSI with length, and the change in GSI with season of year.

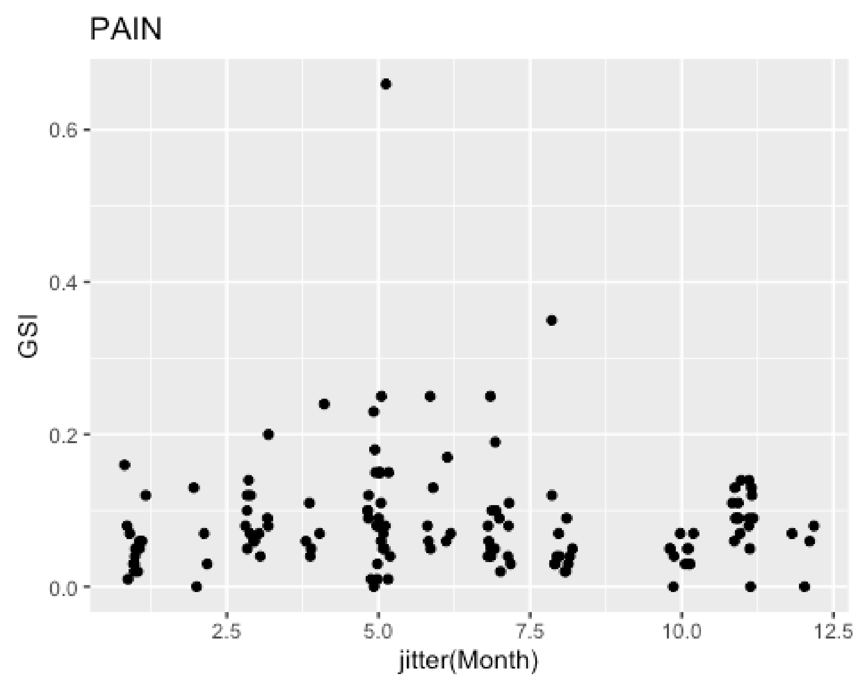
| Month | Location | Species | Length | Total | Sex | Mass | GonadMass | GSI |
|---|---|---|---|---|---|---|---|---|
| 2 | Alan Davis | PAIN | 163 | 187.0000 | M | 89 | 0.0001 | 0.0001 |
| 3 | Waimanalo | PAIN | 168 | 191.0000 | M | 158 | 0.1330 | 0.0800 |
| 4 | Waikiki | PAIN | 176 | 209.0000 | M | 131 | 0.0670 | 0.0500 |
| 8 | Rabbit Island | PAIN | 176 | 204.0000 | M | 115 | 0.0210 | 0.0200 |
| 2 | Alan Davis | PAIN | 178 | 208.0000 | M | 137 | 0.1820 | 0.1300 |
| 7 | Kaiena Pt. | PAIN | 184 | 210.0000 | M | 161 | 0.0790 | 0.0500 |
| 8 | Moku Manu | PAIN | 185 | 216.0000 | M | 135 | 0.0380 | 0.0300 |
| 5 | Moku Manu | PAIN | 187 | 218.0000 | M | 155 | 0.0230 | 0.0100 |
| 10 | Moku Manu | PAIN | 188 | 214.0000 | M | 141 | 0.0470 | 0.0300 |
| 1 | Waimanalo | PAIN | 189 | 219.0000 | M | 147 | 0.0460 | 0.0300 |
| 3 | Rabbit | PAIN | 189 | 219.0000 | M | 146 | 0.0610 | 0.0400 |
| 3 | Rabbit Island | PAIN | 189 | 221.0000 | M | 155 | 0.0950 | 0.0600 |
| 5 | Mokuleia | PAIN | 190 | 217.0000 | M | 172 | 0.0150 | 0.0100 |
| 5 | Makapuu | PAIN | 194 | 225.0000 | M | 156 | 0.0640 | 0.0400 |
| 5 | Kahala | PAIN | 195 | 220.0000 | M | 164 | 0.0001 | 0.0001 |
| 2 | Alan Davis | PAIN | 195 | 227.0000 | M | 162 | 0.1140 | 0.0700 |
| 8 | Moku Manu | PAIN | 195 | 223.0000 | M | 161 | 0.0590 | 0.0400 |
| 5 | Mokuleia | PAIN | 204 | 231.0000 | M | 209 | 0.0600 | 0.0300 |
| 8 | K Bay | PAIN | 205 | 229.0000 | M | 207 | 0.0580 | 0.0300 |
| 5 | K Bay | PAIN | 206 | 237.0000 | M | 224 | 0.1230 | 0.0500 |
| 5 | Mokuleia | PAIN | 207 | 236.0000 | M | 196 | 0.0190 | 0.0100 |
| 4 | Moku Manu | PAIN | 209 | 245.0000 | M | 230 | 0.0960 | 0.0400 |
| 10 | RABBIT | PAIN | 209 | 250.0000 | M | 252 | 0.1370 | 0.0500 |
| 5 | Moku Manu | PAIN | 209 | 241.0000 | M | 232 | 0.2290 | 0.1000 |
| 8 | Moku Manu | PAIN | 210 | 244.0000 | M | 211 | 0.0900 | 0.0400 |
| 1 | Alan Davis | PAIN | 211 | 241.0000 | M | 207 | 0.0180 | 0.0100 |
| 3 | Moku Manu | PAIN | 211 | 230.0000 | M | 174 | 0.1240 | 0.0700 |
| 1 | Waimanalo | PAIN | 213 | 242.0000 | M | 216 | 0.0330 | 0.0200 |
| 7 | Kaena W | PAIN | 213 | 254.0000 | M | 239 | 0.2280 | 0.1000 |
| 8 | NA | PAIN | 213 | 246.0000 | M | 224 | 0.0960 | 0.0400 |
| 8 | Moku Manu | PAIN | 215 | 249.0000 | M | 240 | 0.0700 | 0.0300 |
| 2 | Alan Davis | PAIN | 216 | 245.0000 | M | 210 | 0.0560 | 0.0300 |

| Month | Location | Species | Length | Total | Sex | Mass | GonadMass | GSI |
|---|---|---|---|---|---|---|---|---|
| 1 | Hanauma Point S | PAIN | 216 | 250.0000 | M | 227 | 0.1200 | 0.0500 |
| 10 | Kaaawa | PAIN | 217 | NA | M | 245 | 0.1220 | 0.0500 |
| 5 | Kahala | PAIN | 218 | 250.0000 | M | 246 | 0.2270 | 0.0900 |
| 5 | Moku Manu | PAIN | 218 | 250.0000 | M | 226 | 0.1570 | 0.0700 |
| 7 | Market | PAIN | 220 | 260.0000 | M | 259 | 0.0960 | 0.0400 |
| 1 | Moku Manu | PAIN | 221 | 255.0000 | M | 223 | 0.1140 | 0.0500 |
| 7 | Rabbit | PAIN | 223 | 259.0000 | M | 268 | 0.0960 | 0.0400 |
| 1 | NA | PAIN | 225 | 258.0000 | M | 255 | 0.1450 | 0.0600 |
| 8 | North Shore | PAIN | 225 | 259.0000 | M | 254 | 0.1330 | 0.0500 |
| 11 | Makaha | PAIN | 226 | 262.7498 | M | 248 | 0.2010 | 0.0800 |
| 1 | Moku Manu | PAIN | 226 | 267.0000 | M | 275 | 0.1100 | 0.0400 |
| 3 | Rabbit Island | PAIN | 228 | 263.0000 | M | 299 | 0.1560 | 0.0500 |
| 12 | Kahala Barge | PAIN | 230 | 267.0930 | M | 288 | 0.2360 | 0.0800 |
| 1 | Waimanalo | PAIN | 232 | 342.0000 | M | 690 | 0.4330 | 0.0600 |
| 1 | Hanauma Point S | PAIN | 235 | 272.0000 | M | 294 | 0.1400 | 0.0500 |
| 10 | NA | PAIN | 236 | 271.0000 | M | 274 | 0.1430 | 0.0500 |
| 1 | Waimanalo | PAIN | 238 | 280.0000 | M | 332 | 0.0730 | 0.0200 |
| 5 | Mokuleia | PAIN | 238 | 276.0000 | M | 327 | 0.2580 | 0.0800 |
| 6 | Moku Manu | PAIN | 239 | 274.0000 | M | 304 | 0.1840 | 0.0600 |
| 6 | Moku Manu | PAIN | 239 | 274.0000 | M | 345 | 0.2900 | 0.0800 |
| 11 | LANAI LOOKOUT | PAIN | 242 | 273.0000 | M | 297 | 0.3870 | 0.1300 |
| 5 | Mokuleia | PAIN | 242 | 273.0000 | M | 323 | 0.1480 | 0.0500 |
| 5 | Moku Manu | PAIN | 242 | 280.0000 | M | 341 | 0.3000 | 0.0900 |
| 5 | Makapuu | PAIN | 243 | 287.0000 | M | 359 | 0.5220 | 0.1500 |
| 6 | Moku Manu | PAIN | 243 | 279.0000 | M | 367 | 0.2010 | 0.0500 |
| 11 | LANAI LOOKOUT | PAIN | 245 | 280.0000 | M | 344 | 0.3720 | 0.1100 |
| 4 | Rabbit | PAIN | 247 | 278.0000 | M | 327 | 0.2140 | 0.0700 |
| 4 | Rabbit | PAIN | 248 | 288.0000 | M | 438 | 0.2660 | 0.0600 |
| 7 | Kaena W | PAIN | 249 | 297.0000 | M | 390 | 0.7500 | 0.1900 |
| 10 | Alan Davis | PAIN | 251 | 285.0000 | M | 335 | 0.0930 | 0.0300 |
| 7 | Kaiena Pt. | PAIN | 253 | 300.0000 | M | 421 | 0.3850 | 0.0900 |
| 7 | Market | PAIN | 253 | 299.0000 | M | 418 | 0.3460 | 0.0800 |
| 10 | NA | PAIN | 254 | 289.0000 | M | 349 | 0.1760 | 0.0500 |
| 11 | LANAI LOOKOUT | PAIN | 254 | 287.0000 | M | 374 | 0.3520 | 0.0900 |
| 11 | KANEOHE | PAIN | 255 | 288.0000 | M | 404 | 0.2030 | 0.0500 |

| Month | Location | Species | Length | Total | Sex | Mass | GonadMass | GSI |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 7 | Market | PAIN | 255 | 295.0000 | M | 389 | 0.1620 | 0.0400 |
| 1 | Waimanalo | PAIN | 259 | 290.0000 | M | 390 | 0.1240 | 0.0300 |
| 5 | Moku Manu | PAIN | 259 | 292.0000 | M | 363 | 0.2200 | 0.0600 |
| 5 | K Bay | PAIN | 260 | 298.0000 | M | 438 | 0.5350 | 0.1200 |
| 3 | Rabbit Island | PAIN | 260 | 297.0000 | M | 470 | 0.4640 | 0.1000 |
| 7 | NA | PAIN | 260 | 295.0000 | M | 388 | 0.3100 | 0.0800 |
| 5 | K Bay | PAIN | 261 | 304.0000 | M | 425 | 0.3420 | 0.0800 |
| 11 | KAENA | PAIN | 261 | 296.0000 | M | 416 | 0.3870 | 0.0900 |
| 7 | K Bay | PAIN | 263 | 310.0000 | M | 493 | 0.5240 | 0.1100 |
| 5 | Moku Manu | PAIN | 264 | 299.0000 | M | 425 | 0.3460 | 0.0800 |
| 3 | Moku Manu | PAIN | 265 | 317.0000 | M | 495 | 0.3350 | 0.0700 |
| 11 | LANAI LOOKOUT | PAIN | 265 | 305.0000 | M | 421 | 0.4500 | 0.1100 |
| 10 | Moku Manu | PAIN | 266 | 303.0000 | M | 398 | 0.1220 | 0.0300 |
| 11 | MOKU MANU | PAIN | 266 | 313.0000 | M | 487 | 0.3470 | 0.0700 |
| 7 | NA | PAIN | 267 | 296.0000 | M | 366 | 0.3510 | 0.1000 |
| 11 | LANAI LOOKOUT | PAIN | 268 | 303.0000 | M | 445 | 0.5620 | 0.1300 |
| 11 | LANAI LOOKOUT | PAIN | 271 | 306.0000 | M | 454 | 0.6460 | 0.1400 |
| 5 | K Bay - Red Can | PAIN | 273 | 314.0000 | M | 528 | 0.7820 | 0.1500 |
| 8 | K Bay | PAIN | 273 | 317.0000 | M | 503 | 0.3610 | 0.0700 |
| 5 | Turtle Bay | PAIN | 273 | 308.0000 | M | 443 | 0.4820 | 0.1100 |
| 11 | LANAI LOOKOUT | PAIN | 274 | 309.0000 | M | 395 | 0.3590 | 0.0900 |
| 11 | MOKU MANU | PAIN | 275 | 312.0000 | M | 474 | 0.4200 | 0.0900 |
| 1 | Makapuu | PAIN | 276 | 311.0000 | M | 528 | 0.4320 | 0.0800 |
| 5 | Kaneohe | PAIN | 277 | 311.0000 | M | 526 | 0.7950 | 0.1500 |
| 6 | Moku Manu | PAIN | 277 | 305.0000 | M | 456 | 0.5850 | 0.1300 |
| 1 | Alan Davis | PAIN | 278 | 318.0000 | M | 511 | 0.6180 | 0.1200 |
| 5 | Moku Manu | PAIN | 278 | 315.0000 | M | 463 | 0.4410 | 0.1000 |
| 11 | Reef Runway | PAIN | 279 | 320.2972 | M | 531 | 0.3410 | 0.0600 |
| 3 | Rabbit Island | PAIN | 279 | 314.0000 | M | 531 | 0.7320 | 0.1400 |
| 1 | Waimanalo | PAIN | 280 | 314.0000 | M | 454 | 0.2260 | 0.0500 |
| 8 | Ka’awa | PAIN | 280 | 310.0000 | M | 615 | 0.7300 | 0.1200 |
| 12 | Outside K-Bay | PAIN | 282 | 323.5546 | M | 518 | 0.3160 | 0.0600 |
| 3 | Rabbit | PAIN | 282 | 316.0000 | M | 523 | 0.6200 | 0.1200 |
| 6 | Moku Manu | PAIN | 282 | 324.0000 | M | 549 | 0.3100 | 0.0600 |
| 3 | Moku Manu | PAIN | 283 | 320.0000 | M | 486 | 0.3710 | 0.0800 |

| Month | Location | Species | Length | Total | Sex | Mass | GonadMass | GSI |
|---|---|---|---|---|---|---|---|---|
| 3 | NA | PAIN | 283 | 320.0000 | M | 474 | 0.2620 | 0.0600 |
| 10 | Moku Manu | PAIN | 284 | 326.0000 | M | 554 | 0.2140 | 0.0400 |
| 5 | Kaaawa | PAIN | 284 | 320.0000 | M | 583 | 0.8660 | 0.1500 |
| 5 | Moku Manu | PAIN | 285 | 325.0000 | M | 595 | 1.3800 | 0.2300 |
| 5 | Moku Manu | PAIN | 287 | 330.0000 | M | 586 | 1.0510 | 0.1800 |
| 6 | Moku Manu | PAIN | 287 | 423.0000 | M | 596 | 1.4820 | 0.2500 |
| 6 | Kaaawa | PAIN | 290 | 325.0000 | M | 566 | 0.9520 | 0.1700 |
| 11 | MOKU MANU | PAIN | 291 | 327.0000 | M | 512 | 0.4560 | 0.0900 |
| 3 | Moku Manu | PAIN | 293 | 322.0000 | M | 554 | 1.0970 | 0.2000 |
| 1 | Waimanalo | PAIN | 295 | 337.0000 | M | 639 | 0.9950 | 0.1600 |
| 11 | LANAI LOOKOUT | PAIN | 295 | 331.0000 | M | 501 | 0.7250 | 0.1400 |
| 5 | Kaaawa | PAIN | 295 | 333.0000 | M | 669 | 1.0130 | 0.1500 |
| 3 | NA | PAIN | 295 | 336.0000 | M | 571 | 0.4950 | 0.0900 |
| 10 | Lanikai | PAIN | 296 | 331.0000 | M | 590 | 0.4220 | 0.0700 |
| 1 | Waimanalo | PAIN | 298 | 337.0000 | M | 637 | 0.4180 | 0.0700 |
| 4 | K Bay | PAIN | 299 | 331.0000 | M | 608 | 0.6660 | 0.1100 |
| 3 | NA | PAIN | 302 | 334.0000 | M | 656 | 0.7970 | 0.1200 |
| 7 | Sunset | PAIN | 305 | 338.0000 | M | 646 | 1.6100 | 0.2500 |
| 4 | K Bay | PAIN | 306 | 353.0000 | M | 745 | 1.8250 | 0.2400 |
| 5 | Moku Manu | PAIN | 315 | 350.0000 | M | 705 | 1.7970 | 0.2500 |
| 11 | Reef Runway | PAIN | 316 | 360.4718 | M | 630 | 0.7390 | 0.1200 |
| 8 | Mokuleia | PAIN | 330 | 370.0000 | M | 915 | 3.1630 | 0.3500 |
| 10 | waikiki | PAIN | 333 | 379.0000 | M | 912 | 0.6160 | 0.0700 |
| 8 | NA | PAIN | 335 | 381.1020 | M | 760 | 0.7000 | 0.0900 |
| 5 | Turtle Bay | PAIN | 344 | 380.0000 | M | 1018 | 6.6870 | 0.6600 |
| 12 | Magic Island | PAIN | 350 | 397.3890 | M | 840 | 0.5600 | 0.0700 |
| 8 | Rabbit Island | PAIN | 140 | 162.0000 | U | 57 | 0.0140 | 0.0200 |
| 11 | Black Island | PAIN | 160 | NA | U | 89 | 0.0001 | 0.0001 |
| 7 | NA | PAIN | 161 | 188.0000 | U | 93 | 0.0490 | 0.0500 |
| 7 | Rabbit Island | PAIN | 173 | 201.0000 | U | 124 | 0.0230 | 0.0200 |
| 7 | NA | PAIN | 175 | 200.0000 | U | 109 | 0.0270 | 0.0300 |
| 12 | Kahala Barge | PAIN | 180 | NA | U | 121 | 0.0001 | 0.0001 |
| 10 | Moku Manu | PAIN | 184 | 212.0000 | U | 149 | 0.0001 | 0.0001 |
| 7 | NA | PAIN | 220 | 252.0000 | U | 238 | 0.1490 | 0.0600 |
| 6 | Kaaawa | PAIN | 236 | 268.0000 | U | 340 | 0.2270 | 0.0700 |




A Principal Component analysis is conducted on body mass and gonad mass (which together are the GSI), using R package sizeMat (Josymar Torrejon-Magallanes). This separates the population into two groups with different slopes of gonad mass vs. body mass, where the mature individuals have a steeper slope. This occurs because prior to the onset of maturity an individual is a allocating energy to somatic growth, whereas after onset of maturity it allocates a portion to reproductive development/output.

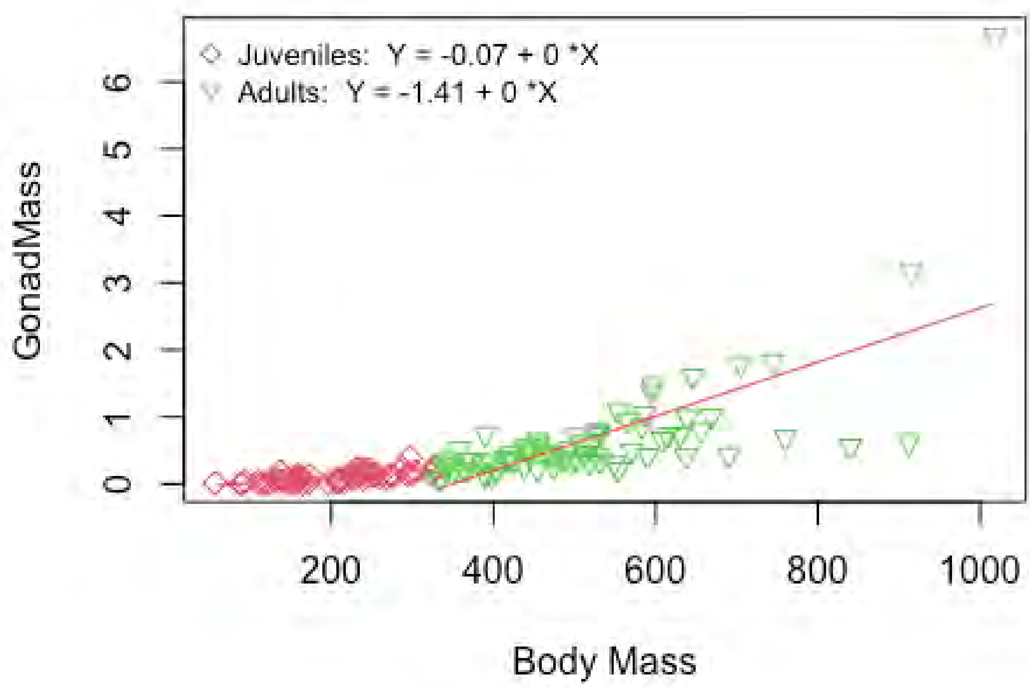
The method is used in other studies, e.g.,

Parvizi, E., Naderloo, R., Keikhosravi, A., and Schubart, C. D., 2017, Life history traits and patterns of sexual dimorphism in the freshwater crab Potamon ibericum (Bieberstein, 1809) (Decapoda: Brachyura: Potamidae) from the western Alborz Mountains, Iran: Journal of Crustacean Biology, v. 37, no. 3, p. 323-331.

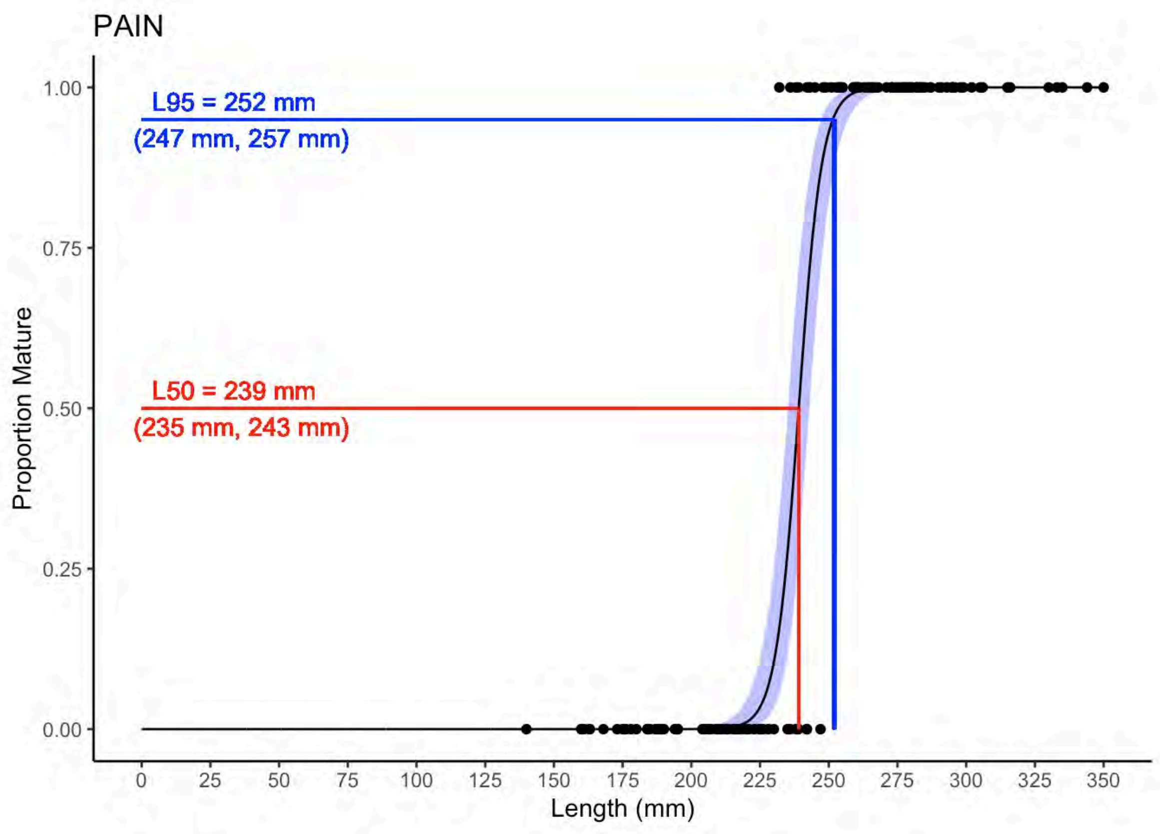
Caill-Milly, N., Sanchez, F., Benito, D., Ruiz, P., Izagirre, U., and Briaudeau, T., 2023, Assessment of size at first maturity for Ruditapes philippinarum from Arcachon Bay (French Atlantic coast): New insights for fishery management: Estuarine, Coastal and Shelf Science, v. 285, p. 108321.

```
## all individuals were used in the analysis
```

The plot below shows the results of the assignment with principal component analysis. The Red diamonds show individuals assigned as immature, while the green triangles show individuals assigned as mature. Body mass and gonad mass are both in grams.



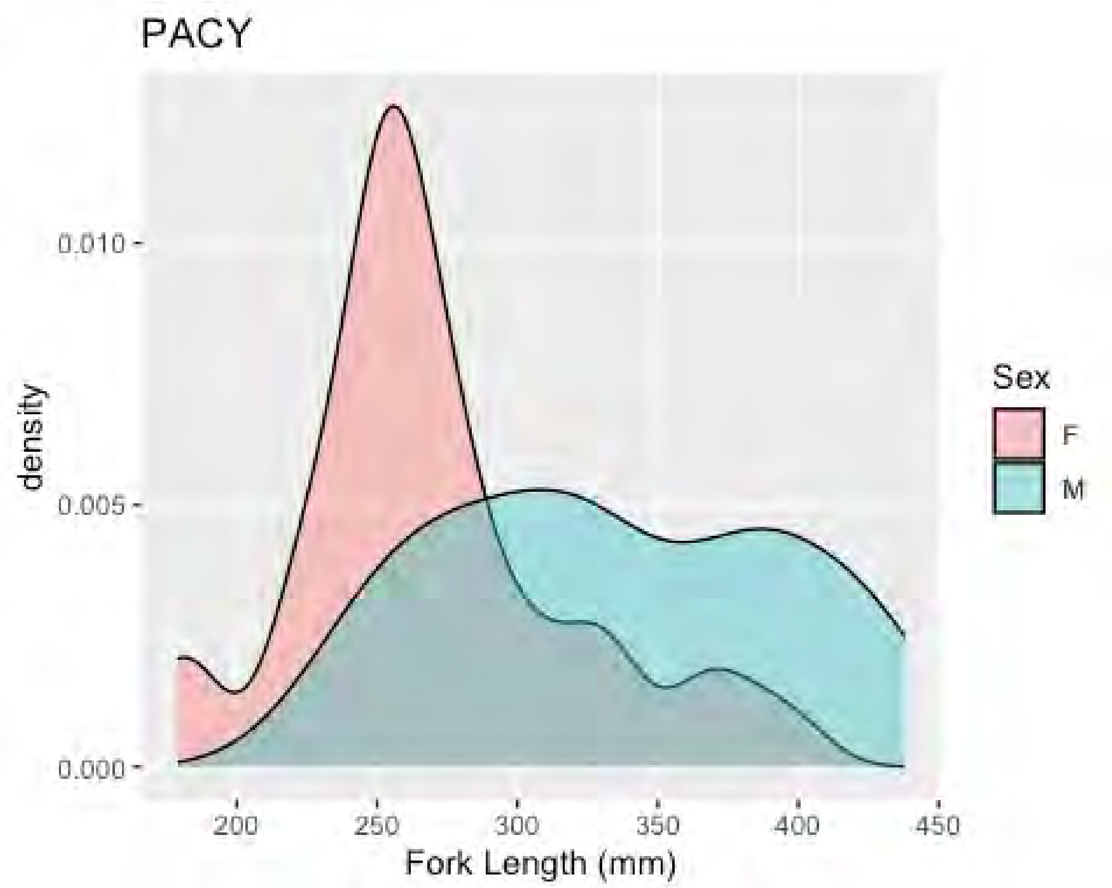

The maturity ogive for males is shown below. Black line is the logistic estimate of the proportion of the population that as reached maturity at each fork length. Purple shading shows the 95% confidence envelope. Red line shows the length where 50% of the population is mature (L50), with the 95% confidence range of values given in parentheses. Blue line shows the same information for the L95. Black dots show each individual fish used for the input dataset.




## 6.3 Moano kea, moano kali, blue goatfish, yellowsaddle goatfish, Parupeneus cyclostomus

A live P. cyclostomus captured off Alan Davis with a sabiki, showing the colors of a living specimen. Photo: K Weng.

The size distribution for females and males was as follows:

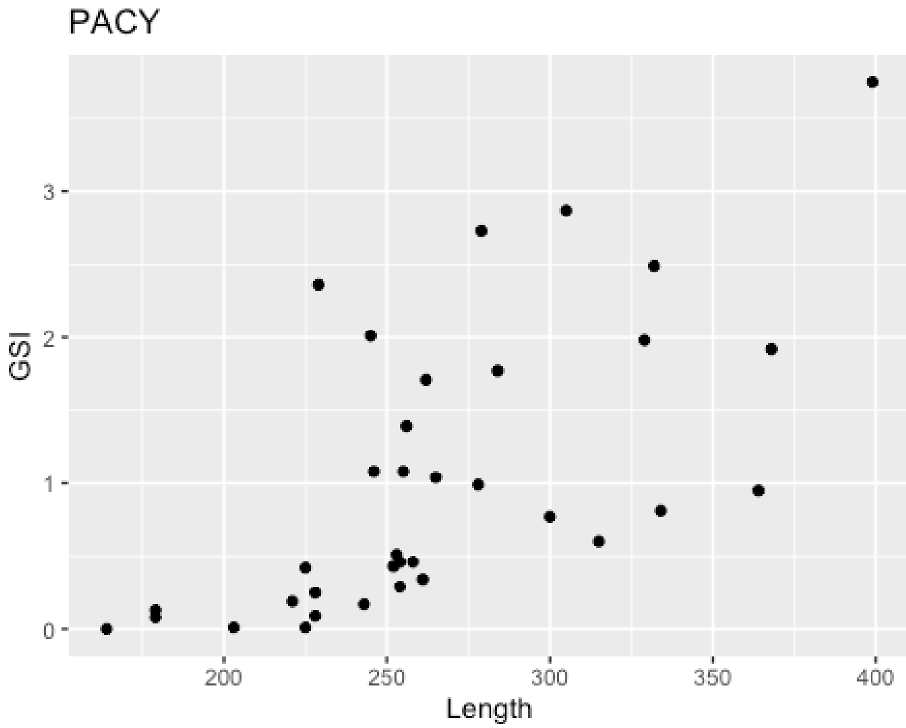


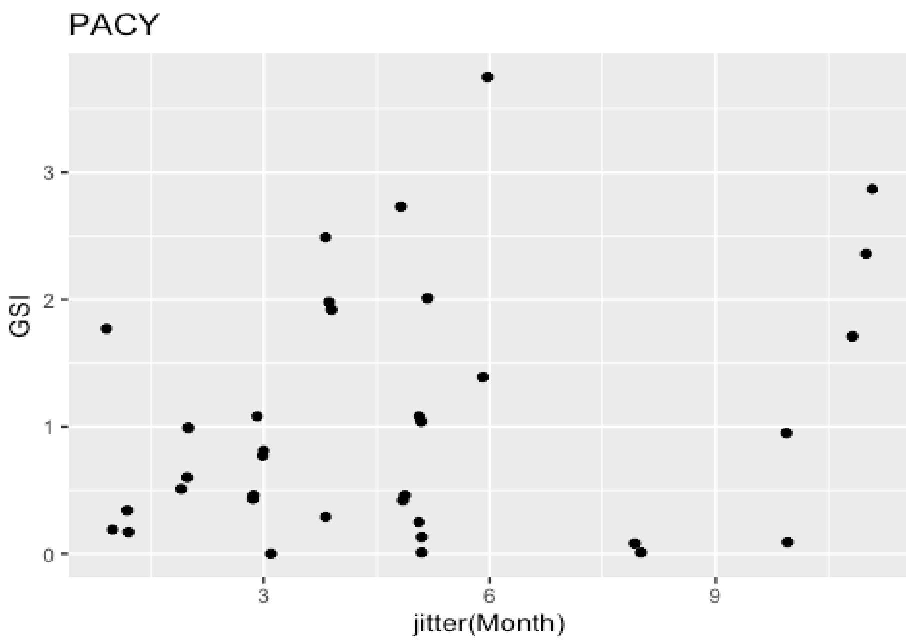

### 6.3.1 PACY Females

In the table below, Length = Fork Length, Total = Total Length. Maturity was assigned based on oocyte stages (microscopic assignment) and appearance of ovaries (macroscopic assignment). 1 = mature, 0 = immature. Scatterplots are shown for the change in GSI with length, and the change in GSI with season of year.

| | Month | Location | Species | Length | Total | Sex | Mass | GonadMass | GSI | Maturity |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 5 | Alan Davis | PACY | 179 | 205 | F | 114 | 0.1500 | 0.1300 | 0 |
| 2 | 8 | Uppers, North Shore | PACY | 179 | 204 | F | 108 | 0.0890 | 0.0800 | 0 |
| 4 | 1 | Waimanalo | PACY | 221 | 253 | F | 213 | 0.4090 | 0.1900 | 0 |
| 6 | 5 | Moku manu | PACY | 225 | 260 | F | 228 | 0.9580 | 0.4200 | 1 |
| 7 | 5 | Mokuleia | PACY | 228 | 259 | F | 266 | 0.6760 | 0.2500 | 0 |
| 8 | 11 | Moku manu | PACY | 229 | 265 | F | 295 | 6.9670 | 2.3600 | 1 |

| | Month | Location | Species | Length | Total | Sex | Mass | GonadMass | GSI | Maturity |
|---|---|---|---|---|---|---|---|---|---|---|
| 9 | 1 | Hanauma Point S | PACY | 243 | 279 | F | 278 | 0.4790 | 0.1700 | 0 |
| 11 | 5 | Kaaawa | PACY | 245 | 279 | F | 302 | 6.0560 | 2.0100 | 1 |
| 13 | 5 | Moku manu | PACY | 246 | 282 | F | 285 | 3.0660 | 1.0800 | 1 |
| 15 | 3 | rabbit | PACY | 252 | 292 | F | 333 | 1.4170 | 0.4300 | 0 |
| 16 | 2 | Alan Davis | PACY | 253 | 288 | F | 348 | 1.7710 | 0.5100 | 1 |
| 17 | 3 | Makapuu | PACY | 254 | 293 | F | 360 | 1.6570 | 0.4600 | 0 |
| 18 | 4 | Rabbit | PACY | 254 | 289 | F | 298 | 0.8780 | 0.2900 | 0 |
| 19 | 3 | Makapuu | PACY | 255 | 297 | F | 322 | 3.4890 | 1.0800 | 1 |
| 20 | 6 | Kaaawa | PACY | 256 | 290 | F | 340 | 4.7420 | 1.3900 | 1 |
| 21 | 5 | Turtule Bay | PACY | 258 | 299 | F | 373 | 1.7080 | 0.4600 | 0 |
| 22 | 1 | Alan Davis | PACY | 261 | 290 | F | 327 | 1.1220 | 0.3400 | 0 |
| 25 | 11 | Moku manu | PACY | 262 | 297 | F | 373 | 6.3640 | 1.7100 | 1 |
| 26 | 5 | Moku Manu | PACY | 265 | 302 | F | 370 | 3.8470 | 1.0400 | 1 |
| 30 | 2 | Alan Davis | PACY | 278 | 315 | F | 446 | 4.4160 | 0.9900 | 1 |
| 31 | 5 | K Bay | PACY | 279 | 329 | F | 503 | 13.7290 | 2.7300 | 1 |
| 32 | 1 | moku manu | PACY | 284 | 326 | F | 472 | 8.3500 | 1.7700 | 1 |
| 34 | 3 | Rabbit | PACY | 300 | 348 | F | 524 | 4.0520 | 0.7700 | 1 |
| 35 | 11 | WAIMANALO | PACY | 305 | 350 | F | 577 | 16.5830 | 2.8700 | 1 |
| 36 | 2 | Alan Davis | PACY | 315 | 360 | F | 592 | 3.5380 | 0.6000 | 1 |
| 37 | 4 | Koolina | PACY | 329 | 369 | F | 605 | 11.9680 | 1.9800 | 1 |
| 38 | 4 | MARKET | PACY | 332 | 377 | F | 818 | 20.3360 | 2.4900 | 1 |
| 39 | 3 | Makapuu | PACY | 334 | 393 | F | 822 | 6.6540 | 0.8100 | 1 |
| 40 | 10 | Kualoa | PACY | 364 | 400 | F | 901 | 8.5620 | 0.9500 | 1 |
| 41 | 4 | koolina | PACY | 368 | 420 | F | 1080 | 20.7460 | 1.9200 | 1 |
| 43 | 6 | Moku Manu | PACY | 399 | 353 | F | 530 | 19.8540 | 3.7500 | 1 |
| 45 | 3 | rabbit | PACY | 164 | 191 | U | 88 | 0.0001 | 0.0001 | 0 |
| 48 | 8 | Rabbit Island | PACY | 203 | 233 | U | 176 | 0.0210 | 0.0100 | 0 |
| 49 | 5 | Mokuleia | PACY | 225 | 260 | U | 242 | 0.0220 | 0.0100 | 0 |
| 50 | 10 | Moku Manu | PACY | 228 | 260 | U | 200 | 0.1700 | 0.0900 | 0 |

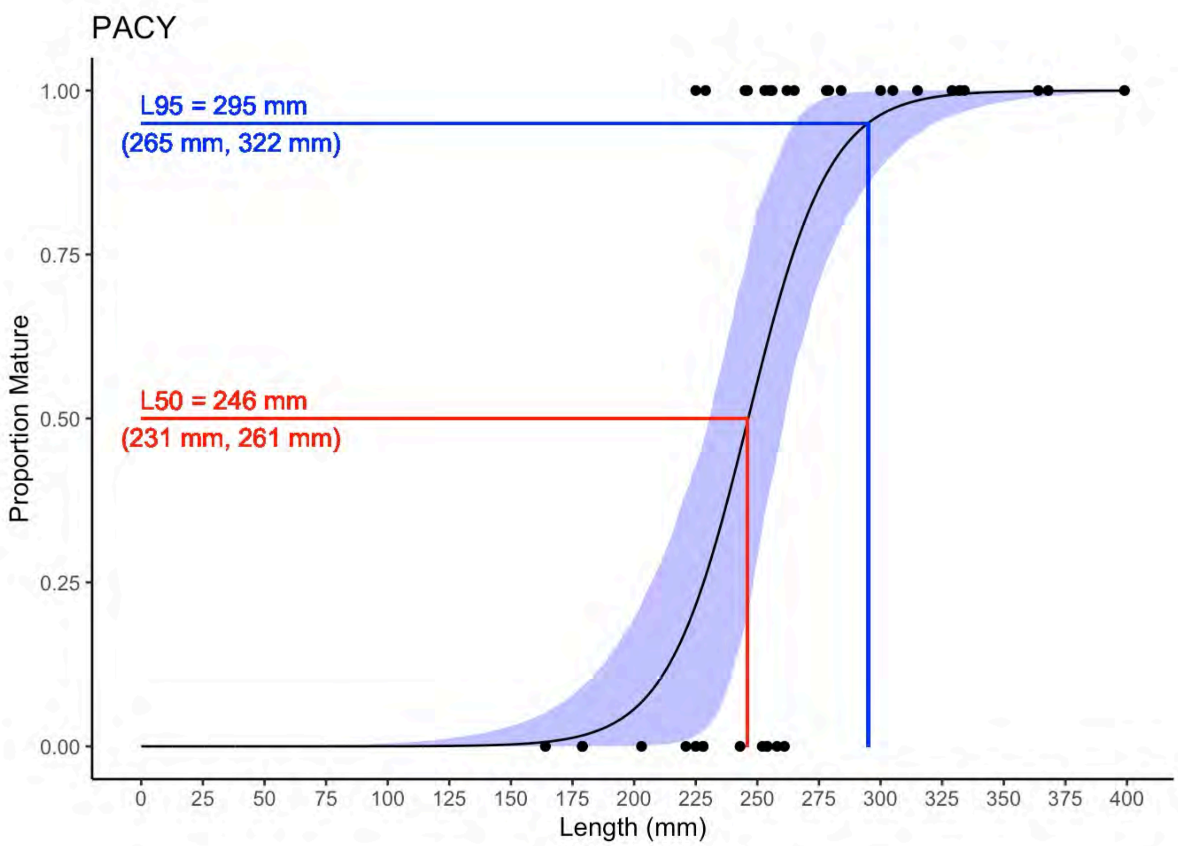



Once the maturity assignment is made for each individual, a logistic function is used to estimate size at maturity. The dataset is run through a general linear model with binomial error structure, using Length as the explanatory variable, and GSI as the response variable (R package: AquaticLifeHistory, Jonathan Smart).

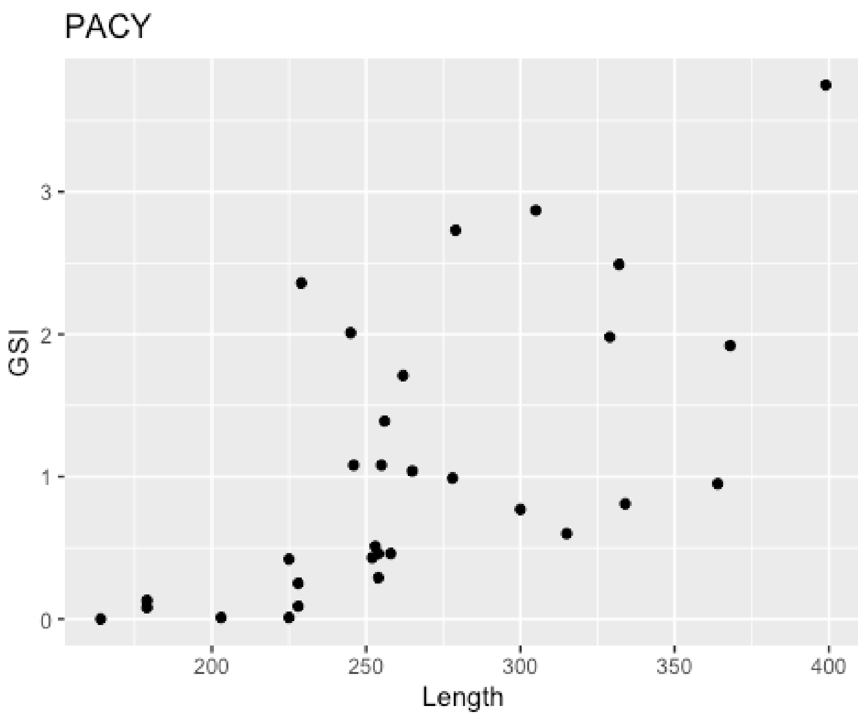
Smart J, Chin A, Tobin A, Simpfendorfer C (2016). "Multimodel approaches in shark and ray growth studies: strengths, weaknesses and the future." Fish and Fisheries, 17, 955–971.

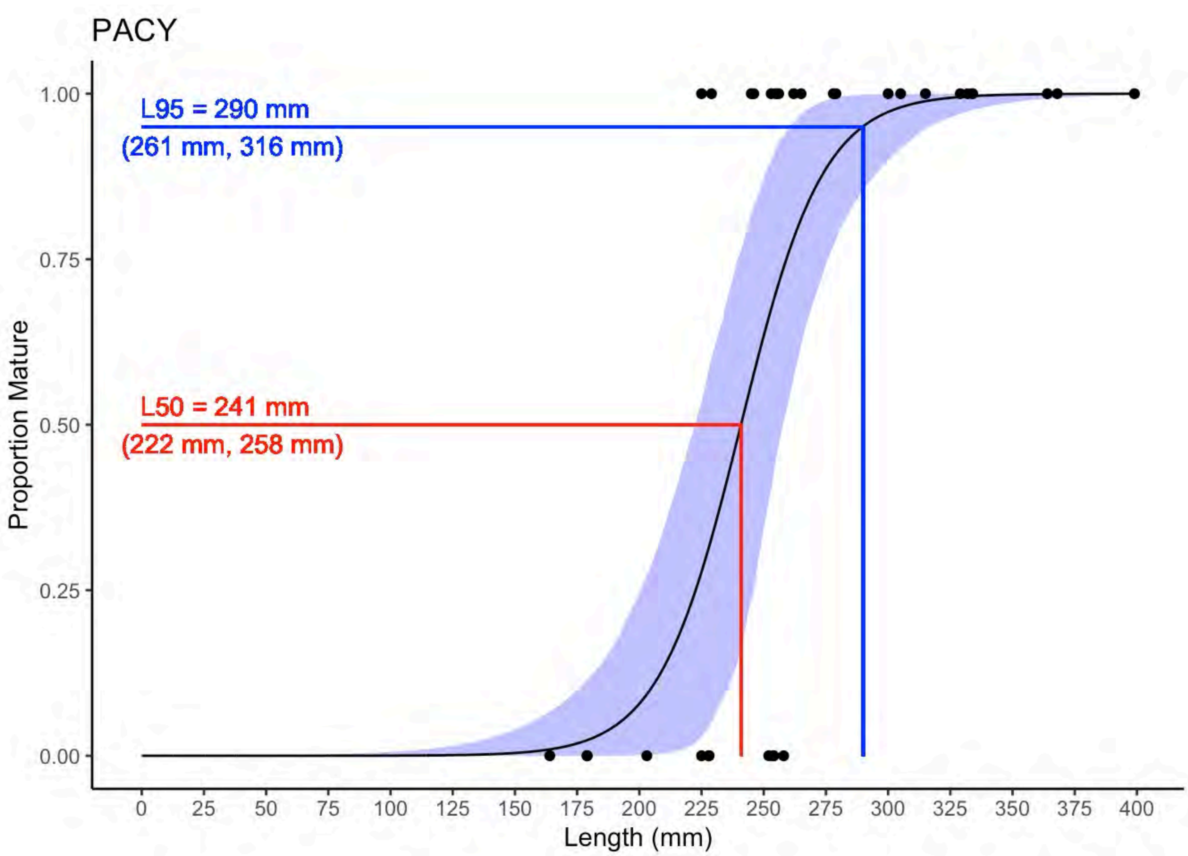
The maturity ogive for all females is shown below. Black line is the logistic estimate of the proportion of the population that as reached maturity at each fork length. Purple shading shows the 95% confidence envelope. Red line shows the length where 50% of the population is mature (L50), with the 95% confidence range of values given in parentheses. Blue line shows the same information for the L95. Black dots show each individual fish used for the input dataset.




In temperate zones, fish typically have a short spawning season. This means that during the off season, large mature fish have small gonads and may not have developing and advanced stage oocytes. Therefore, estimates of size at maturity are generally conducted after excluding individuals connected during the off season. This means that any fish included in the analysis was collected during a month when investment in gonads and oocyte development was expected. In tropical and subtropical zones there may be less of a season effect on fish reproduction. In order to determine if there is a strong effect of season, we can look at a plot of GSI vs month. Those months with high GSI would be considered the spawning season, while low GSI months would be considered the off season. Off season months can be excluded, being months before 2 and after 11.

The maturity ogive for females from spawning months is:


PACY
GSI
0
1
2
3
200
250
300
350
400
Length

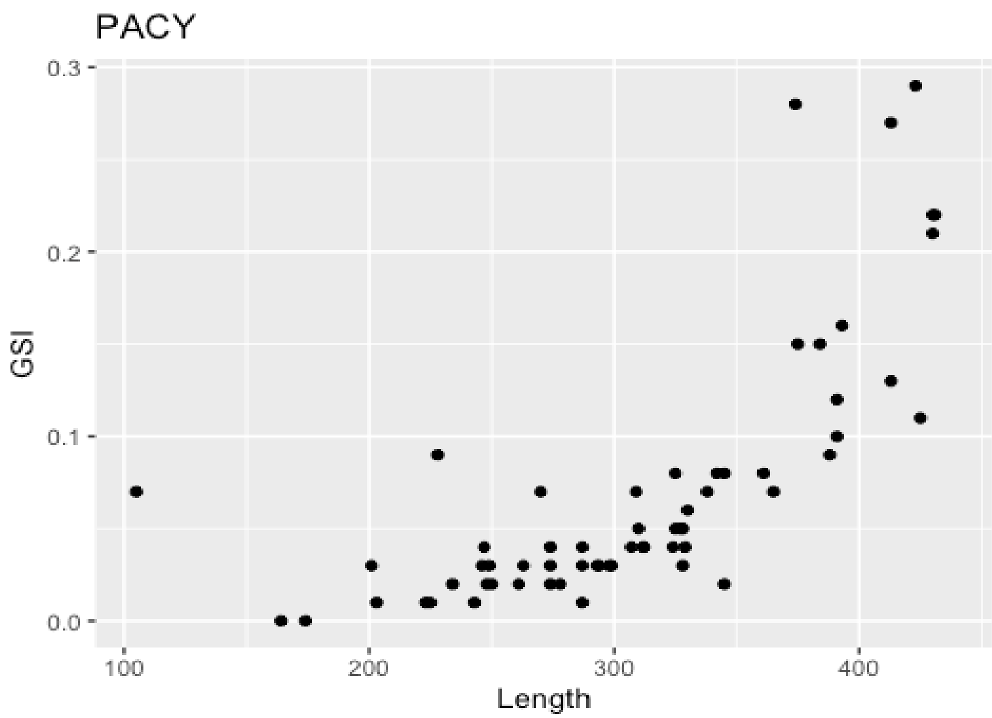

PACY
L95 = 290 mm
(261 mm, 316 mm)
L50 = 241 mm
(222 mm, 258 mm)
Proportion Mature
0.00
0.25
0.50
0.75
1.00
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
Length (mm)

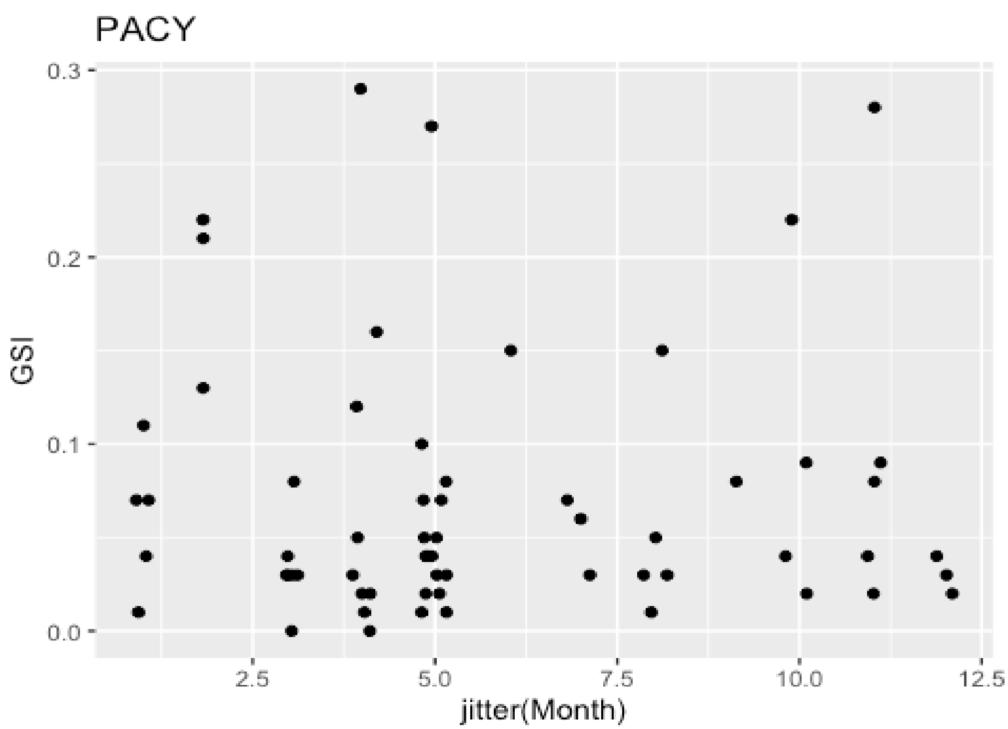
### 6.3.2 PACY Males

In the table below, Length = Fork Length, Total = Total Length. For males it was not possible to conduct micro and macroscopic maturity assignment; histology would be necessary for this purpose. Therefore, maturity is assigned using a statistical approach, described below. Scatterplots are shown for the change in GSI with length, and the change in GSI with season of year.

| Month | Location | Species | Length | Total | Sex | Mass | GonadMass | GSI |
|---|---|---|---|---|---|---|---|---|
| 5 | Mokuleia | PACY | 223 | 251 | M | 221 | 0.0200 | 0.0100 |
| 4 | Rabbit | PACY | 234 | 275 | M | 284 | 0.0520 | 0.0200 |
| 4 | Sunset Beach | PACY | 243 | 278 | M | 296 | 0.0150 | 0.0100 |
| 5 | Moku Manu | PACY | 246 | 286 | M | 324 | 0.0810 | 0.0300 |
| 11 | LANAI LOOKOUT | PACY | 247 | 293 | M | 342 | 0.1240 | 0.0400 |
| 4 | Sunset Beach | PACY | 248 | 281 | M | 323 | 0.0740 | 0.0200 |
| 7 | Uppers | PACY | 249 | 284 | M | 352 | 0.0890 | 0.0300 |
| 5 | Moku Manu | PACY | 250 | 289 | M | 286 | 0.0490 | 0.0200 |
| 11 | WAIMANALO | PACY | 261 | 301 | M | 350 | 0.0640 | 0.0200 |
| 10 | Moku Manu | PACY | 263 | 295 | M | 352 | 0.8000 | NA |
| 12 | NA | PACY | 263 | 301 | M | 352 | 0.0920 | 0.0300 |
| 5 | Turtle Bay | PACY | 270 | 293 | M | 255 | 0.1660 | 0.0700 |
| 10 | Kaaawa | PACY | 274 | NA | M | 399 | 0.1450 | 0.0400 |
| 12 | NA | PACY | 274 | 312 | M | 426 | 0.0810 | 0.0200 |
| 3 | rabbit | PACY | 274 | 312 | M | 404 | 0.1010 | 0.0300 |
| 5 | Mokuleia | PACY | 278 | 313 | M | 425 | 0.0790 | 0.0200 |
| 3 | Makapuu | PACY | 287 | 329 | M | 450 | 0.1530 | 0.0300 |
| 1 | waimanalo | PACY | 287 | 325 | M | 530 | 0.0440 | 0.0100 |
| 5 | Moku Manu | PACY | 287 | 327 | M | 454 | 0.1820 | 0.0400 |
| 3 | Makapuu | PACY | 293 | 336 | M | 476 | 0.1650 | 0.0300 |
| 8 | Oahu | PACY | 294 | 338 | M | 455 | 0.1200 | 0.0300 |
| 5 | Moku Manu | PACY | 298 | 343 | M | 526 | 0.1650 | 0.0300 |
| 3 | Rabbit | PACY | 299 | 345 | M | 548 | 0.1680 | 0.0300 |
| 5 | NA | PACY | 307 | 344 | M | 626 | 0.2640 | 0.0400 |
| 5 | Moku Manu | PACY | 309 | 353 | M | 600 | 0.4220 | 0.0700 |
| 8 | NA | PACY | 310 | 356 | M | 909 | 0.4600 | 0.0500 |
| 1 | Alan Davis | PACY | 312 | 357 | M | 657 | 0.2640 | 0.0400 |
| 5 | China Walls | PACY | 312 | 356 | M | 684 | 0.2660 | 0.0400 |
| 3 | rabbit | PACY | 324 | 373 | M | 698 | 0.2530 | 0.0400 |
| 5 | Waimanalo | PACY | 325 | 372 | M | 746 | 0.6020 | 0.0800 |
| 4 | MARKET | PACY | 325 | 375 | M | 818 | 0.3770 | 0.0500 |
| 5 | Kaaawa | PACY | 327 | 371 | M | 758 | 0.4040 | 0.0500 |
| 5 | Kaaawa | PACY | 328 | 375 | M | 770 | 0.3900 | 0.0500 |
| 8 | NA | PACY | 328 | 345 | M | 687 | 0.2400 | 0.0300 |

| Month | Location | Species | Length | Total | Sex | Mass | GonadMass | GSI |
|---|---|---|---|---|---|---|---|---|
| 12 | NA | PACY | 329 | 378 | M | 637 | 0.2250 | 0.0400 |
| 7 | Rabbit | PACY | 330 | 373 | M | 773 | 0.4410 | 0.0600 |
| 1 | Alan Davis | PACY | 338 | 390 | M | 854 | 0.6310 | 0.0700 |
| 11 | MOKU MANU | PACY | 342 | 389 | M | 816 | 0.6490 | 0.0800 |
| 3 | makapuu | PACY | 345 | 403 | M | 815 | 0.6550 | 0.0800 |
| 10 | Kaaawa | PACY | 345 | NA | M | 745 | 0.1210 | 0.0200 |
| 9 | Kaaawa | PACY | 361 | 412 | M | 958 | 0.7830 | 0.0800 |
| 1 | Alan Davis | PACY | 365 | 419 | M | 999 | 0.7210 | 0.0700 |
| 11 | Moku manu | PACY | 374 | 430 | M | 1080 | 3.0390 | 0.2800 |
| 6 | Kaaawa | PACY | 375 | 420 | M | 1003 | 1.5030 | 0.1500 |
| 1 | Alan Davis | PACY | 376 | 422 | M | 956 | 0.5570 | NA |
| 1 | alan davis | PACY | 378 | 430 | M | 1127 | 0.7500 | NA |
| 8 | NA | PACY | 380 | 431 | M | 1121 | 0.4870 | NA |
| 8 | NA | PACY | 384 | 436 | M | 1163 | 1.6950 | 0.1500 |
| 3 | Rabbit | PACY | 387 | 445 | M | 1144 | 0.1580 | NA |
| 11 | Moku manu | PACY | 388 | 441 | M | 1055 | 0.9140 | 0.0900 |
| 1 | Alan Davis | PACY | 388 | 441 | M | 1100 | 0.6140 | NA |
| 5 | Waimanalo | PACY | 391 | 447 | M | 1304 | 1.2710 | 0.1000 |
| 4 | MARKET | PACY | 391 | 448 | M | 1457 | 1.7600 | 0.1200 |
| 4 | Koolina | PACY | 393 | 448 | M | 1234 | 1.9980 | 0.1600 |
| 1 | Alan Davis | PACY | 401 | 453 | M | 1300 | 1.1870 | NA |
| 5 | Waimanalo | PACY | 413 | 466 | M | 1322 | 3.5530 | 0.2700 |
| 2 | market | PACY | 413 | 459 | M | 1537 | 2.0340 | 0.1300 |
| 8 | Maui | PACY | 420 | 474 | M | 1320 | 0.7000 | NA |
| 4 | MARKET | PACY | 423 | 480 | M | 1722 | 5.0660 | 0.2900 |
| 1 | Alan Davis | PACY | 425 | 488 | M | 1615 | 1.8020 | 0.1100 |
| 10 | Kaaawa | PACY | 426 | NA | M | 1415 | 1.0790 | NA |
| 2 | market | PACY | 430 | 485 | M | 1826 | 3.8500 | 0.2100 |
| 2 | market | PACY | 430 | 477 | M | 1805 | 3.9450 | 0.2200 |
| 10 | Maui | PACY | 431 | NA | M | 1620 | 3.6300 | 0.2200 |
| 10 | Makapuu Wall | PACY | 438 | 483 | M | 1499 | NA | NA |
| 7 | NA | PACY | 105 | 120 | U | 24 | 0.0160 | 0.0700 |
| 3 | rabbit | PACY | 164 | 191 | U | 88 | 0.0001 | 0.0001 |
| 4 | Waikiki | PACY | 174 | 204 | U | 103 | NA | 0.0001 |
| 4 | NA | PACY | 201 | 227 | U | 151 | 0.0460 | 0.0300 |
| 8 | Rabbit Island | PACY | 203 | 233 | U | 176 | 0.0210 | 0.0100 |
| 5 | Mokuleia | PACY | 225 | 260 | U | 242 | 0.0220 | 0.0100 |
| 10 | Moku Manu | PACY | 228 | 260 | U | 200 | 0.1700 | 0.0900 |




A Principal Component analysis is conducted on body mass and gonad mass (which together are the GSI), using R package sizeMat (Josymar Torrejon-Magallanes). This separates the population into two groups with different slopes of gonad mass vs. body mass, where the mature individuals have a steeper slope. This occurs because prior to the onset of maturity an individual is a allocating energy to somatic growth, whereas after onset of maturity it allocates a portion to reproductive development/output.

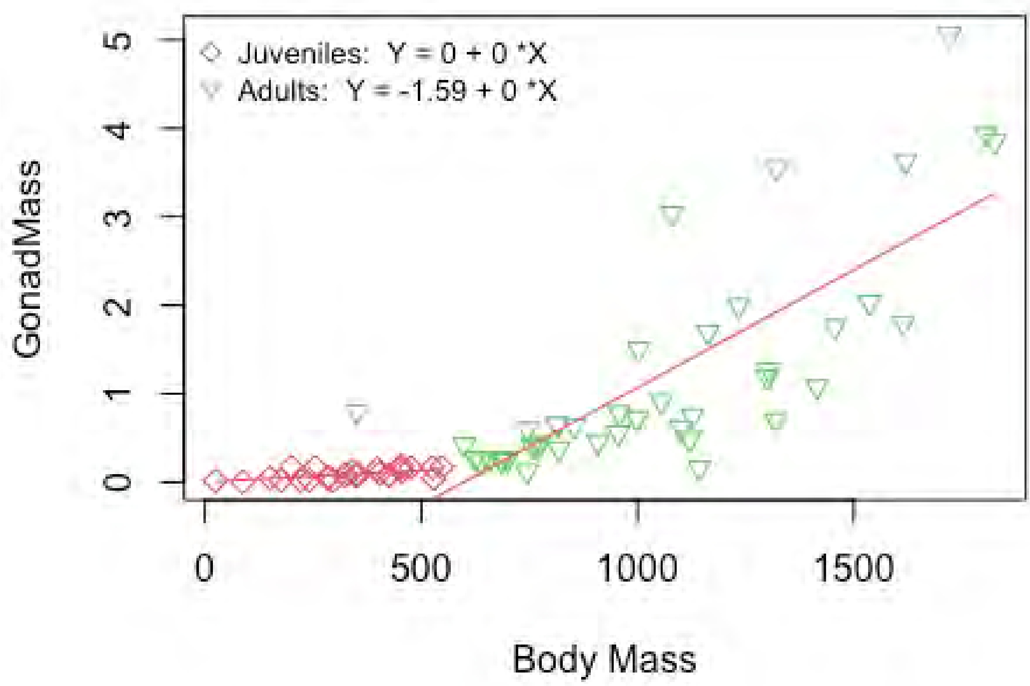
The method is used in other studies, e.g.,

Parvizi, E., Naderloo, R., Keikhosravi, A., and Schubart, C. D., 2017, Life history traits and patterns of sexual dimorphism in the freshwater crab Potamon ibericum (Bieberstein, 1809) (Decapoda: Brachyura: Potamidae) from the western Alborz Mountains, Iran: Journal of Crustacean Biology, v. 37, no. 3, p. 323-331.

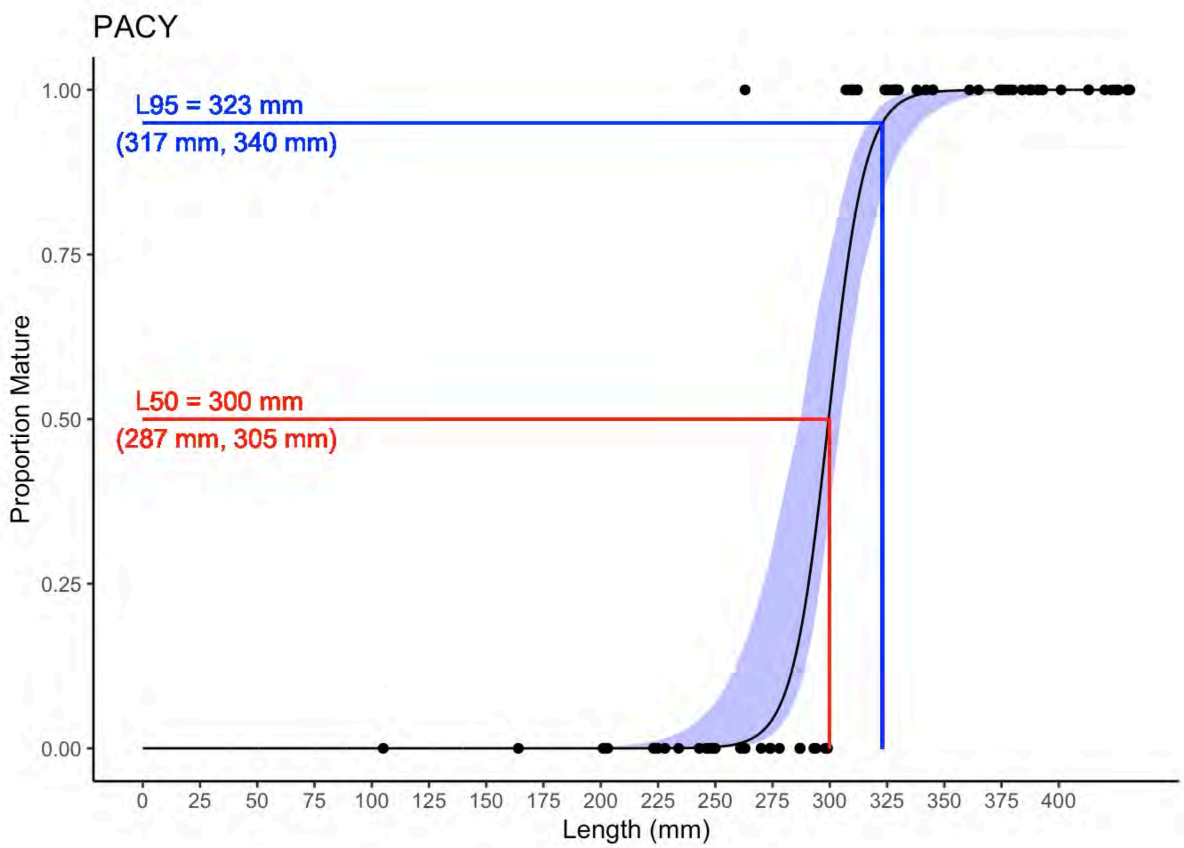
Caill-Milly, N., Sanchez, F., Benito, D., Ruiz, P., Izagirre, U., and Briaudeau, T., 2023, Assessment of size at first maturity for Ruditapes philippinarum from Arcachon Bay (French Atlantic coast): New insights for fishery management: Estuarine, Coastal and Shelf Science, v. 285, p. 108321.

```
## all individuals were used in the analysis
```

The plot below shows the results of the assignment with principal component analysis. The Red diamonds show individuals assigned as immature, while the green triangles show individuals assigned as mature. Body mass and gonad mass are both in grams.



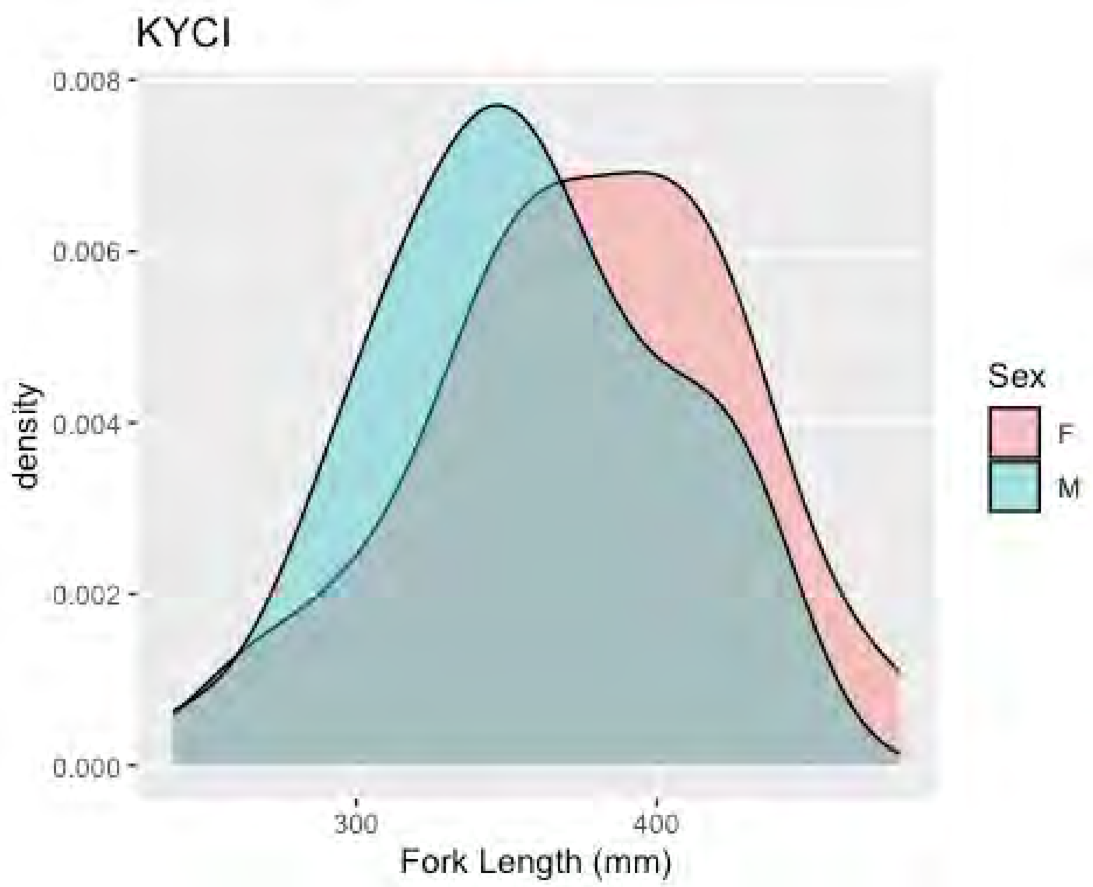

The maturity ogive for males is shown below. Black line is the logistic estimate of the proportion of the population that as reached maturity at each fork length. Purple shading shows the 95% confidence envelope. Red line shows the length where 50% of the population is mature (L50), with the 95% confidence range of values given in parentheses. Blue line shows the same information for the L95. Black dots show each individual fish used for the input dataset.



## 6.4 Kyphosus cinerascens

K. cinerascens photographed in waters off the fire station at Pupukea, O'ahu. Photo: K Weng.

The size distribution for females and males was as follows:

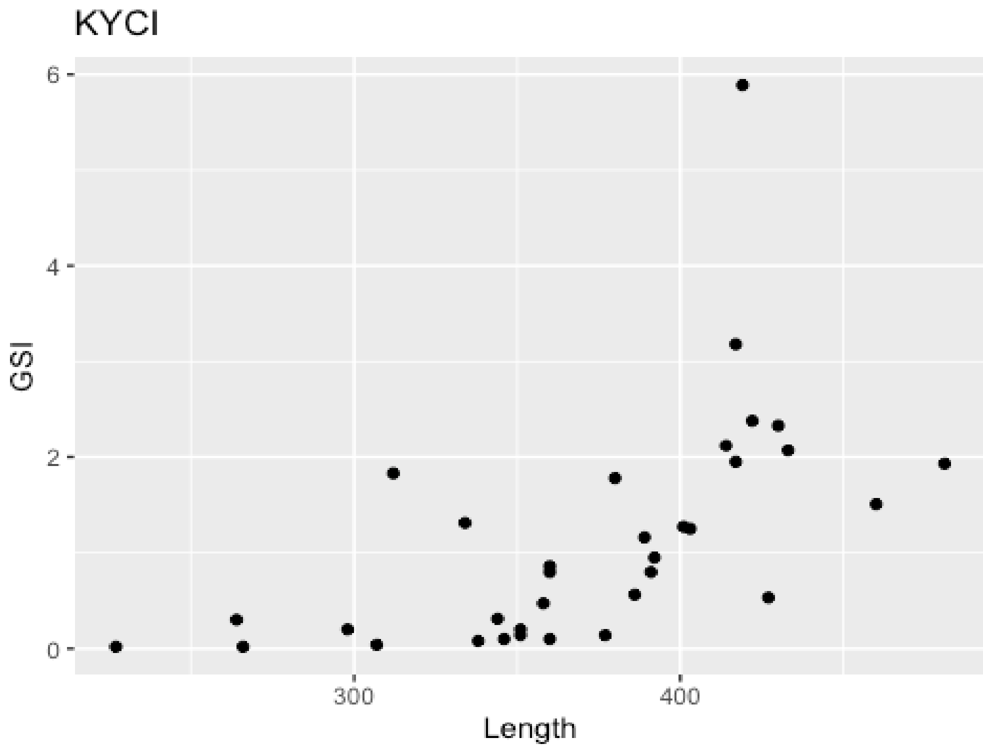


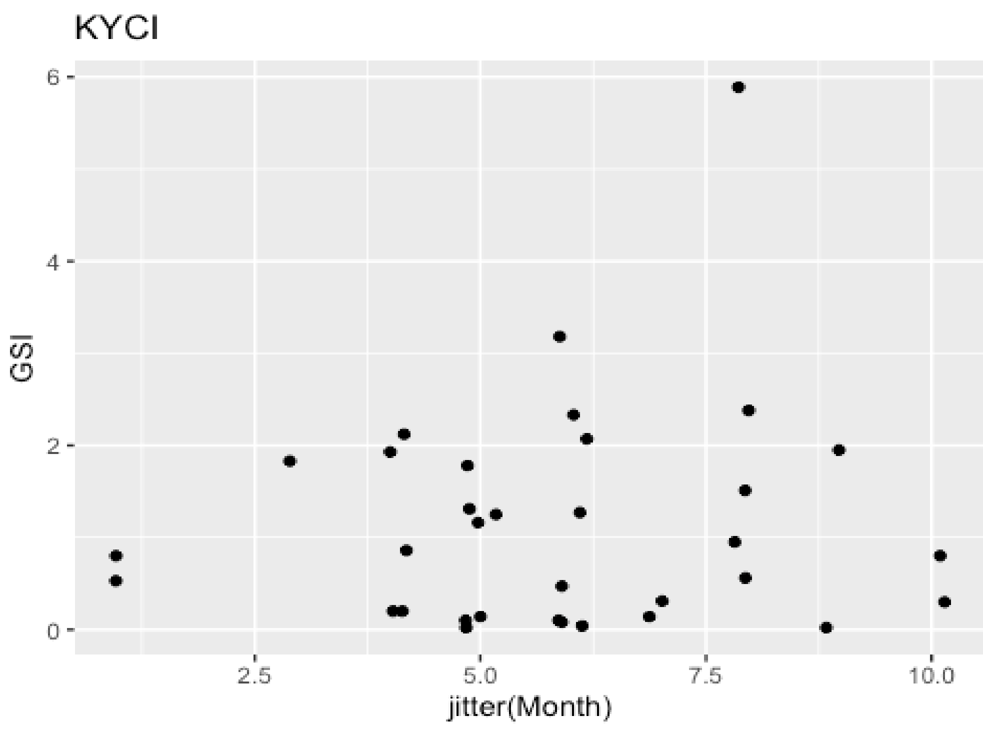

### 6.4.1 KYCI Females

In the table below, Length = Fork Length, Total = Total Length. Maturity was assigned based on oocyte stages (microscopic assignment) and appearance of ovaries (macroscopic assignment). 1 = mature, 0 = immature. Scatterplots are shown for the change in GSI with length, and the change in GSI with season of year.

| Month | Location | Species | Length | Total | Sex | Mass | GonadMass | GSI | Maturity |
|---|---|---|---|---|---|---|---|---|---|
| 10 | Market | KYCI | 264 | 301 | F | 481 | 1.436 | 0.30 | 0 |
| 9 | Market | KYCI | 266 | 305 | F | 489 | 0.110 | 0.02 | 0 |
| 4 | Market | KYCI | 298 | 339 | F | 712 | 1.424 | 0.20 | 0 |
| 6 | Moku manu | KYCI | 307 | 351 | F | 702 | 0.264 | 0.04 | 0 |
| 3 | Moku Manu | KYCI | 312 | 351 | F | 797 | 14.562 | 1.83 | 1 |
| 5 | Makapuu | KYCI | 334 | 377 | F | 911 | 11.920 | 1.31 | 1 |
| 6 | Moku manu | KYCI | 338 | 377 | F | 951 | 0.780 | 0.08 | 0 |
| 7 | Kaena w | KYCI | 344 | 398 | F | 1028 | 3.164 | 0.31 | 1 |

| Month | Location | Species | Length | Total | Sex | Mass | GonadMass | GSI | Maturity |
|---|---|---|---|---|---|---|---|---|---|
| 5 | K Bay | KYCI | 346 | 392 | F | 1100 | 1.111 | 0.10 | 0 |
| 7 | K Bay | KYCI | 351 | 401 | F | 1319 | 1.823 | 0.14 | 0 |
| 4 | Market | KYCI | 351 | 400 | F | 1187 | 2.380 | 0.20 | 0 |
| 6 | Market | KYCI | 358 | 402 | F | 1206 | 5.705 | 0.47 | 1 |
| 6 | Market | KYCI | 360 | 402 | F | 1123 | 1.163 | 0.10 | 0 |
| 10 | Moku Manu | KYCI | 360 | 410 | F | 1198 | 9.568 | 0.80 | 1 |
| 4 | Market | KYCI | 360 | 404 | F | 1287 | 11.060 | 0.86 | 1 |
| 5 | K Bay | KYCI | 377 | 429 | F | 1576 | 2.281 | 0.14 | 0 |
| 5 | Moku Manu | KYCI | 380 | 417 | F | 1458 | 26.000 | 1.78 | 1 |
| 8 | Moku Manu | KYCI | 386 | 431 | F | 1421 | 7.955 | 0.56 | 1 |
| 5 | Mokuleia | KYCI | 389 | 440 | F | 1421 | 16.540 | 1.16 | 1 |
| 1 | Moku Manu | KYCI | 391 | 442 | F | 1470 | 11.762 | 0.80 | 1 |
| 8 | Moku Manu | KYCI | 392 | 443 | F | 1635 | 15.521 | 0.95 | 1 |
| 6 | Market | KYCI | 401 | 457 | F | 1771 | 22.558 | 1.27 | 1 |
| 5 | Mokuleia | KYCI | 403 | 448 | F | 1589 | 19.935 | 1.25 | 1 |
| 4 | NS | KYCI | 414 | 464 | F | 1609 | 34.128 | 2.12 | 1 |
| 6 | Market | KYCI | 417 | 475 | F | 2044 | 65.000 | 3.18 | 1 |
| 9 | Market | KYCI | 417 | 474 | F | 1874 | 36.616 | 1.95 | 1 |
| 8 | Moku Manu | KYCI | 419 | 471 | F | 1799 | 106.000 | 5.89 | 0 |
| 8 | Moku Manu | KYCI | 422 | 474 | F | 1849 | 44.000 | 2.38 | 1 |
| 1 | Moku Manu | KYCI | 427 | 488 | F | 2141 | 11.400 | 0.53 | 1 |
| 6 | Market | KYCI | 430 | 485 | F | 2319 | 54.000 | 2.33 | 1 |
| 6 | Market | KYCI | 433 | 490 | F | 1980 | 41.000 | 2.07 | 1 |
| 8 | Makua | KYCI | 460 | 508 | F | 2907 | 44.000 | 1.51 | 1 |
| 4 | Market | KYCI | 481 | 547 | F | 3159 | 61.000 | 1.93 | 1 |
| 5 | Moku Manu | KYCI | 227 | 261 | U | 302 | 0.049 | 0.02 | 0 |

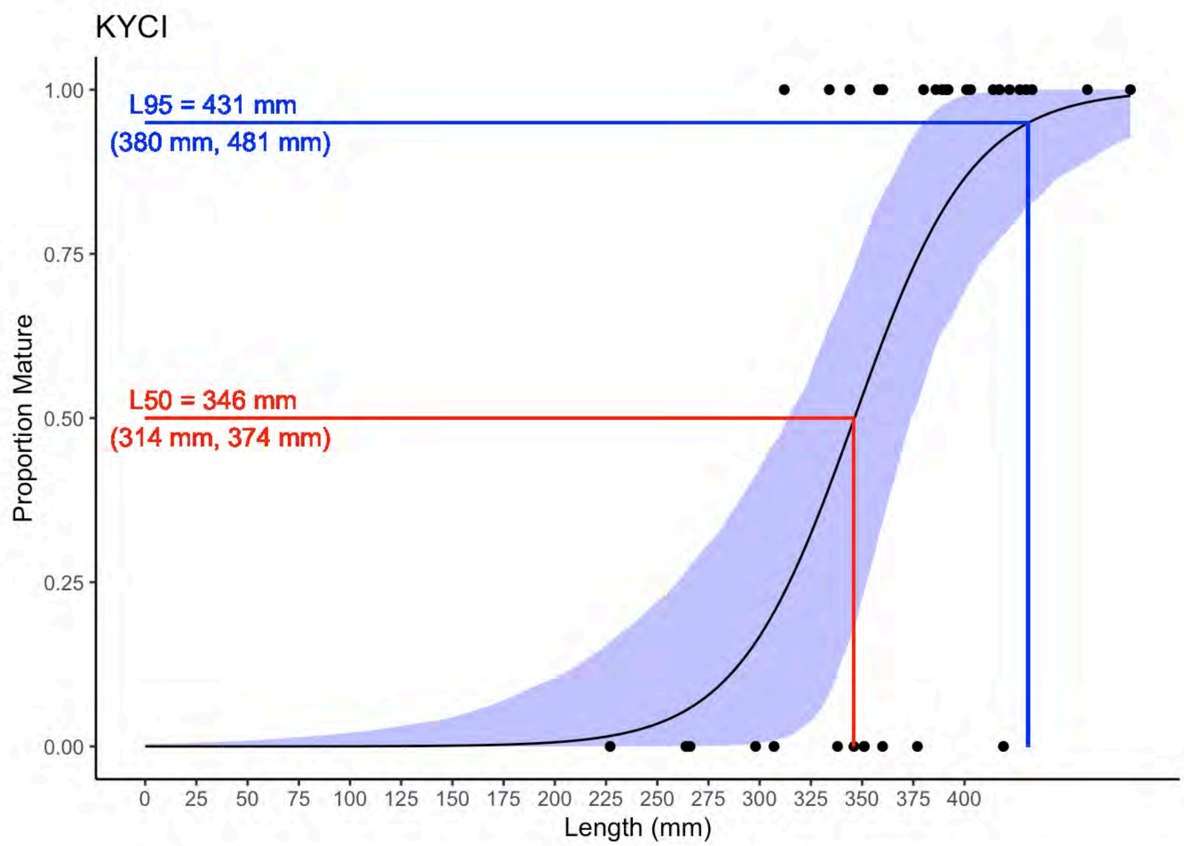



Once the maturity assignment is made for each individual, a logistic function is used to estimate size at maturity. The dataset is run through a general linear model with binomial error structure, using Length as the explanatory variable, and GSI as the response variable (R package: AquaticLifeHistory, Jonathan Smart).

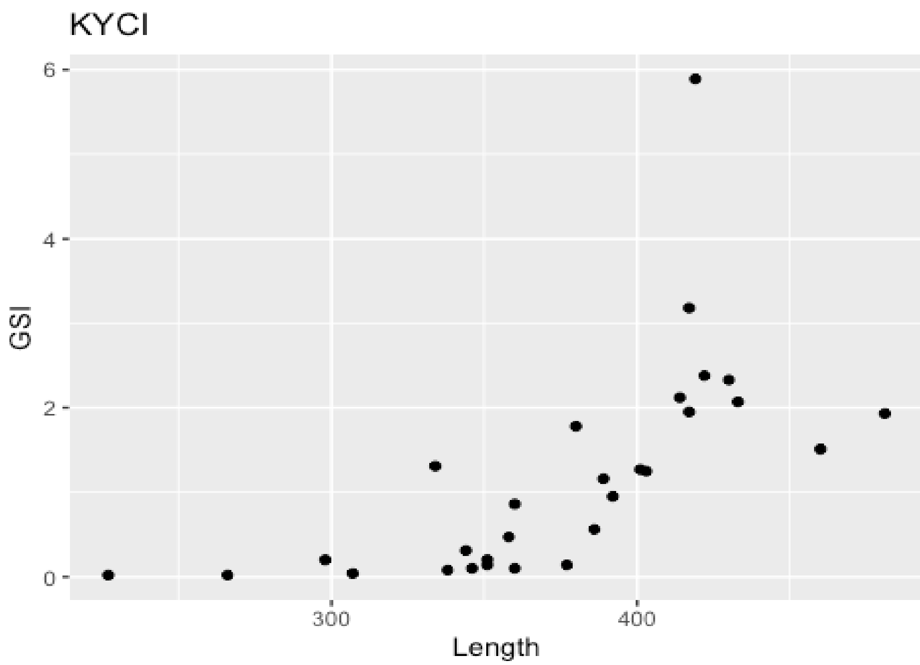
Smart J, Chin A, Tobin A, Simpfendorfer C (2016). "Multimodel approaches in shark and ray growth studies: strengths, weaknesses and the future." Fish and Fisheries, 17, 955–971.

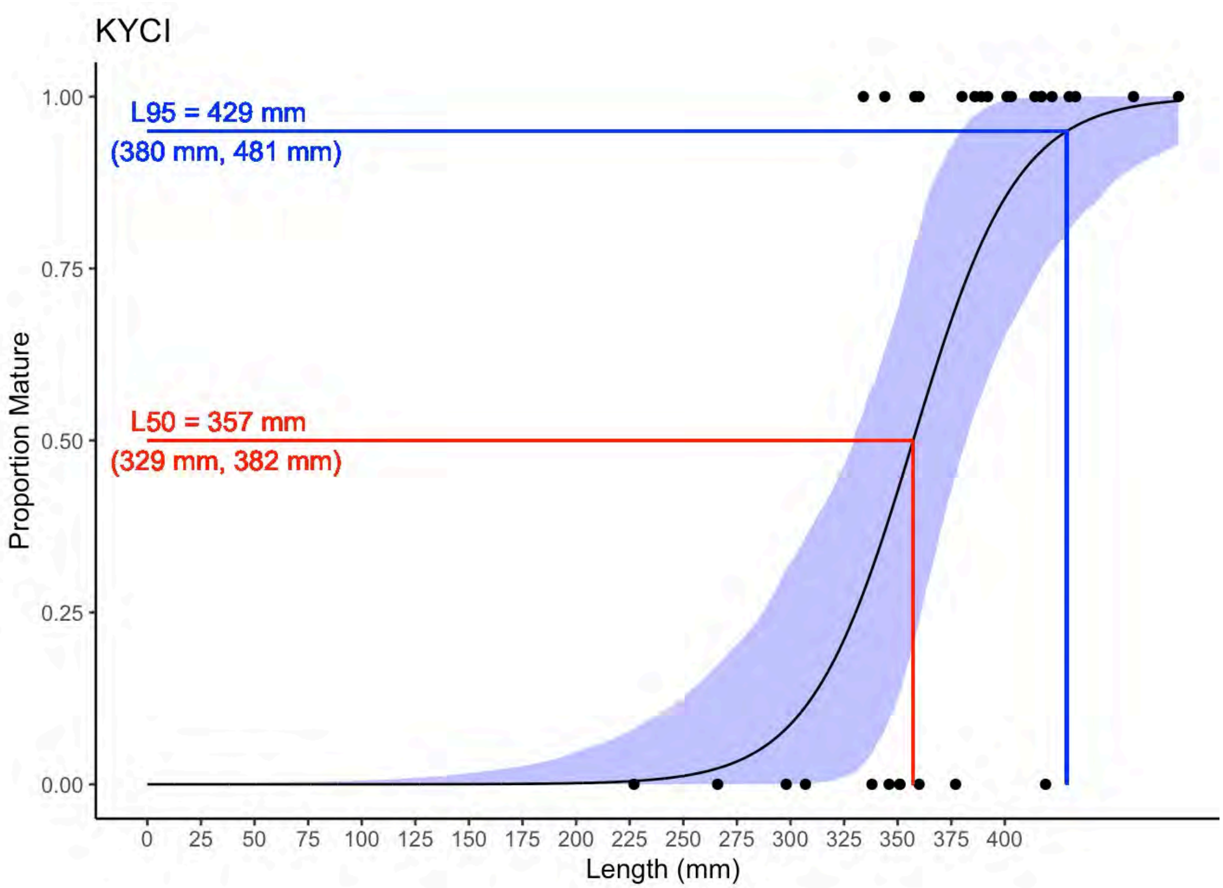
The maturity ogive for all females is shown below. Black line is the logistic estimate of the proportion of the population that as reached maturity at each fork length. Purple shading shows the 95% confidence envelope. Red line shows the length where 50% of the population is mature (L50), with the 95% confidence range of values given in parentheses. Blue line shows the same information for the L95. Black dots show each individual fish used for the input dataset.




In temperate zones, fish typically have a short spawning season. This means that during the off season, large mature fish have small gonads and may not have developing and advanced stage oocytes. Therefore, estimates of size at maturity are generally conducted after excluding individuals connected during the off season. This means that any fish included in the analysis was collected during a month when investment in gonads and oocyte development was expected. In tropical and subtropical zones there may be less of a season effect on fish reproduction. In order to determine if there is a strong effect of season, we can look at a plot of GSI vs month. Those months with high GSI would be considered the spawning season, while low GSI months would be considered the off season. Off season months can be excluded, being months before 4 and after 9.

The maturity ogive for females from spawning months is:


KYCI
GSI
6
4
2
0
300
400
Length

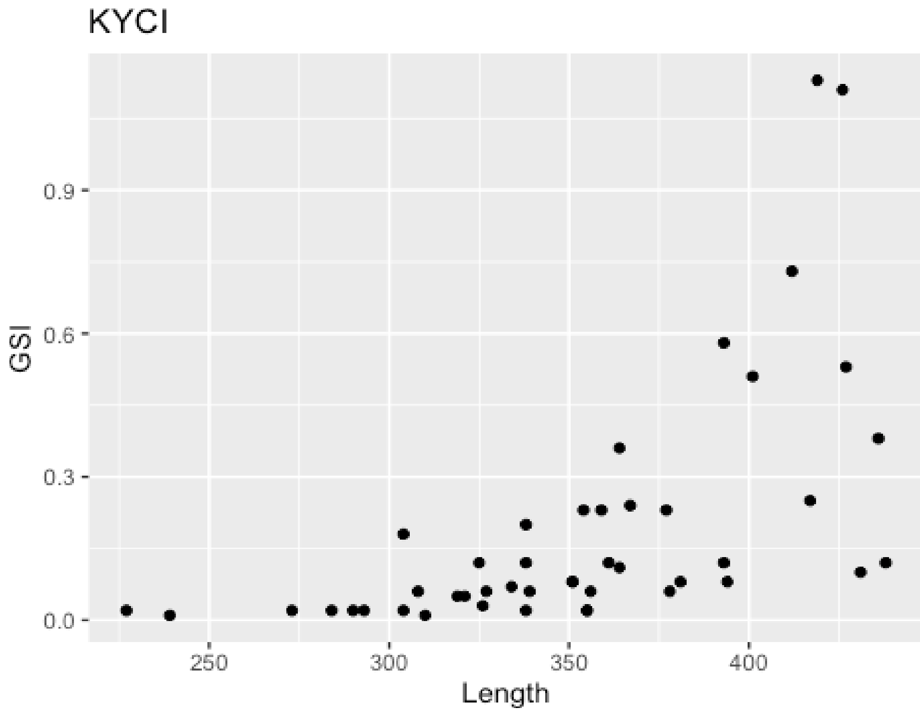

KYCI
L95 = 429 mm
(380 mm, 481 mm)
L50 = 357 mm
(329 mm, 382 mm)
Proportion Mature
1.00
0.75
0.50
0.25
0.00
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
Length (mm)

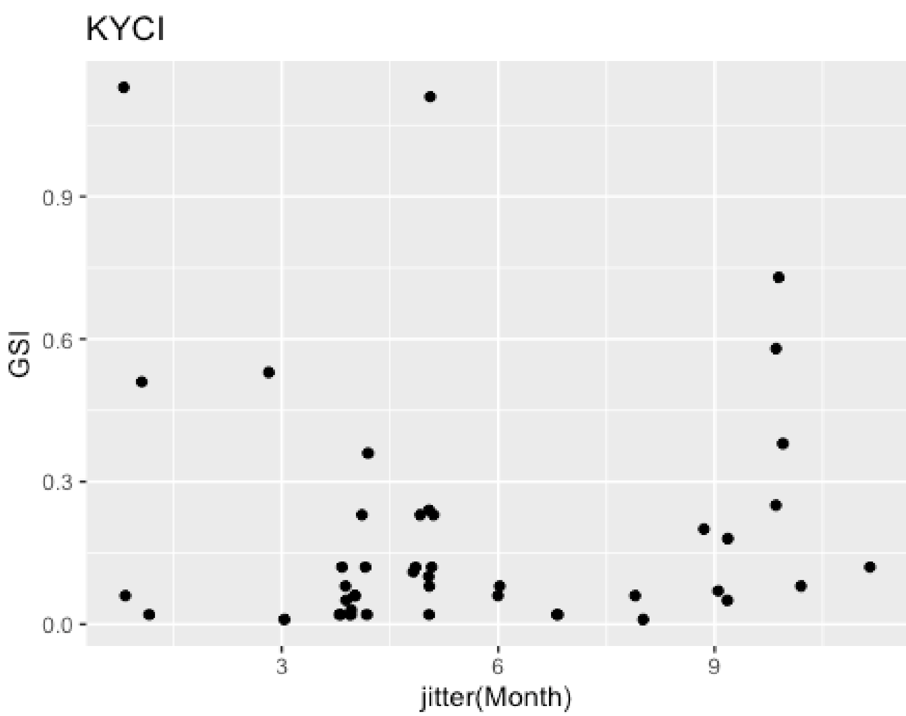
### 6.4.2 KYCI Males

In the table below, Length = Fork Length, Total = Total Length. For males it was not possible to conduct micro and macroscopic maturity assignment; histology would be necessary for this purpose. Therefore, maturity is assigned using a statistical approach, described below. Scatterplots are shown for the change in GSI with length, and the change in GSI with season of year.

| Month | Location | Species | Length | Total | Sex | Mass | GonadMass | GSI |
|---|---|---|---|---|---|---|---|---|
| 8 | Market | KYCI | 239 | 269 | M | 326 | 0.040 | 0.01 |
| 7 | Market | KYCI | 273 | 316 | M | 511 | 0.081 | 0.02 |
| 4 | UPPERS | KYCI | 284 | 315 | M | 498 | 0.080 | 0.02 |
| 4 | Market | KYCI | 290 | 330 | M | 624 | 0.110 | 0.02 |
| 4 | Market | KYCI | 293 | 334 | M | 651 | 0.120 | 0.02 |
| 9 | Market | KYCI | 304 | 344 | M | 756 | 1.348 | 0.18 |
| 1 | Makapuu | KYCI | 304 | 353 | M | 722 | 0.177 | 0.02 |
| 6 | Moku manu | KYCI | 308 | 355 | M | 826 | 0.485 | 0.06 |
| 3 | Rabbit | KYCI | 310 | 354 | M | 756 | 0.067 | 0.01 |
| 4 | Market | KYCI | 319 | 365 | M | 861 | 0.454 | 0.05 |
| 9 | Market | KYCI | 321 | 368 | M | 879 | 0.411 | 0.05 |
| 11 | Black Island | KYCI | 325 | 369 | M | 940 | 1.150 | 0.12 |
| 4 | Market | KYCI | 326 | 373 | M | 953 | 0.274 | 0.03 |
| 4 | Market | KYCI | 327 | 374 | M | 939 | 0.591 | 0.06 |
| 9 | Market | KYCI | 334 | 374 | M | 974 | 0.705 | 0.07 |
| 4 | Market | KYCI | 338 | 385 | M | 1050 | 0.198 | 0.02 |
| 5 | Moku Manu | KYCI | 338 | 374 | M | 952 | 1.149 | 0.12 |
| 9 | Market | KYCI | 338 | 384 | M | 985 | 2.000 | 0.20 |
| 8 | Moku Manu | KYCI | 339 | 382 | M | 1033 | 0.661 | 0.06 |
| 10 | Moku Manu | KYCI | 351 | 394 | M | 1022 | 0.769 | 0.08 |
| 5 | Mokuleia | KYCI | 351 | 398 | M | 1168 | 0.984 | 0.08 |
| 5 | Mokuleia | KYCI | 354 | 402 | M | 1127 | 2.549 | 0.23 |
| 7 | K Bay | KYCI | 355 | 400 | M | 1285 | 0.282 | 0.02 |
| 4 | Market | KYCI | 355 | 400 | M | 1214 | 0.230 | 0.02 |
| 5 | Market | KYCI | 359 | 400 | M | 1146 | 2.670 | 0.23 |
| 4 | Market | KYCI | 361 | 404 | M | 1208 | 1.470 | 0.12 |
| 5 | Moku Manu | KYCI | 364 | 414 | M | 1293 | 1.397 | 0.11 |
| 4 | Sunset Beach | KYCI | 364 | 410 | M | 1358 | 4.929 | 0.36 |
| 5 | Moku Manu | KYCI | 367 | 420 | M | 1253 | 2.965 | 0.24 |
| 4 | MARKET | KYCI | 377 | 427 | M | 1390 | 3.256 | 0.23 |
| 4 | Waimanalo | KYCI | 378 | 428 | M | 1451 | 0.853 | 0.06 |
| 4 | Waimanalo | KYCI | 381 | 430 | M | 1363 | 1.104 | 0.08 |
| 10 | Moku Manu | KYCI | 393 | 442 | M | 1369 | 7.938 | 0.58 |

| Month | Location | Species | Length | Total | Sex | Mass | GonadMass | GSI |
|---|---|---|---|---|---|---|---|---|
| 5 | Moku Manu | KYCI | 393 | 428 | M | 1426 | 1.641 | 0.12 |
| 6 | Moku manu | KYCI | 394 | 442 | M | 1540 | 1.207 | 0.08 |
| 1 | Hanauma Point S | KYCI | 401 | 450 | M | 1607 | 8.176 | 0.51 |
| 10 | Moku Manu | KYCI | 412 | 463 | M | 1680 | 12.193 | 0.73 |
| 10 | Moku Manu | KYCI | 417 | 471 | M | 1770 | 4.442 | 0.25 |
| 1 | Hanauma Point S | KYCI | 419 | 473 | M | 2063 | 23.360 | 1.13 |
| 5 | Moku Manu | KYCI | 426 | 466 | M | 2047 | 22.770 | 1.11 |
| 3 | Moku Manu | KYCI | 427 | 482 | M | 2200 | 11.611 | 0.53 |
| 5 | Makapuu | KYCI | 431 | 484 | M | 1986 | 2.070 | 0.10 |
| 10 | Moku Manu | KYCI | 436 | 490 | M | 2034 | 7.693 | 0.38 |
| 4 | Sunset Beach | KYCI | 438 | 487 | M | 1953 | 2.407 | 0.12 |
| 5 | Moku Manu | KYCI | 227 | 261 | U | 302 | 0.049 | 0.02 |
| 1 | Makapuu | KYCI | 356 | 401 | U | 1105 | 0.662 | 0.06 |




A Principal Component analysis is conducted on body mass and gonad mass (which together are the GSI), using R package sizeMat (Josymar Torrejon-Magallanes). This separates the population into two groups with different slopes of gonad mass vs. body mass, where the mature individuals have a steeper slope. This occurs because prior to the onset of maturity an individual is a allocating energy to somatic growth, whereas after onset of maturity it allocates a portion to reproductive development/output.

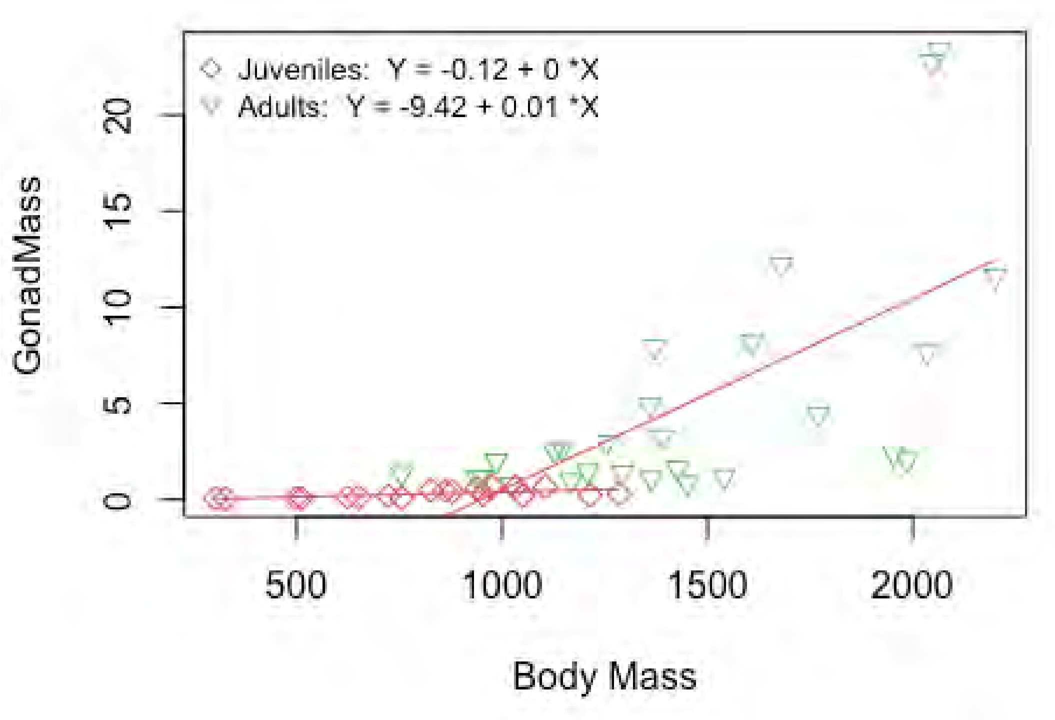
The method is used in other studies, e.g.,

Parvizi, E., Naderloo, R., Keikhosravi, A., and Schubart, C. D., 2017, Life history traits and patterns of sexual dimorphism in the freshwater crab Potamon ibericum (Bieberstein, 1809) (Decapoda: Brachyura: Potamidae) from the western Alborz Mountains, Iran: Journal of Crustacean Biology, v. 37, no. 3, p. 323-331.

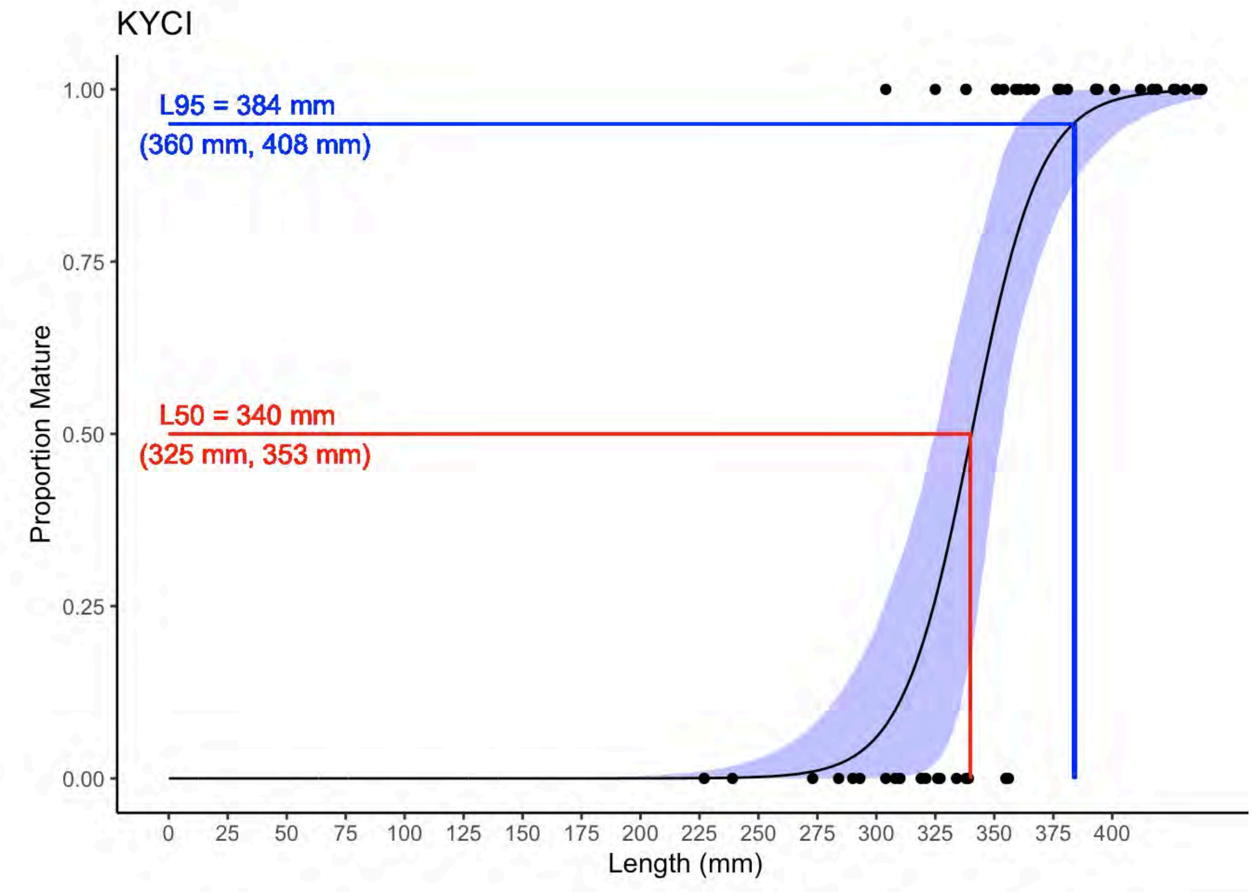
Caill-Milly, N., Sanchez, F., Benito, D., Ruiz, P., Izagirre, U., and Briaudeau, T., 2023, Assessment of size at first maturity for Ruditapes philippinarum from Arcachon Bay (French Atlantic coast): New insights for fishery management: Estuarine, Coastal and Shelf Science, v. 285, p. 108321.

```
## all individuals were used in the analysis
```

The plot below shows the results of the assignment with principal component analysis. The Red diamonds show individuals assigned as immature, while the green triangles show individuals assigned as mature. Body mass and gonad mass are both in grams.



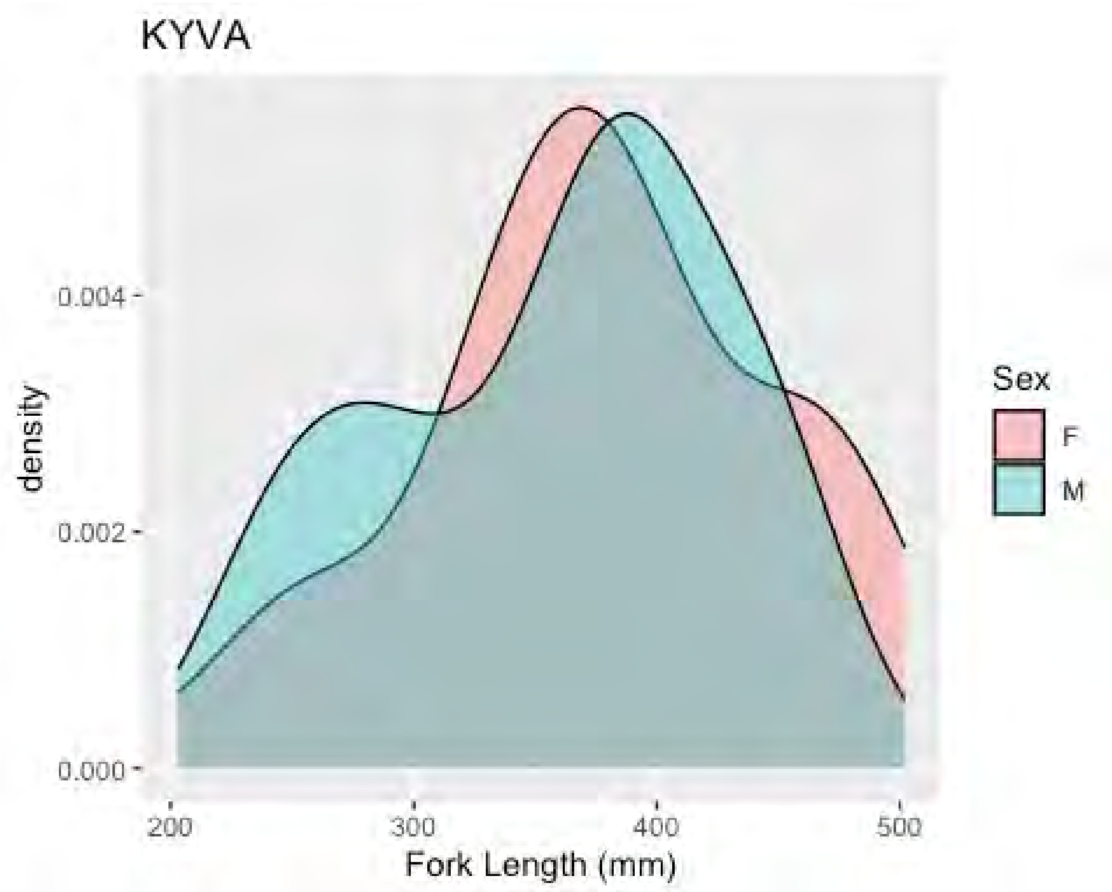

The maturity ogive for males is shown below. Black line is the logistic estimate of the proportion of the population that as reached maturity at each fork length. Purple shading shows the 95% confidence envelope. Red line shows the length where 50% of the population is mature (L50), with the 95% confidence range of values given in parentheses. Blue line shows the same information for the L95. Black dots show each individual fish used for the input dataset.




### 6.5 Kyphosus vaigiensis, lowfin chub


K. vaigiensis captured in O'ahu waters being measured and dissected.

The size distribution for females and males was as follows:

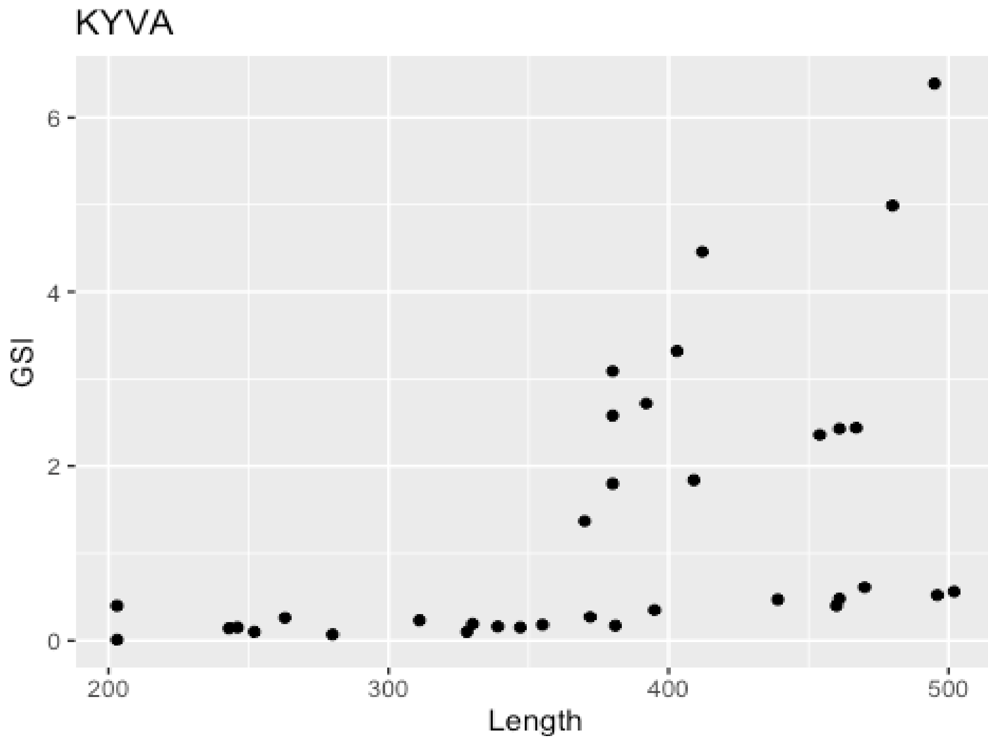


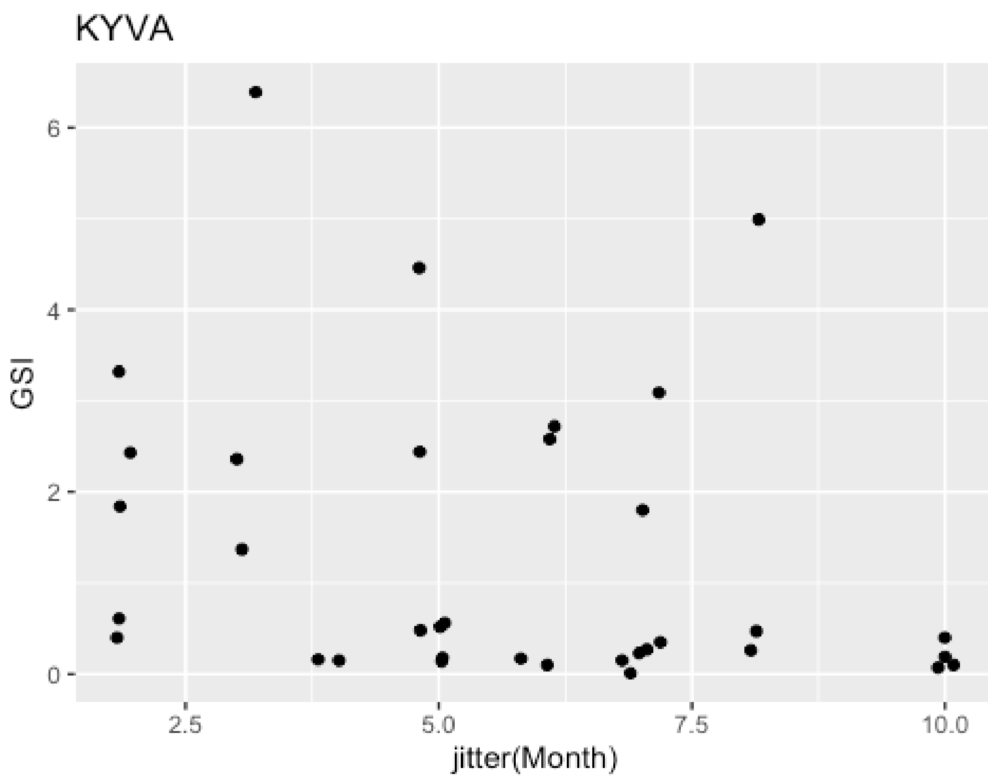

### 6.5.1 KYVA Females

In the table below, Length = Fork Length, Total = Total Length. Maturity was assigned based on oocyte stages (microscopic assignment) and appearance of ovaries (macroscopic assignment). 1 = mature, 0 = immature. Scatterplots are shown for the change in GSI with length, and the change in GSI with season of year.

| | Month | Location | Species | Length | Total | Sex | Mass | GonadMass | GSI | Maturity |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 10 | Market | KYVA | 203 | 230 | F | 200 | 0.799 | 0.40 | 0 |
| 2 | 5 | Mokuleia | KYVA | 243 | 282 | F | 338 | 0.466 | 0.14 | 0 |
| 3 | 4 | Moku Manu | KYVA | 246 | 276 | F | 396 | 0.595 | 0.15 | 0 |
| 4 | 10 | Moku Manu | KYVA | 252 | 290 | F | 353 | 0.349 | 0.10 | 0 |
| 5 | 8 | Moku manu | KYVA | 263 | 306 | F | 423 | 1.087 | 0.26 | 0 |
| 6 | 10 | Kaaawa | KYVA | 280 | 323 | F | 517 | 0.375 | 0.07 | 0 |
| 8 | 7 | Market | KYVA | 311 | 355 | F | 726 | 1.690 | 0.23 | 0 |
| 9 | 6 | Market | KYVA | 328 | 377 | F | 986 | 0.987 | 0.10 | 0 |
| 10 | 10 | Kaaawa | KYVA | 330 | 383 | F | 907 | 1.739 | 0.19 | 0 |

| | Month | Location | Species | Length | Total | Sex | Mass | GonadMass | GSI | Maturity |
|---|---|---|---|---|---|---|---|---|---|---|
| 13 | 4 | Rabbit | KYVA | 339 | 384 | F | 976 | 1.607 | 0.16 | 0 |
| 16 | 7 | K Bay | KYVA | 347 | 369 | F | 1040 | 1.587 | 0.15 | 0 |
| 18 | 5 | Market | KYVA | 355 | 408 | F | 1091 | 1.920 | 0.18 | 0 |
| 21 | 3 | Rabbit | KYVA | 370 | 422 | F | 1187 | 16.260 | 1.37 | 1 |
| 22 | 7 | K Bay | KYVA | 372 | 427 | F | 1151 | 3.164 | 0.27 | 0 |
| 24 | 7 | Market | KYVA | 380 | 435 | F | 1267 | 39.112 | 3.09 | 1 |
| 25 | 6 | Kaaawa | KYVA | 380 | 424 | F | 1198 | 30.952 | 2.58 | 1 |
| 26 | 7 | uppers? | KYVA | 380 | 440 | F | 1261 | 22.717 | 1.80 | 1 |
| 27 | 6 | Kaaawa | KYVA | 381 | 427 | F | 1233 | 2.113 | 0.17 | 0 |
| 28 | 6 | Market | KYVA | 392 | 453 | F | 1453 | 39.485 | 2.72 | 1 |
| 29 | 7 | K Bay | KYVA | 395 | 450 | F | 1470 | 5.160 | 0.35 | 0 |
| 32 | 2 | Market | KYVA | 403 | 462 | F | 1719 | 57.000 | 3.32 | 1 |
| 33 | 2 | Market | KYVA | 409 | 470 | F | 1783 | 32.788 | 1.84 | 1 |
| 34 | 5 | Mokuleia | KYVA | 412 | 475 | F | 1635 | 73.000 | 4.46 | 1 |
| 36 | 8 | Market | KYVA | 439 | 503 | F | 2185 | 10.202 | 0.47 | 1 |
| 37 | 3 | Rabbit | KYVA | 454 | 512 | F | 2466 | 58.320 | 2.36 | 1 |
| 38 | 2 | Market | KYVA | 460 | 518 | F | 2516 | 9.939 | 0.40 | 1 |
| 39 | 2 | Market | KYVA | 461 | 510 | F | 2634 | 64.000 | 2.43 | 1 |
| 40 | 5 | Market | KYVA | 461 | 521 | F | 2167 | 10.401 | 0.48 | 1 |
| 41 | 5 | Market | KYVA | 467 | 527 | F | 2171 | 53.000 | 2.44 | 1 |
| 42 | 2 | Market | KYVA | 470 | 532 | F | 2540 | 15.535 | 0.61 | 1 |
| 43 | 8 | Ala Moana | KYVA | 480 | 543 | F | 2927 | 146.000 | 4.99 | 1 |
| 44 | 3 | Market | KYVA | 495 | 560 | F | 2897 | 185.000 | 6.39 | 1 |
| 45 | 5 | Market | KYVA | 496 | 568 | F | 2931 | 15.277 | 0.52 | 1 |
| 46 | 5 | Market | KYVA | 502 | 568 | F | 2733 | 15.177 | 0.56 | 1 |
| 47 | 7 | Wainae | KYVA | 203 | 229 | U | 243 | 0.026 | 0.01 | 0 |

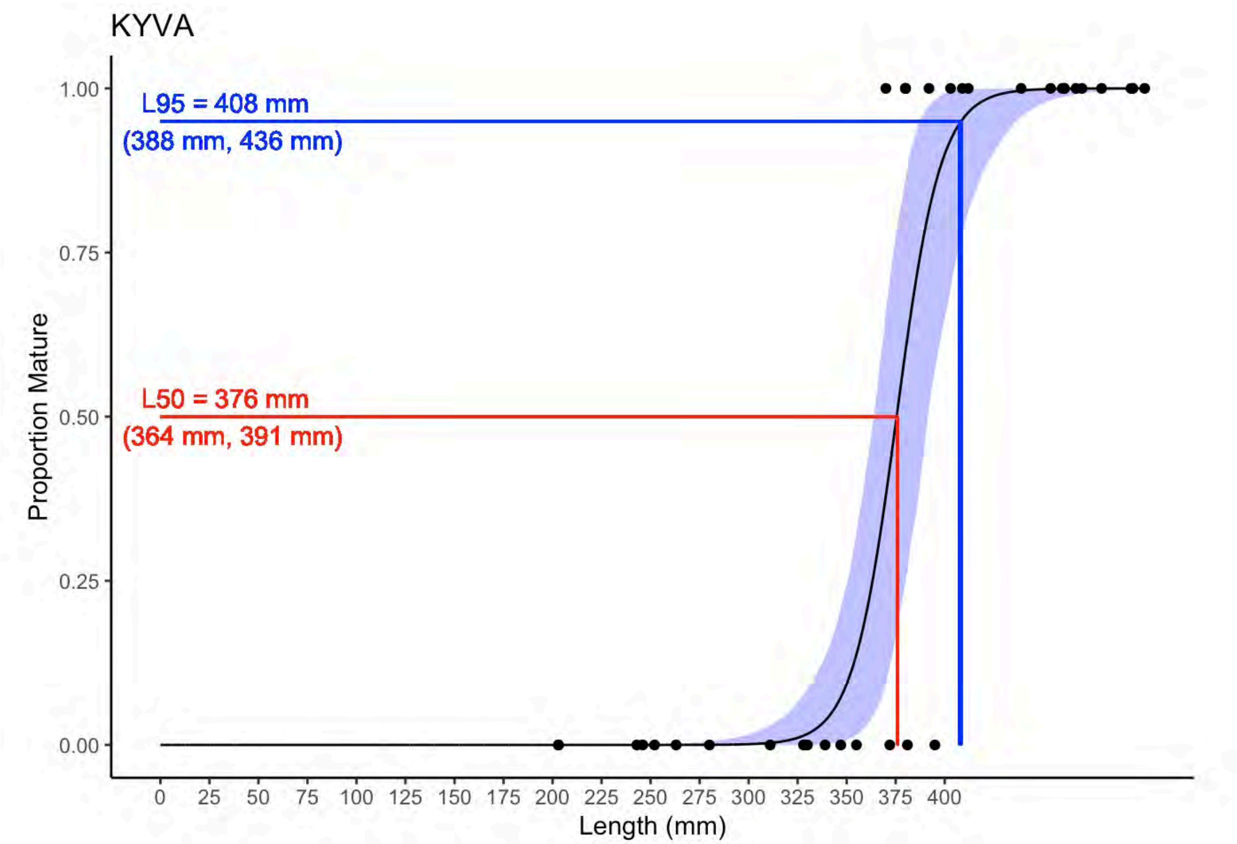



Once the maturity assignment is made for each individual, a logistic function is used to estimate size at maturity. The dataset is run through a general linear model with binomial error structure, using Length as the explanatory variable, and GSI as the response variable (R package: AquaticLifeHistory, Jonathan Smart).

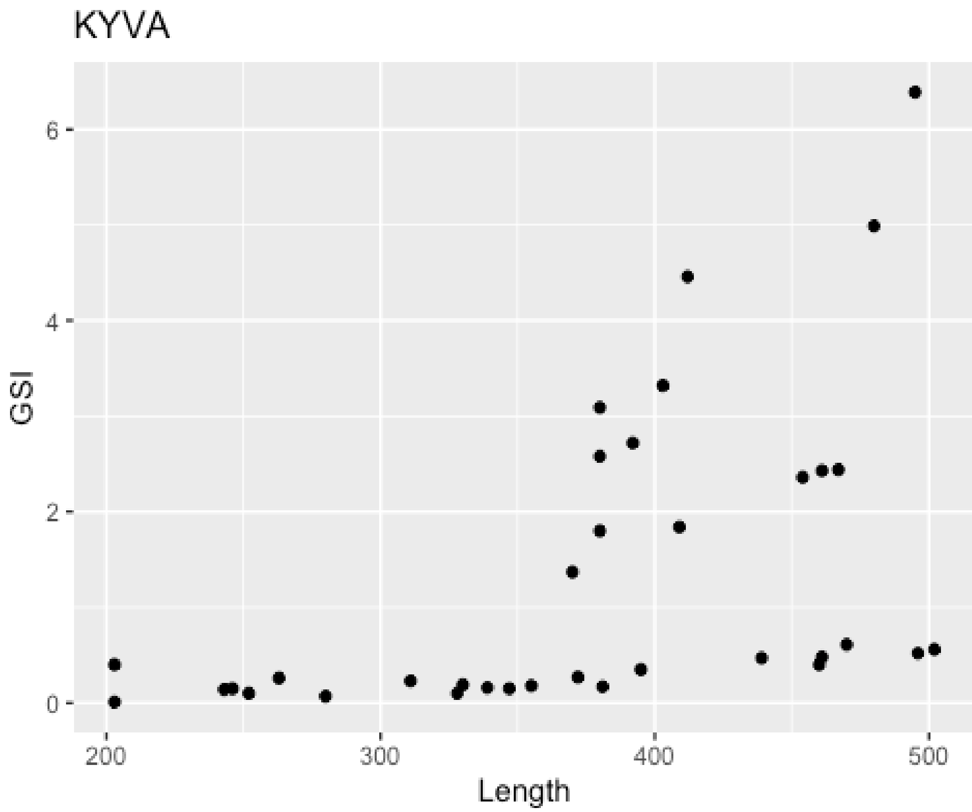
Smart J, Chin A, Tobin A, Simpfendorfer C (2016). "Multimodel approaches in shark and ray growth studies: strengths, weaknesses and the future." Fish and Fisheries, 17, 955–971.

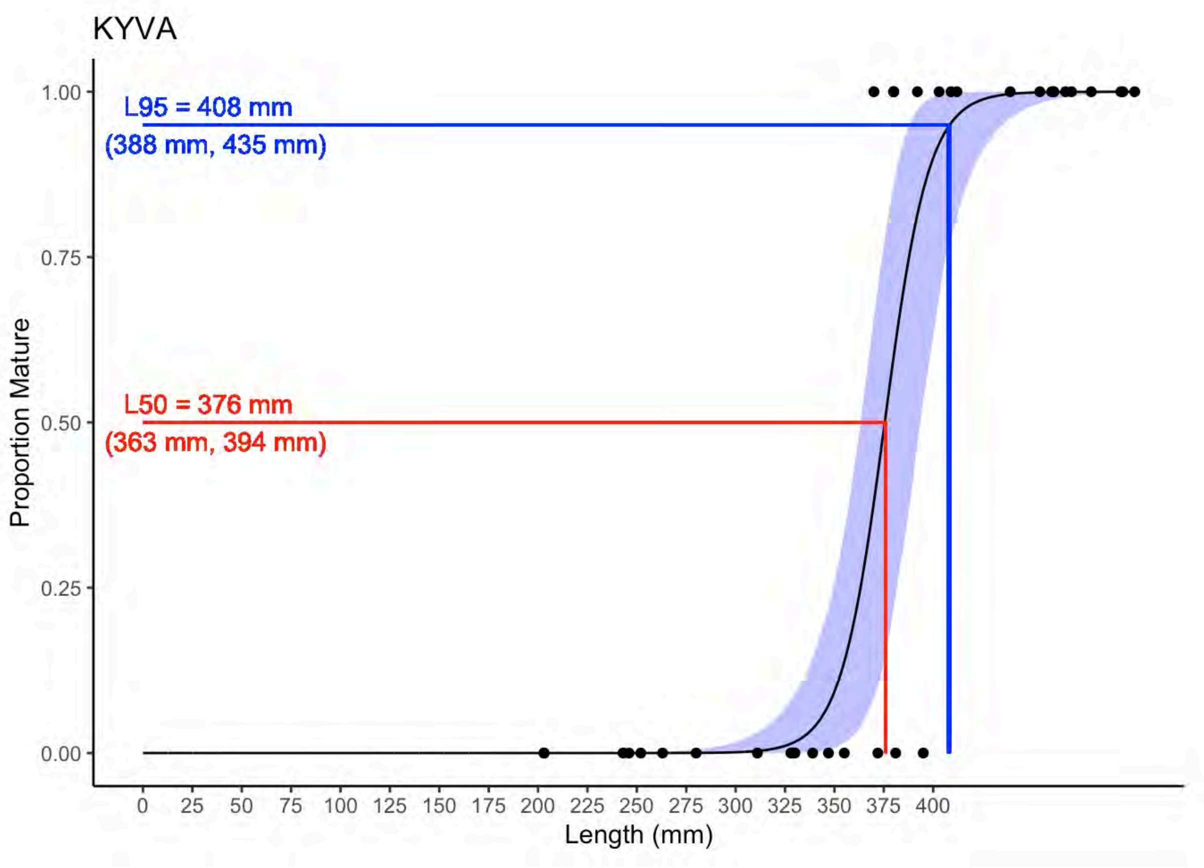
The maturity ogive for all females is shown below. Black line is the logistic estimate of the proportion of the population that as reached maturity at each fork length. Purple shading shows the 95% confidence envelope. Red line shows the length where 50% of the population is mature (L50), with the 95% confidence range of values given in parentheses. Blue line shows the same information for the L95. Black dots show each individual fish used for the input dataset.




In temperate zones, fish typically have a short spawning season. This means that during the off season, large mature fish have small gonads and may not have developing and advanced stage oocytes. Therefore, estimates of size at maturity are generally conducted after excluding individuals connected during the off season. This means that any fish included in the analysis was collected during a month when investment in gonads and oocyte development was expected. In tropical and subtropical zones there may be less of a season effect on fish reproduction. In order to determine if there is a strong effect of season, we can look at a plot of GSI vs month. Those months with high GSI would be considered the spawning season, while low GSI months would be considered the off season. Off season months can be excluded, being months before 2 and after 11.

The maturity ogive for females from spawning months is:


KYVA
GSI
0
2
4
6
200
300
400
500
Length

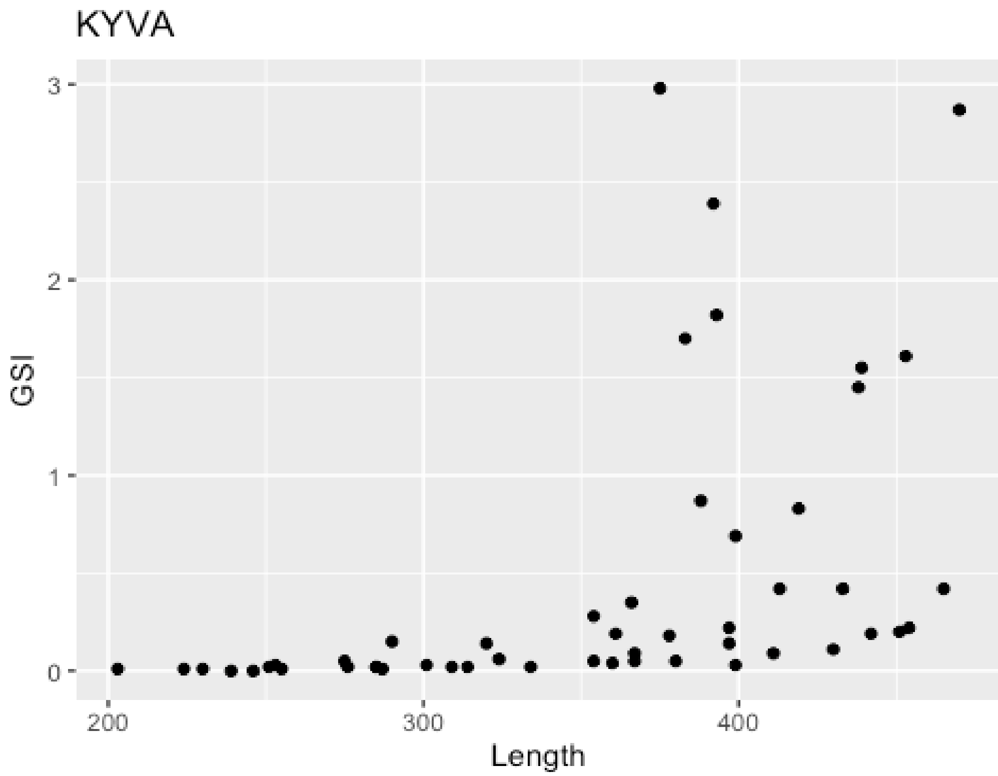

KYVA
L95 = 408 mm
(388 mm, 435 mm)
L50 = 376 mm
(363 mm, 394 mm)
Proportion Mature
0.00
0.25
0.50
0.75
1.00
0 25 50 75 100 125 150 175 200 225 250 275 300 325 350 375 400
Length (mm)

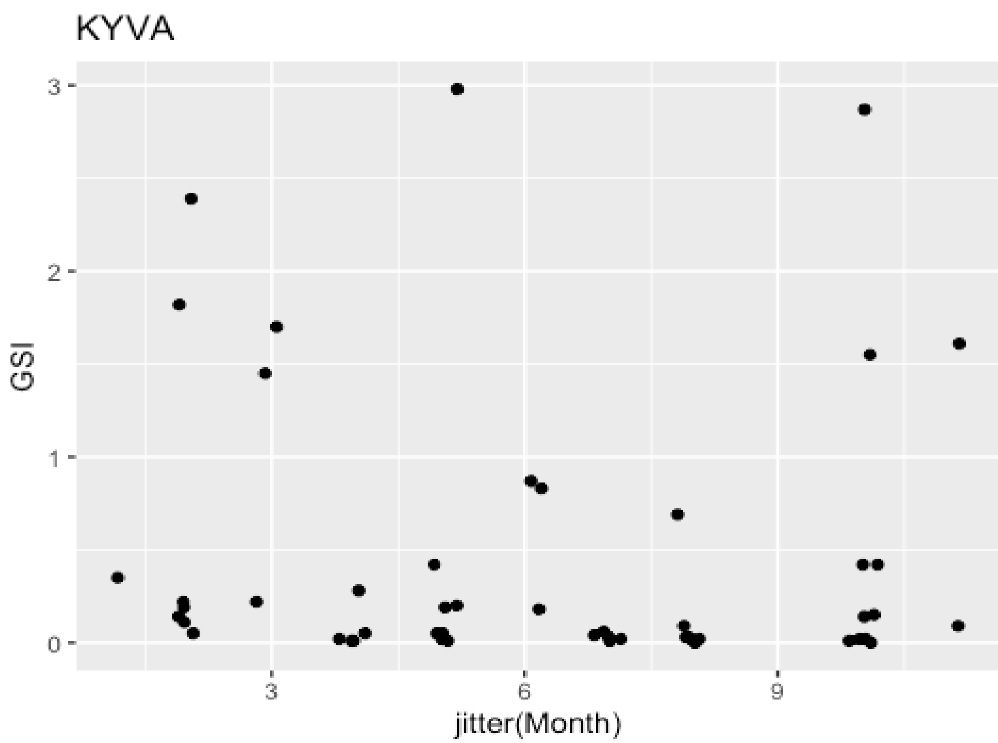
### 6.5.2 KYVA Males

In the table below, Length = Fork Length, Total = Total Length. For males it was not possible to conduct micro and macroscopic maturity assignment; histology would be necessary for this purpose. Therefore, maturity is assigned using a statistical approach, described below. Scatterplots are shown for the change in GSI with length, and the change in GSI with season of year.

| Month | Location | Species | Length | Total | Sex | Mass | GonadMass | GSI |
|---|---|---|---|---|---|---|---|---|
| 5 | Moku Manu | KYVA | 224 | 258 | M | 272 | 0.0190 | 0.0100 |
| 4 | Waimanalo | KYVA | 230 | 270 | M | 229 | 0.0120 | 0.0100 |
| 10 | Rabbit | KYVA | 239 | 267 | M | 307 | 0.0150 | 0.0001 |
| 8 | Market | KYVA | 246 | 287 | M | 359 | 0.0001 | 0.0001 |
| 4 | Moku Manu | KYVA | 251 | 294 | M | 377 | 0.0770 | 0.0200 |
| 8 | Moku Manu | KYVA | 253 | 295 | M | 368 | 0.1190 | 0.0300 |
| 4 | Moku Manu | KYVA | 255 | 291 | M | 428 | 0.0590 | 0.0100 |
| 5 | Moku Manu | KYVA | 275 | 318 | M | 505 | 0.2410 | 0.0500 |
| 8 | Market | KYVA | 276 | 319 | M | 472 | 0.0780 | 0.0200 |
| 7 | Kaena Point | KYVA | 285 | 328 | M | 548 | 0.1120 | 0.0200 |
| 5 | Mokuleia | KYVA | 285 | 328 | M | 542 | 0.1340 | 0.0200 |
| 10 | Kaaawa | KYVA | 287 | 328 | M | 550 | 0.0770 | 0.0100 |
| 10 | Market | KYVA | 290 | 335 | M | 584 | 0.8610 | 0.1500 |
| 10 | Moku Manu | KYVA | 309 | 359 | M | 607 | 0.1090 | 0.0200 |
| 8 | Market | KYVA | 314 | 361 | M | 831 | 0.1970 | 0.0200 |
| 10 | Kaaawa | KYVA | 320 | 365 | M | 823 | 1.1660 | 0.1400 |
| 7 | Market | KYVA | 324 | 367 | M | 778 | 0.4410 | 0.0600 |
| 10 | Kaaawa | KYVA | 334 | 386 | M | 1032 | 0.1960 | 0.0200 |
| 4 | Unknown (market) | KYVA | 354 | 404 | M | 1144 | 0.6190 | 0.0500 |
| 4 | NS | KYVA | 354 | 396 | M | 921 | 2.6000 | 0.2800 |
| 7 | K Bay | KYVA | 360 | 410 | M | 1174 | 0.5120 | 0.0400 |
| 5 | Kaaawa | KYVA | 361 | 411 | M | 1206 | 2.2420 | 0.1900 |
| 1 | Makapuu Wall | KYVA | 366 | 415 | M | 1046 | 3.6520 | 0.3500 |
| 5 | Market | KYVA | 367 | 414 | M | 1318 | 0.6370 | 0.0500 |
| 11 | Barbers Point | KYVA | 367 | 418 | M | 1229 | 1.1390 | 0.0900 |
| 5 | Moku Manu | KYVA | 375 | 432 | M | 1208 | 36.0000 | 2.9800 |
| 6 | Kaaawa | KYVA | 378 | 423 | M | 1207 | 2.2260 | 0.1800 |
| 2 | Red Can K-Bay | KYVA | 380 | 436 | M | 1303 | 0.6660 | 0.0500 |
| 3 | Moku Manu | KYVA | 383 | 442 | M | 1283 | 21.7830 | 1.7000 |
| 6 | Market | KYVA | 387 | 444 | M | 1578 | NA | NA |
| 6 | Market | KYVA | 388 | 442 | M | 1448 | 12.6340 | 0.8700 |
| 2 | Market | KYVA | 392 | 445 | M | 1675 | 40.0000 | 2.3900 |

| Month | Location | Species | Length | Total | Sex | Mass | GonadMass | GSI |
|---|---|---|---|---|---|---|---|---|
| 2 | Market | KYVA | 393 | 450 | M | 1445 | 26.3420 | 1.8200 |
| 2 | Red Can K-Bay | KYVA | 397 | 449 | M | 1357 | 3.0430 | 0.2200 |
| 2 | Market | KYVA | 397 | 455 | M | 1629 | 2.3090 | 0.1400 |
| 8 | Market | KYVA | 399 | 457 | M | 1530 | 10.5260 | 0.6900 |
| 8 | Market | KYVA | 399 | 452 | M | 1546 | 0.4960 | 0.0300 |
| 8 | Market | KYVA | 411 | 469 | M | 1606 | 1.4290 | 0.0900 |
| 10 | Moku Manu | KYVA | 413 | 468 | M | 1787 | 7.5420 | 0.4200 |
| 6 | Kaaawa | KYVA | 419 | 466 | M | 1560 | 12.8750 | 0.8300 |
| 2 | Market | KYVA | 430 | 492 | M | 2012 | 2.1140 | 0.1100 |
| 10 | Market | KYVA | 433 | 493 | M | 2002 | 8.3570 | 0.4200 |
| 3 | Market | KYVA | 438 | 501 | M | 2001 | 28.9700 | 1.4500 |
| 10 | Market | KYVA | 439 | 503 | M | 1876 | 29.0000 | 1.5500 |
| 2 | Market | KYVA | 442 | 507 | M | 2199 | 4.1110 | 0.1900 |
| 5 | Moku Manu | KYVA | 451 | 510 | M | 1941 | 3.9310 | 0.2000 |
| 11 | MOKU MANU | KYVA | 453 | 556 | M | 1957 | 31.5730 | 1.6100 |
| 3 | Market | KYVA | 454 | 519 | M | 2214 | 4.8640 | 0.2200 |
| 5 | Turtle Bay | KYVA | 465 | 531 | M | 1925 | 8.1400 | 0.4200 |
| 10 | Market | KYVA | 470 | 538 | M | 2333 | 67.0000 | 2.8700 |
| 7 | Wainae | KYVA | 203 | 229 | U | 243 | 0.0260 | 0.0100 |
| 7 | K Bay | KYVA | 301 | 345 | U | 610 | 0.1800 | 0.0300 |
| 7 | K Bay | KYVA | 362 | 412 | U | 1254 | NA | NA |
| 3 | Rabbit | KYVA | 395 | 452 | U | 1466 | 2.6970 | NA |




A Principal Component analysis is conducted on body mass and gonad mass (which together are the GSI), using R package sizeMat (Josymar Torrejon-Magallanes). This separates the population into two groups with different slopes of gonad mass vs. body mass, where the mature individuals have a steeper slope. This occurs because prior to the onset of maturity an individual is a allocating energy to somatic growth, whereas after onset of maturity it allocates a portion to reproductive development/output.

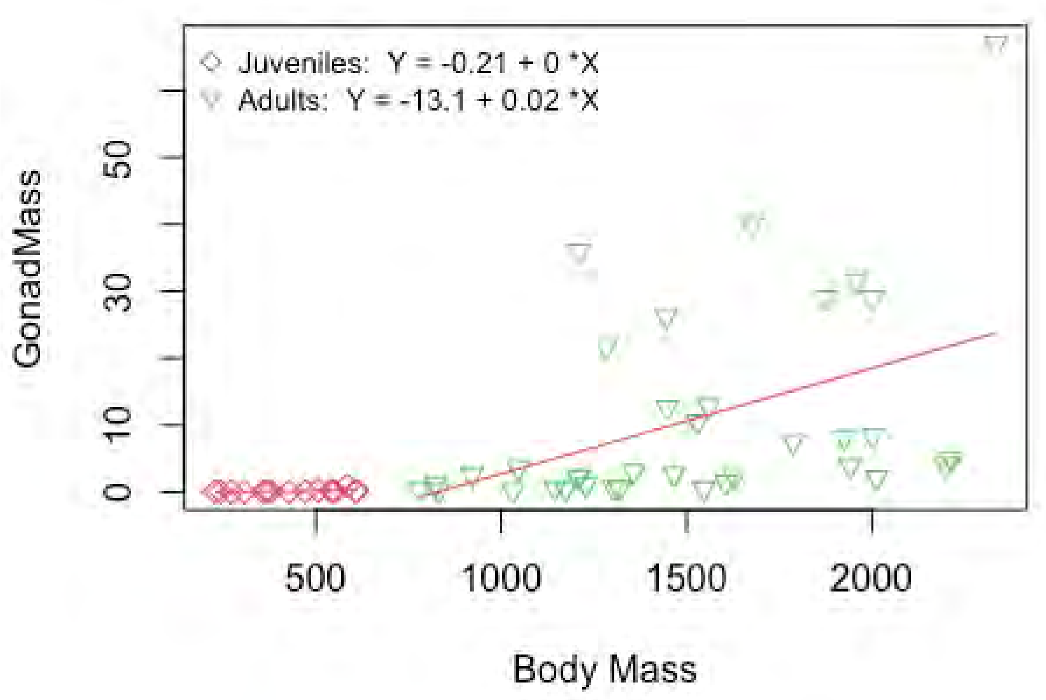
The method is used in other studies, e.g.,

Parvizi, E., Naderloo, R., Keikhosravi, A., and Schubart, C. D., 2017, Life history traits and patterns of sexual dimorphism in the freshwater crab Potamon ibericum (Bieberstein, 1809) (Decapoda: Brachyura: Potamidae) from the western Alborz Mountains, Iran: Journal of Crustacean Biology, v. 37, no. 3, p. 323-331.

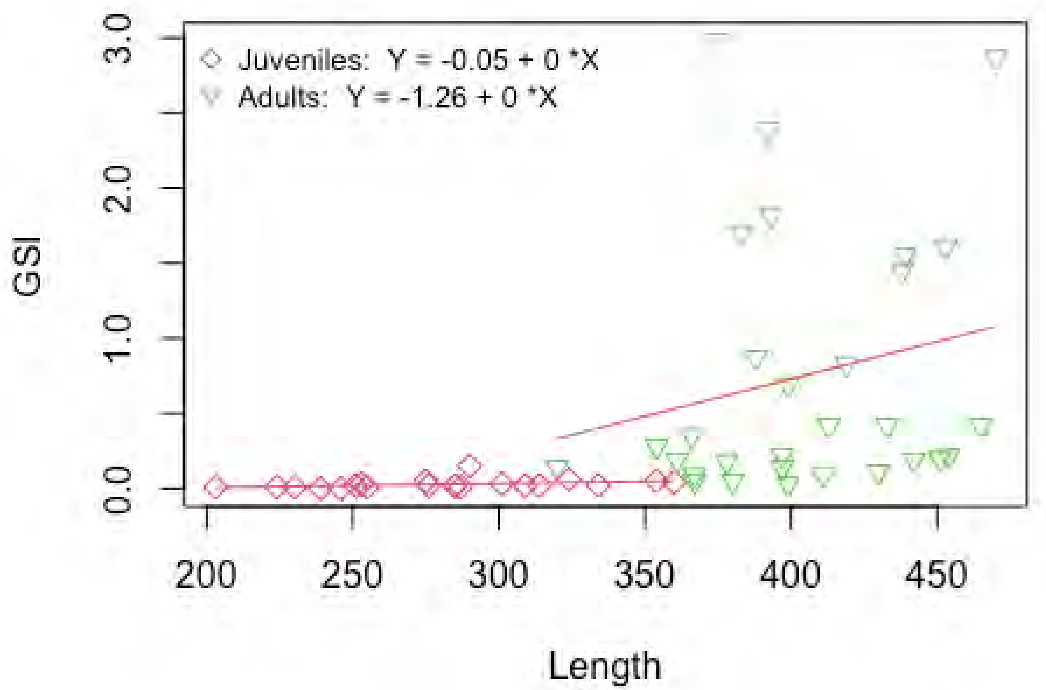
Caill-Milly, N., Sanchez, F., Benito, D., Ruiz, P., Izagirre, U., and Briaudeau, T., 2023, Assessment of size at first maturity for Ruditapes philippinarum from Arcachon Bay (French Atlantic coast): New insights for fishery management: Estuarine, Coastal and Shelf Science, v. 285, p. 108321.

```
## all individuals were used in the analysis
```

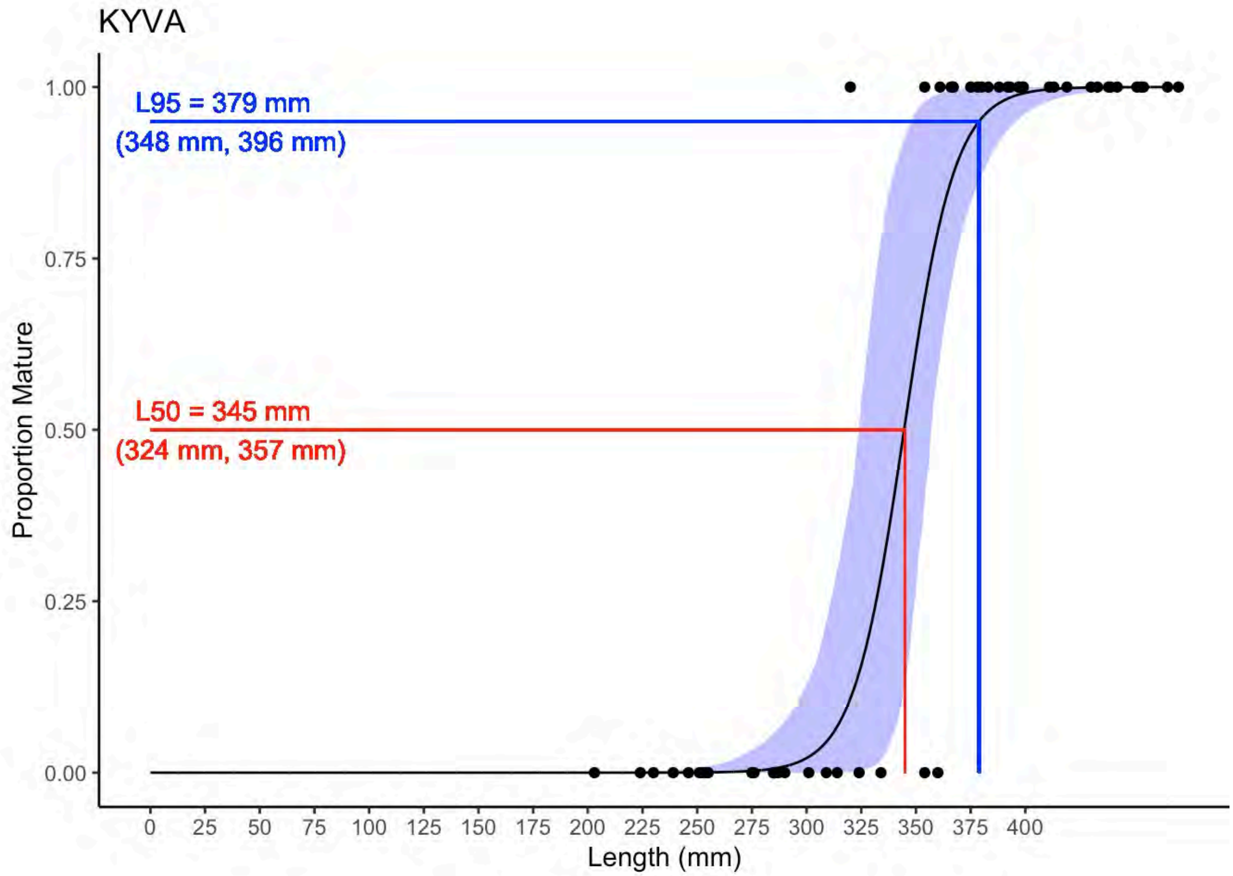
The plot below shows the results of the assignment with principal component analysis. The Red diamonds show individuals assigned as immature, while the green triangles show individuals assigned as mature. Body mass and gonad mass are both in grams.



For K. vaigiensis the principal component method using body mass and gonad mass did not allow the logistic model to estimate the 95% confidence interval. Therefore we conducted the principal component analysis using length and GSI, which resulted in the following assignment.

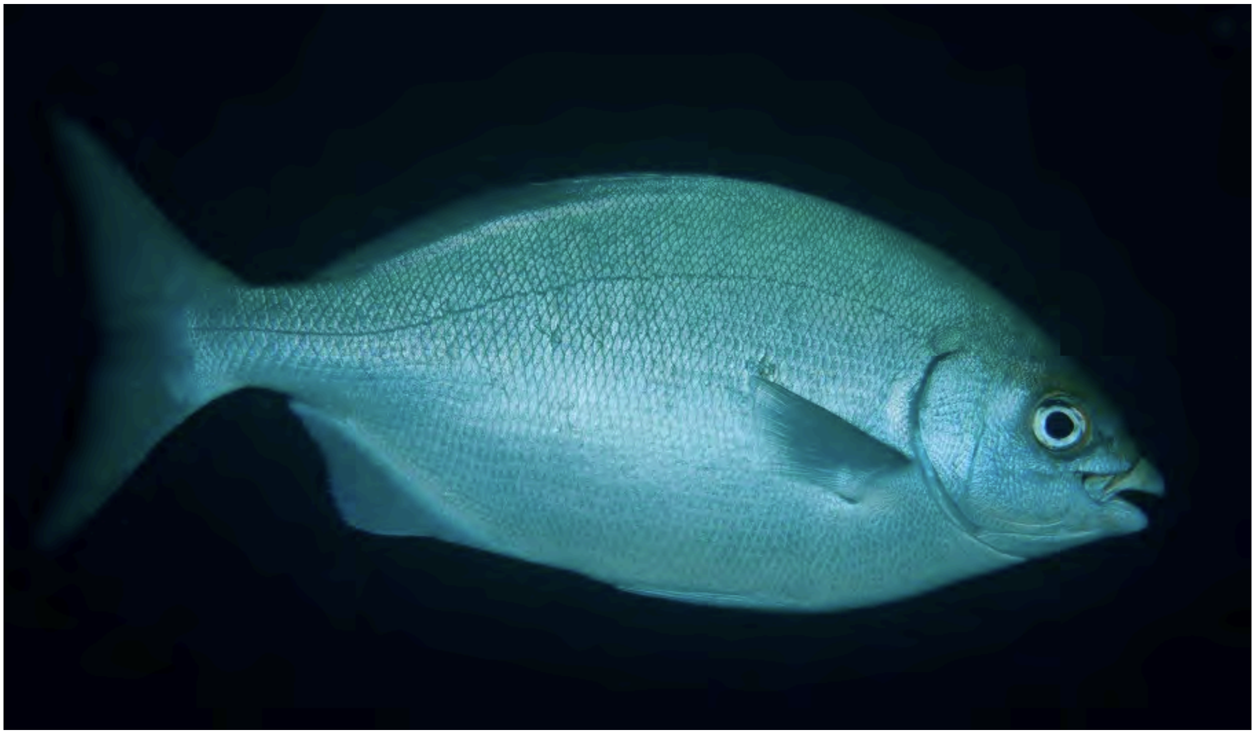



The maturity ogive for males is shown below. Black line is the logistic estimate of the proportion of the population that as reached maturity at each fork length. Purple shading shows the 95% confidence envelope. Red line shows the length where 50% of the population is mature (L50), with the 95% confidence range of values given in parentheses. Blue line shows the same information for the L95. Black dots show each individual fish used for the input dataset.


KYVA
L95 = 379 mm
(348 mm, 396 mm)
L50 = 345 mm
(324 mm, 357 mm)
Proportion Mature
1.00
0.75
0.50
0.25
0.00
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
Length (mm)

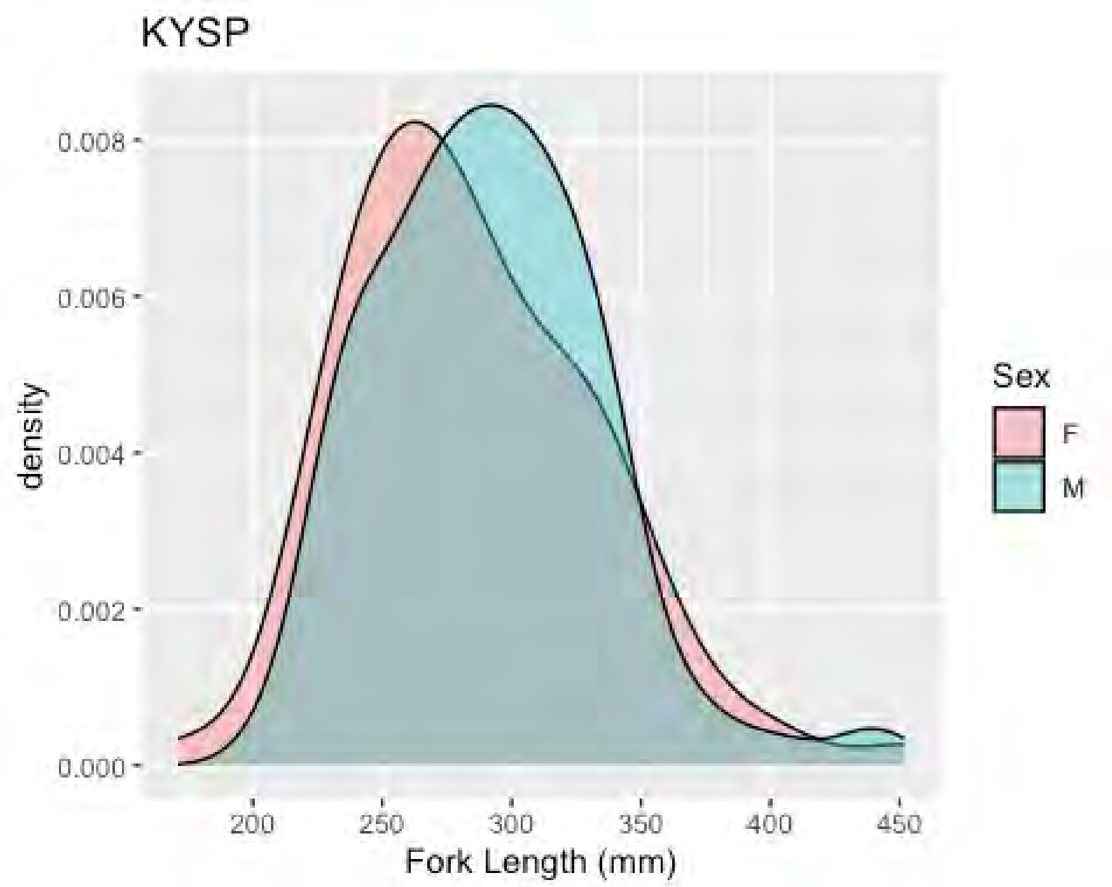
### 6.6 Group: Kyphosus hawaiiensis, Kyphosus elegans and Kyphosus sectatrix

Three Kyphosid species were grouped because species identification requires x-raying each individual and making counts of fin rays and other hard strucutres, which was not feasible.



Kyphosus spp. photographed in waters off the fire station at Pupukea, O'ahu. Photo: K Weng.

The size distribution for females and males was as follows:



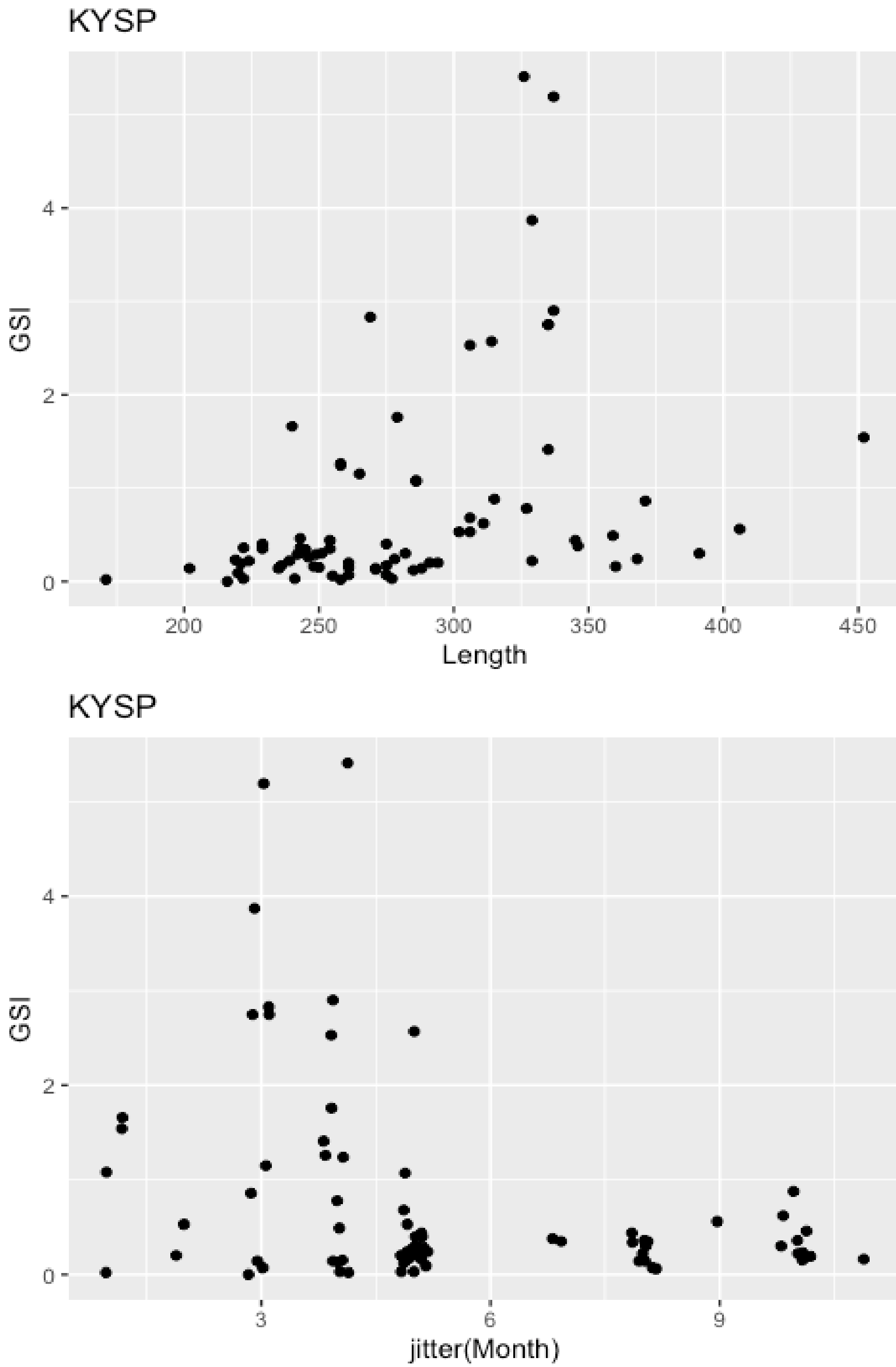

### 6.6.1 KYSP Females

In the table below, Length = Fork Length, Total = Total Length. Maturity was assigned based on oocyte stages (microscopic assignment) and appearance of ovaries (macroscopic assignment). 1 = mature, 0 = immature. Scatterplots are shown for the change in GSI with length, and the change in GSI with season of year.

| | Month | Location | Species | Length | Total | Sex | Mass | GonadMass | GSI | Maturity |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | Market | KYSP | 171 | 200 | F | 129 | 0.032 | 0.0200 | 0 |
| 2 | 4 | Moku Manu | KYSP | 222 | 250 | F | 241 | 0.062 | 0.0300 | 0 |
| 3 | 5 | Turtle Bay | KYSP | 275 | 315 | F | 403 | 0.680 | 0.1700 | 0 |
| 4 | 5 | Mokuleia | KYSP | 275 | 317 | F | 627 | 2.477 | 0.4000 | 1 |
| 5 | 5 | Turtle Bay | KYSP | 291 | 334 | F | 420 | 0.853 | 0.2000 | 0 |
| 6 | 3 | Moku Manu | KYSP | 335 | 372 | F | 887 | 24.397 | 2.7500 | 1 |
| 7 | 4 | Moku Manu | KYSP | 202 | 234 | F | 221 | 0.302 | 0.1400 | 0 |
| 8 | 5 | Moku Manu | KYSP | 220 | 247 | F | 255 | 0.233 | 0.0900 | 0 |
| 9 | 10 | Moku Manu | KYSP | 250 | 282 | F | 334 | 0.505 | 0.1500 | 0 |
| 10 | 4 | Rabbit | KYSP | 258 | 301 | F | 428 | 5.387 | 1.2600 | 0 |
| 11 | 4 | uppers | KYSP | 258 | 290 | F | 358 | 0.075 | 0.0200 | 0 |

| | Month | Location | Species | Length | Total | Sex | Mass | GonadMass | GSI | Maturity |
|---|---|---|---|---|---|---|---|---|---|---|
| 12 | 4 | Moku Manu | KYSP | 258 | 302 | F | 457 | 5.687 | 1.2400 | 1 |
| 14 | 4 | Moku Manu | KYSP | 261 | 294 | F | 527 | 0.779 | 0.1500 | 0 |
| 15 | 8 | Moku Manu | KYSP | 261 | 292 | F | 424 | 0.309 | 0.0700 | 0 |
| 16 | 5 | Moku Manu | KYSP | 261 | 289 | F | 518 | 1.015 | 0.2000 | 0 |
| 17 | 3 | Rabbit | KYSP | 265 | 308 | F | 429 | 4.918 | 1.1500 | 0 |
| 19 | 3 | Moku Manu | KYSP | 269 | 311 | F | 453 | 12.840 | 2.8300 | 1 |
| 20 | 4 | Rabbit | KYSP | 271 | 314 | F | 419 | 0.525 | 0.1300 | 0 |
| 22 | 5 | Moku Manu | KYSP | 278 | 312 | F | 535 | 1.275 | 0.2400 | 0 |
| 23 | 4 | Moku Manu | KYSP | 279 | 326 | F | 541 | 9.528 | 1.7600 | 1 |
| 24 | 3 | Moku Manu | KYSP | 288 | 320 | F | 542 | 0.735 | 0.1400 | 0 |
| 27 | 2 | Red Can K-Bay | KYSP | 294 | 329 | F | 699 | 1.368 | 0.2000 | 0 |
| 29 | 2 | Red Can K-Bay | KYSP | 302 | 345 | F | 686 | 3.640 | 0.5300 | 1 |
| 30 | 4 | Rabbit | KYSP | 306 | 345 | F | 746 | 18.903 | 2.5300 | 1 |
| 31 | 5 | Moku Manu | KYSP | 306 | 343 | F | 756 | 5.123 | 0.6800 | 1 |
| 32 | 5 | Moku Manu | KYSP | 306 | 346 | F | 787 | 4.164 | 0.5300 | 1 |
| 33 | 10 | Moku Manu | KYSP | 311 | 347 | F | 849 | 5.263 | 0.6200 | 1 |
| 35 | 5 | Turtle Bay | KYSP | 314 | 360 | F | 721 | 18.505 | 2.5700 | 1 |
| 36 | 4 | K Bay | KYSP | 326 | 352 | F | 686 | 37.105 | 5.4100 | 1 |
| 37 | 4 | Moku Manu | KYSP | 327 | 360 | F | 1061 | 8.268 | 0.7800 | 1 |
| 38 | 5 | Moku Manu | KYSP | 329 | 356 | F | 772 | 1.715 | 0.2200 | 0 |
| 40 | 3 | Moku Manu | KYSP | 335 | 372 | F | 887 | 24.397 | 2.7500 | 1 |
| 41 | 4 | Moku Manu | KYSP | 335 | 371 | F | 1057 | 14.864 | 1.4100 | 1 |
| 42 | 5 | Mokuleia | KYSP | 345 | 385 | F | 1037 | 4.550 | 0.4400 | 1 |
| 44 | 4 | Moku Manu | KYSP | 359 | 395 | F | 1214 | 5.988 | 0.4900 | 1 |
| 45 | 5 | Kaaawa | KYSP | 368 | 406 | F | 1384 | 3.273 | 0.2400 | 0 |
| 46 | 3 | Moku Manu | KYSP | 371 | 408 | F | 1387 | 11.920 | 0.8600 | 1 |
| 47 | 5 | Mokuleia | KYSP | 391 | 437 | F | 1489 | 4.526 | 0.3000 | 0 |
| 48 | 3 | Rabbit | KYSP | 216 | 246 | U | 225 | 0.001 | 0.0001 | 0 |
| 49 | 8 | Moku Manu | KYSP | 255 | 295 | U | 399 | 0.230 | 0.0600 | 0 |
| 50 | 5 | Kahala | KYSP | 360 | 410 | U | 986 | 1.610 | 0.1600 | 0 |
| 52 | 10 | Moku Manu | KYSP | 219 | 252 | F | 260 | 0.603 | 0.2300 | 0 |
| 53 | 10 | Market | KYSP | 221 | 259 | F | 273 | 0.525 | 0.1900 | 0 |
| 54 | 8 | Moku Manu | KYSP | 222 | 256 | F | 242 | 0.867 | 0.3600 | 0 |
| 55 | 8 | Moku Manu | KYSP | 224 | 257 | F | 253 | 0.554 | 0.2200 | 0 |
| 56 | 5 | Moku Manu | KYSP | 229 | 267 | F | 272 | 1.080 | 0.4000 | 0 |
| 57 | 7 | K Bay | KYSP | 229 | 263 | F | 261 | 0.912 | 0.3500 | 0 |
| 58 | 8 | Market | KYSP | 235 | 276 | F | 311 | 0.444 | 0.1400 | 0 |
| 59 | 5 | Moku Manu | KYSP | 236 | 276 | F | 316 | 0.550 | 0.1700 | 0 |

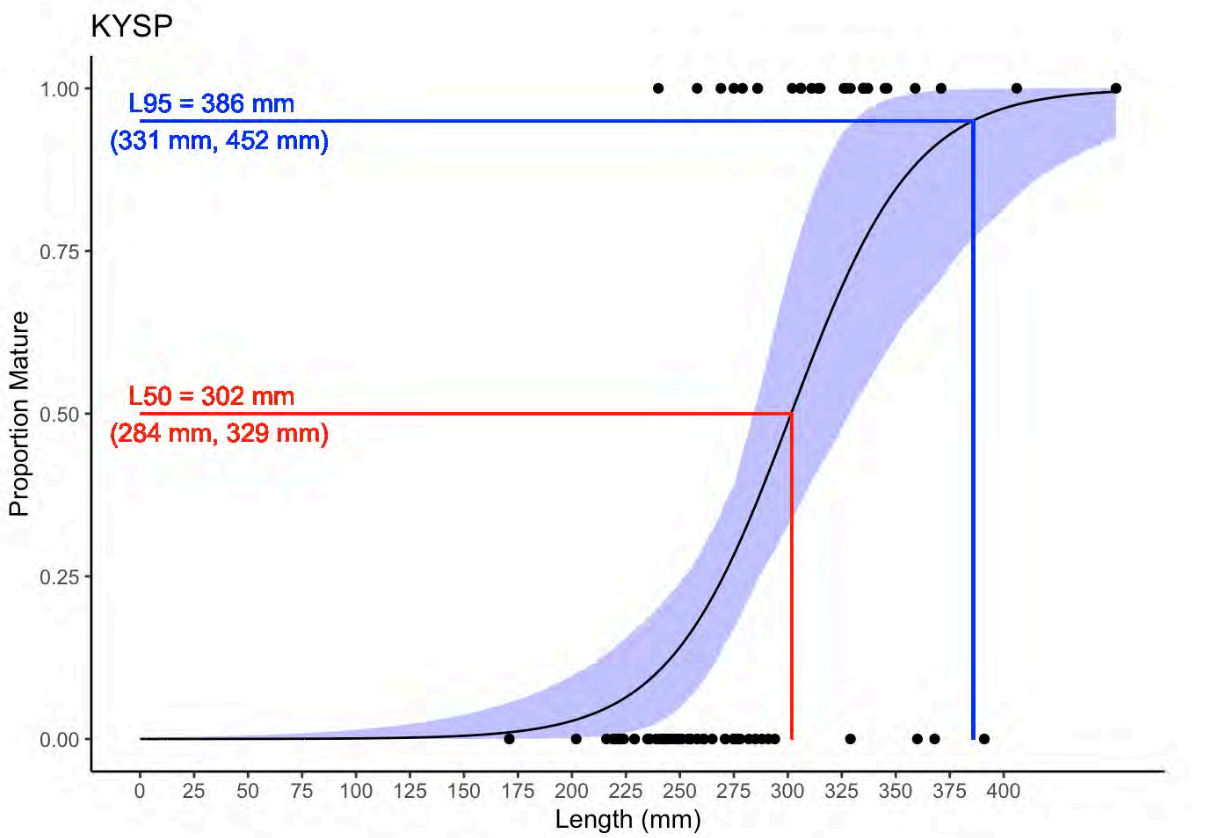
| | Month | Location | Species | Length | Total | Sex | Mass | GonadMass | GSI | Maturity |
|---|---|---|---|---|---|---|---|---|---|---|
| 61 | 10 | Market | KYSP | 239 | 270 | F | 338 | 0.748 | 0.2200 | 0 |
| 62 | 1 | Moku Manu | KYSP | 240 | 279 | F | 325 | 5.391 | 1.6600 | 1 |
| 63 | 5 | Moku Manu | KYSP | 241 | 280 | F | 332 | 0.106 | 0.0300 | 0 |
| 64 | 5 | Moku Manu | KYSP | 242 | 280 | F | 264 | 0.760 | 0.2900 | 0 |
| 65 | 10 | Moku Manu | KYSP | 243 | 280 | F | 343 | 1.586 | 0.4600 | 0 |
| 66 | 10 | Moku Manu | KYSP | 243 | 280 | F | 330 | 1.181 | 0.3600 | 0 |
| 67 | 5 | Moku Manu | KYSP | 246 | 286 | F | 319 | 0.845 | 0.2600 | 0 |
| 68 | 11 | Black Island | KYSP | 248 | 288 | F | 345 | 0.567 | 0.1600 | 0 |
| 69 | 5 | Moku Manu | KYSP | 249 | 290 | F | 347 | 0.995 | 0.2900 | 0 |
| 70 | 10 | Market | KYSP | 251 | 242 | F | 420 | 1.241 | 0.3000 | 0 |
| 72 | 8 | ? | KYSP | 254 | 292 | F | 331 | 1.457 | 0.4400 | 0 |
| 73 | 8 | Moku Manu | KYSP | 254 | 292 | F | 374 | 1.307 | 0.3500 | 0 |
| 74 | 8 | Market | KYSP | 271 | 309 | F | 426 | 0.579 | 0.1400 | 0 |
| 75 | 3 | Moku Manu | KYSP | 275 | 314 | F | 480 | 0.337 | 0.0700 | 0 |
| 76 | 5 | Mokuleia | KYSP | 277 | 323 | F | 533 | 0.153 | 0.0300 | 0 |
| 78 | 8 | Moku Manu | KYSP | 282 | 323 | F | 474 | 1.416 | 0.3000 | 0 |
| 79 | 5 | Mokuleia | KYSP | 285 | 382 | F | 540 | 0.641 | 0.1200 | 0 |
| 80 | 1 | Makapuu | KYSP | 286 | 327 | F | 496 | 5.381 | 1.0800 | 1 |
| 81 | 5 | Moku Manu | KYSP | 286 | 338 | F | 586 | 6.261 | 1.0700 | 1 |
| 84 | 3 | Moku Manu | KYSP | 329 | 376 | F | 852 | 32.950 | 3.8700 | 1 |
| 86 | 3 | Rabbit | KYSP | 337 | 395 | F | 990 | 51.425 | 5.1900 | 1 |
| 87 | 7 | Malaekahana | KYSP | 346 | 398 | F | 1135 | 4.280 | 0.3800 | 1 |
| 88 | 9 | Market | KYSP | 406 | 478 | F | 1651 | 9.238 | 0.5600 | 1 |
| 89 | 8 | Moku Manu | KYSP | 245 | 286 | U | 311 | 1.045 | 0.3400 | 0 |
| 91 | 10 | Moku Manu | KYSP | 315 | 347 | F | 853 | 7.472 | 0.8800 | 1 |
| 92 | 4 | NS | KYSP | 337 | 382 | F | 961 | 27.872 | 2.9000 | 1 |
| 94 | 1 | Makapuu | KYSP | 452 | 493 | F | 1981 | 30.517 | 1.5400 | 1 |




Once the maturity assignment is made for each individual, a logistic function is used to estimate size at maturity. The dataset is run through a general linear model with binomial error structure, using Length as the explanatory variable, and GSI as the response variable (R package: AquaticLifeHistory, Jonathan Smart).

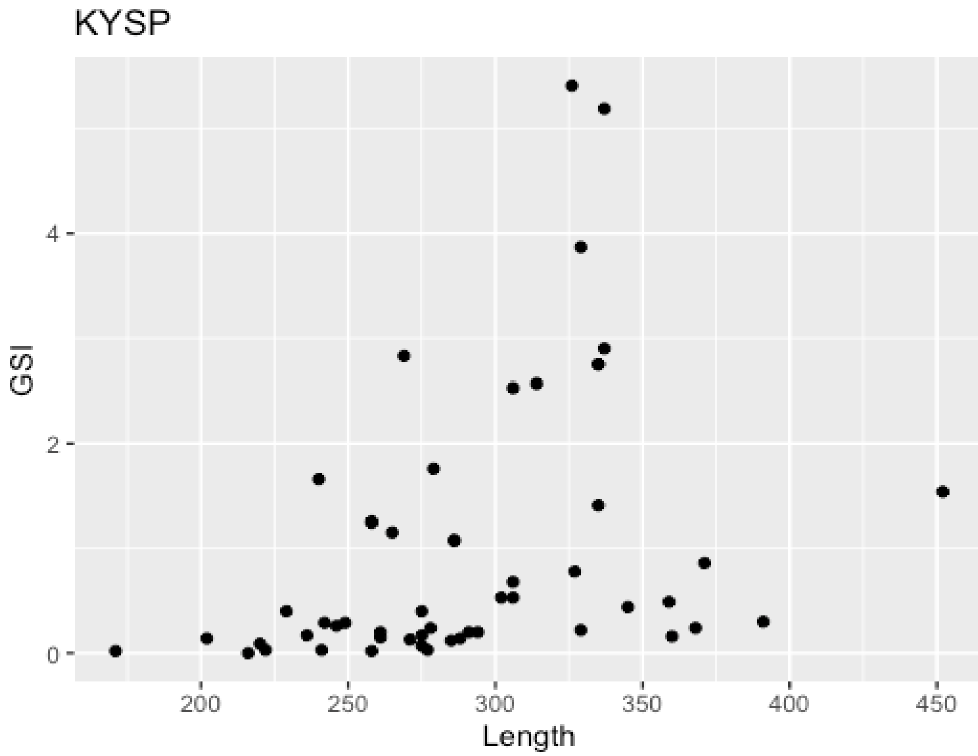
Smart J, Chin A, Tobin A, Simpfendorfer C (2016). "Multimodel approaches in shark and ray growth studies: strengths, weaknesses and the future." Fish and Fisheries, 17, 955–971.

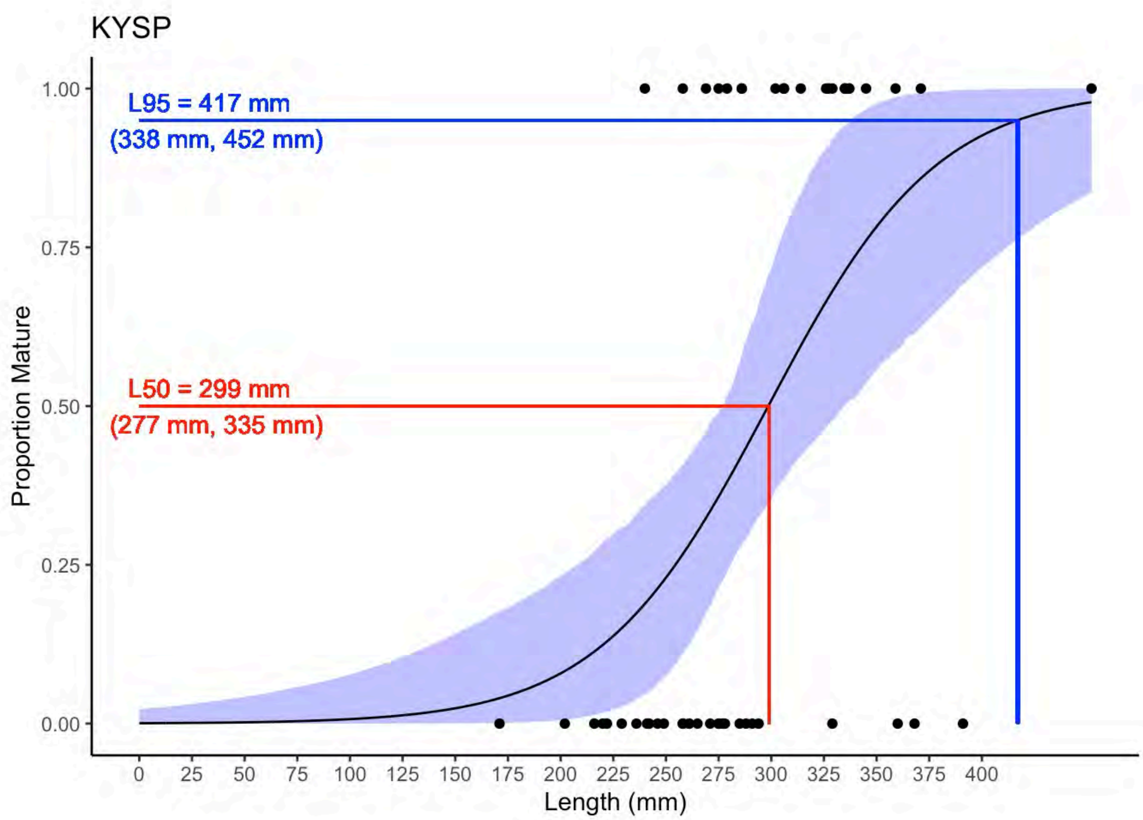
The maturity ogive for all females is shown below. Black line is the logistic estimate of the proportion of the population that as reached maturity at each fork length. Purple shading shows the 95% confidence envelope. Red line shows the length where 50% of the population is mature (L50), with the 95% confidence range of values given in parentheses. Blue line shows the same information for the L95. Black dots show each individual fish used for the input dataset.




In temperate zones, fish typically have a short spawning season. This means that during the off season, large mature fish have small gonads and may not have developing and advanced stage oocytes. Therefore, estimates of size at maturity are generally conducted after excluding individuals connected during the off season. This means that any fish included in the analysis was collected during a month when investment in gonads and oocyte development was expected. In tropical and subtropical zones there may be less of a season effect on fish reproduction. In order to determine if there is a strong effect of season, we can look at a plot of GSI vs month. Those months with high GSI would be considered the spawning season, while low GSI months would be considered the off season. Off season months can be excluded, being months before 1 and after 5.

The maturity ogive for females from spawning months is:


KYSP
GSI
Length
0
2
4
200
250
300
350
400
450


KYSP
L95 = 417 mm
(338 mm, 452 mm)
L50 = 299 mm
(277 mm, 335 mm)
Proportion Mature
Length (mm)
0.00
0.25
0.50
0.75
1.00
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400

### 6.6.2 KYSP Males

In the table below, Length = Fork Length, Total = Total Length. For males it was not possible to conduct micro and macroscopic maturity assignment; histology would be necessary for this purpose. Therefore, maturity is assigned using a statistical approach, described below. Scatterplots are shown for the change in GSI with length, and the change in GSI with season of year.

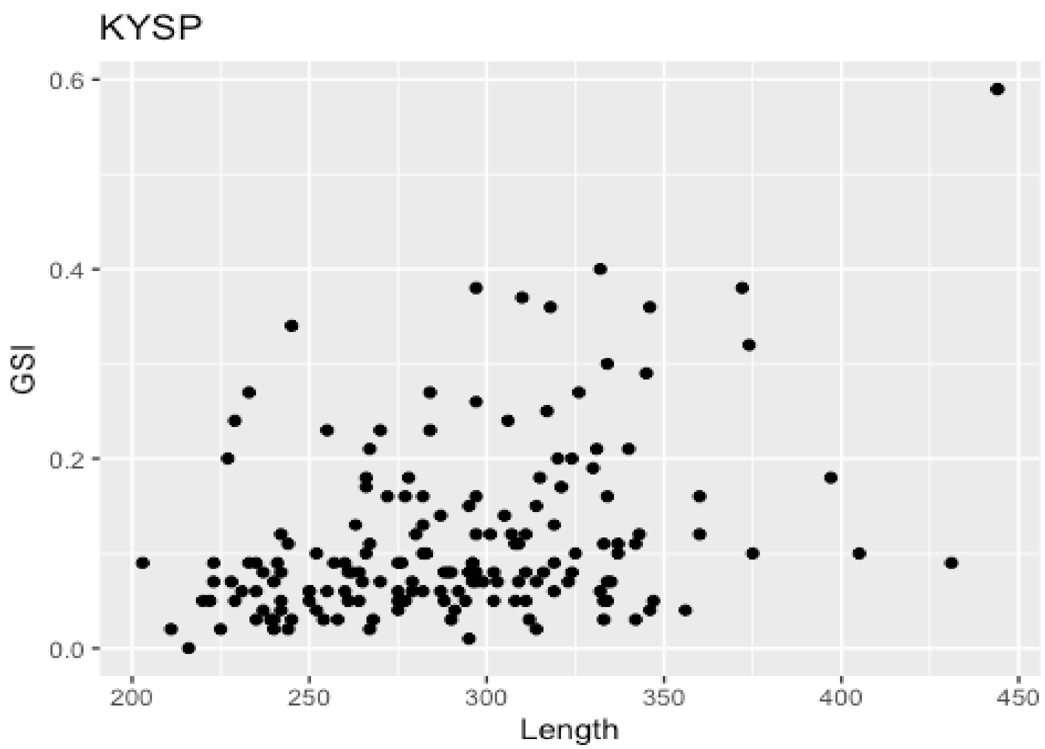
| Month | Location | Species | Length | Total | Sex | Mass | GonadMass | GSI |
|---|---|---|---|---|---|---|---|---|
| 4 | Market | KYSP | 254 | 303 | M | 452 | 0.148 | 0.0300 |
| 3 | Moku Manu | KYSP | 297 | 349 | M | 583 | 0.673 | 0.1200 |
| 1 | Makapuu | KYSP | 310 | 360 | M | 840 | 3.088 | 0.3700 |
| 9 | Market | KYSP | 372 | 422 | M | 1469 | 5.627 | 0.3800 |
| 6 | Moku Manu | KYSP | 220 | 251 | M | 267 | 0.137 | 0.0500 |
| 4 | Moku Manu | KYSP | 229 | 262 | M | 381 | 0.175 | 0.0500 |
| 6 | Moku Manu | KYSP | 235 | 263 | M | 378 | 0.102 | 0.0300 |
| 6 | Moku Manu | KYSP | 237 | 271 | M | 415 | 0.335 | 0.0800 |
| 10 | Moku Manu | KYSP | 240 | 282 | M | 276 | 0.086 | 0.0300 |
| 4 | Rabbit | KYSP | 242 | 281 | M | 338 | 0.398 | 0.1200 |
| 8 | Moku Manu | KYSP | 242 | 274 | M | 353 | 0.141 | 0.0400 |
| 12 | Outside K-Bay | KYSP | 250 | NA | M | 702 | 0.454 | 0.0600 |
| 2 | Red Can K-Bay | KYSP | 250 | 288 | M | 391 | 0.222 | 0.0600 |
| 10 | Moku Manu | KYSP | 258 | 294 | M | 366 | 0.096 | 0.0300 |
| 3 | Rabbit | KYSP | 261 | 303 | M | 380 | NA | NA |
| 11 | Kaena Point | KYSP | 262 | NA | M | 414 | 0.316 | 0.0800 |
| 4 | Moku Manu | KYSP | 263 | 302 | M | 419 | 0.549 | 0.1300 |
| 5 | Moku Manu | KYSP | 264 | 296 | M | 468 | 0.379 | 0.0800 |
| 8 | Market | KYSP | 267 | 300 | M | 438 | 0.097 | 0.0200 |
| 3 | Rabbit | KYSP | 272 | 316 | M | 492 | 0.802 | 0.1600 |
| 12 | Rabbit Island | KYSP | 275 | NA | M | 467 | 0.189 | 0.0400 |
| 10 | Moku Manu | KYSP | 277 | 306 | M | 588 | 0.311 | 0.0500 |
| 1 | Makapuu Wall | KYSP | 279 | 323 | M | 487 | 0.293 | 0.0600 |
| 4 | Rabbit | KYSP | 280 | 311 | M | 613 | 0.717 | 0.1200 |
| 12 | Rabbit Island | KYSP | 282 | NA | M | 532 | 0.513 | 0.1000 |
| 8 | Moku Manu | KYSP | 282 | 315 | M | 552 | 0.350 | 0.0600 |
| 4 | Uppers | KYSP | 282 | 335 | M | 522 | 0.666 | 0.1300 |
| 2 | Red Can K-Bay | KYSP | 284 | 328 | M | 549 | 1.486 | 0.2700 |
| 4 | Rabbit | KYSP | 289 | 334 | M | 552 | 0.438 | 0.0800 |
| 6 | Kaaawa | KYSP | 290 | 326 | M | 509 | 0.394 | 0.0800 |
| 8 | Moku Manu | KYSP | 292 | 322 | M | 633 | 0.386 | 0.0600 |
| 10 | Moku Manu | KYSP | 294 | 335 | M | 515 | 0.263 | 0.0500 |
| 2 | Red Can K-Bay | KYSP | 295 | 338 | M | 572 | 0.830 | 0.1500 |

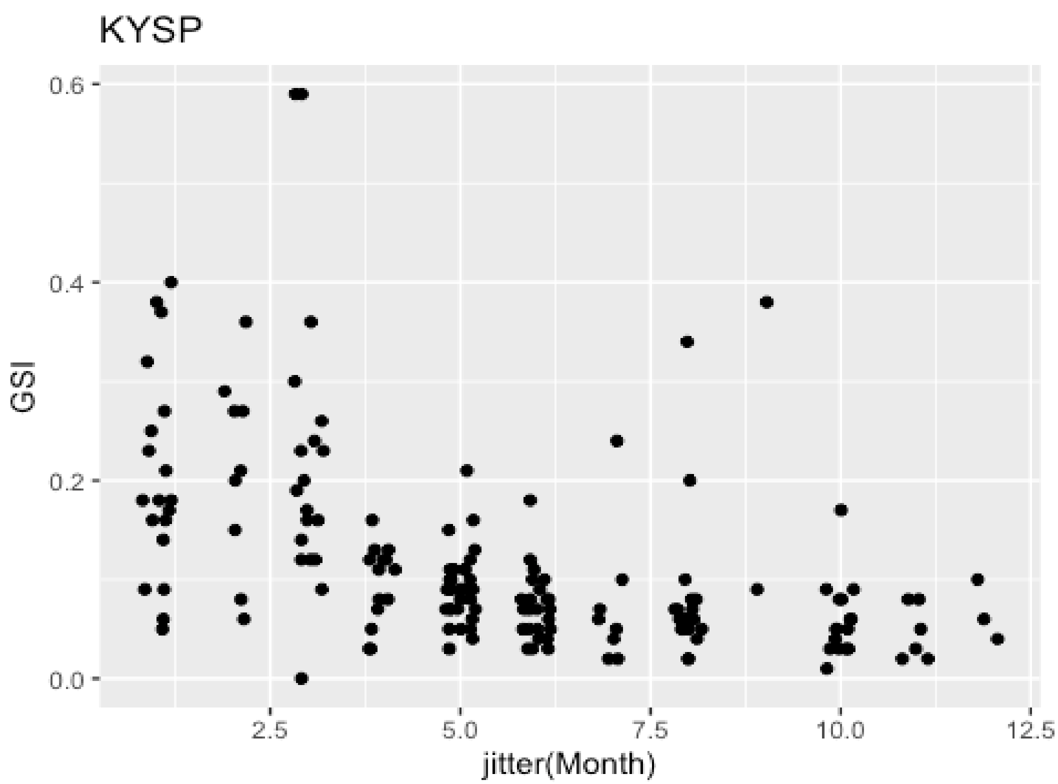
| Month | Location | Species | Length | Total | Sex | Mass | GonadMass | GSI |
|---|---|---|---|---|---|---|---|---|
| 5 | Moku Manu | KYSP | 295 | 336 | M | 760 | 0.617 | 0.0800 |
| 6 | Moku Manu | KYSP | 295 | 325 | M | 624 | 0.485 | 0.0800 |
| 10 | Moku Manu | KYSP | 296 | 332 | M | 748 | 0.702 | 0.0900 |
| 10 | Moku Manu | KYSP | 296 | 327 | M | 726 | 0.683 | 0.0900 |
| 4 | Rabbit | KYSP | 297 | 345 | M | 568 | 0.905 | 0.1600 |
| 4 | Moku Manu | KYSP | 297 | 334 | M | 685 | 0.564 | 0.0800 |
| 6 | Kaaawa | KYSP | 299 | 343 | M | 566 | 0.372 | 0.0700 |
| 3 | Moku Manu | KYSP | 301 | 353 | M | 559 | 0.645 | 0.1200 |
| 2 | Red Can K-Bay | KYSP | 302 | 341 | M | 625 | 0.525 | 0.0800 |
| 4 | Rabbit | KYSP | 309 | 357 | M | 624 | 0.697 | 0.1100 |
| 8 | Moku Manu | KYSP | 309 | 346 | M | 666 | 0.464 | 0.0700 |
| 8 | Moku Manu | KYSP | 311 | 357 | M | 683 | 0.333 | 0.0500 |
| 3 | Moku Manu | KYSP | 311 | 343 | M | 796 | 0.924 | 0.1200 |
| 5 | Turtle Bay | KYSP | 314 | 363 | M | 705 | NA | NA |
| 5 | Moku Manu | KYSP | 314 | 352 | M | 840 | 1.276 | 0.1500 |
| 10 | Moku Manu | KYSP | 316 | 353 | M | 861 | 0.713 | 0.0800 |
| 3 | Moku Manu | KYSP | 318 | 361 | M | 733 | 2.603 | 0.3600 |
| 5 | Moku Manu | KYSP | 319 | 373 | M | 766 | 0.469 | 0.0600 |
| 5 | Moku Manu | KYSP | 319 | 353 | M | 828 | 1.052 | 0.1300 |
| 2 | Red Can K-Bay | KYSP | 320 | 365 | M | 771 | 1.575 | 0.2000 |
| 10 | Moku Manu | KYSP | 321 | 366 | M | 943 | 1.594 | 0.1700 |
| 1 | Makapu’u | KYSP | 321 | 369 | M | 793 | 1.317 | 0.1700 |
| 6 | Moku Manu | KYSP | 323 | 363 | M | 824 | 0.591 | 0.0700 |
| 3 | Moku Manu | KYSP | 324 | 365 | M | 821 | 1.648 | 0.2000 |
| 6 | Moku Manu | KYSP | 324 | 357 | M | 872 | 0.691 | 0.0800 |
| 2 | Red Can K-Bay | KYSP | 326 | 380 | M | 795 | 2.137 | 0.2700 |
| 2 | Red Can K-Bay | KYSP | 331 | 381 | M | 792 | 1.627 | 0.2100 |
| 8 | Moku Manu | KYSP | 332 | 367 | M | 877 | 0.562 | 0.0600 |
| 5 | Makapuu | KYSP | 333 | 372 | M | 908 | 1.027 | 0.1100 |
| 6 | Kaaawa | KYSP | 333 | 367 | M | 1047 | 0.335 | 0.0300 |
| 6 | Kaaawa | KYSP | 333 | 380 | M | 745 | 0.366 | 0.0500 |
| 3 | Moku Manu | KYSP | 334 | 384 | M | 697 | 2.058 | 0.3000 |
| 3 | Moku Manu | KYSP | 334 | 371 | M | 897 | 1.398 | 0.1600 |
| 6 | Kaaawa | KYSP | 334 | 376 | M | 775 | 0.395 | 0.0500 |
| 6 | Moku Manu | KYSP | 337 | 382 | M | 1011 | 1.073 | 0.1100 |
| 5 | Moku Manu | KYSP | 340 | 376 | M | 1141 | 2.355 | 0.2100 |
| 5 | Moku Manu | KYSP | 342 | 377 | M | 1052 | 1.114 | 0.1100 |
| 6 | Moku Manu | KYSP | 342 | 379 | M | 1185 | 0.316 | 0.0300 |
| 4 | Rabbit | KYSP | 343 | 381 | M | 969 | 1.143 | 0.1200 |

| Month | Location | Species | Length | Total | Sex | Mass | GonadMass | GSI |
|---|---|---|---|---|---|---|---|---|
| 2 | Red Can K-Bay | KYSP | 345 | 394 | M | 914 | 2.638 | 0.2900 |
| 2 | Red Can K-Bay | KYSP | 346 | 394 | M | 878 | 3.194 | 0.3600 |
| 7 | K Bay | KYSP | 346 | 384 | M | 1142 | 0.419 | 0.0400 |
| 5 | Turtle Bay | KYSP | 350 | 410 | M | 931 | NA | NA |
| 5 | Mokuleia | KYSP | 356 | 391 | M | 1089 | 0.386 | 0.0400 |
| 6 | Moku Manu | KYSP | 360 | 401 | M | 1212 | 1.405 | 0.1200 |
| 1 | Makapu'u | KYSP | 374 | 411 | M | 1370 | 4.375 | 0.3200 |
| 6 | Moku Manu | KYSP | 375 | 421 | M | 1388 | 1.415 | 0.1000 |
| 6 | Moku Manu | KYSP | 397 | 434 | M | 1711 | 3.008 | 0.1800 |
| 9 | China Walls | KYSP | 431 | 482 | M | 2045 | 1.768 | 0.0900 |
| 3 | Moku Manu | KYSP | 444 | 493 | M | 1887 | 11.196 | 0.5900 |
| 3 | Moku Manu | KYSP | 444 | 493 | M | 1887 | 11.196 | 0.5900 |
| 3 | Rabbit | KYSP | 216 | 246 | U | 225 | 0.001 | 0.0001 |
| 8 | Moku Manu | KYSP | 255 | 295 | U | 399 | 0.230 | 0.0600 |
| 5 | Kahala | KYSP | 360 | 410 | U | 986 | 1.610 | 0.1600 |
| 6 | Moku Manu | KYSP | 297 | 350 | ? | 652 | 0.447 | 0.0700 |
| 6 | Moku Manu | KYSP | 203 | 234 | M | 197 | 0.183 | 0.0900 |
| 7 | K Bay | KYSP | 211 | 244 | M | 221 | 0.047 | 0.0200 |
| 5 | Moku Manu | KYSP | 222 | 255 | M | 260 | 0.137 | 0.0500 |
| 8 | Moku Manu | KYSP | 223 | 263 | M | 337 | 0.230 | 0.0700 |
| 1 | Moku Manu | KYSP | 223 | 260 | M | 272 | 0.248 | 0.0900 |
| 8 | Moku Manu | KYSP | 225 | 261 | M | 244 | 0.053 | 0.0200 |
| 8 | Rabbit Island | KYSP | 227 | 258 | M | 248 | 0.500 | 0.2000 |
| 8 | Moku Manu | KYSP | 228 | 267 | M | 262 | 0.188 | 0.0700 |
| 7 | K Bay | KYSP | 229 | 264 | M | 277 | 0.670 | 0.2400 |
| 8 | Moku Manu | KYSP | 231 | 265 | M | 278 | 0.178 | 0.0600 |
| 5 | Moku Manu | KYSP | 233 | 268 | M | 285 | 0.251 | 0.0900 |
| 1 | Moku Manu | KYSP | 233 | 270 | M | 315 | 0.847 | 0.2700 |
| 3 | Moku Manu | KYSP | 235 | 279 | M | 288 | 0.256 | 0.0900 |
| 6 | Moku Manu | KYSP | 237 | 269 | M | 343 | 0.145 | 0.0400 |
| 5 | Moku Manu | KYSP | 240 | 278 | M | 309 | 0.226 | 0.0700 |
| 7 | Rabbit | KYSP | 240 | 277 | M | 271 | 0.052 | 0.0200 |
| 5 | Moku Manu | KYSP | 241 | 281 | M | 325 | 0.297 | 0.0900 |
| 8 | Moku Manu | KYSP | 242 | 279 | M | 380 | 0.285 | 0.0800 |
| 8 | Moku Manu | KYSP | 242 | 278 | M | 329 | 0.169 | 0.0500 |
| 11 | Black Island | KYSP | 244 | 288 | M | 334 | 0.068 | 0.0200 |
| 5 | Moku Manu | KYSP | 244 | 284 | M | 441 | 0.491 | 0.1100 |
| 5 | Moku Manu | KYSP | 245 | 283 | M | 342 | 0.102 | 0.0300 |
| 8 | Moku Manu | KYSP | 250 | 290 | M | 351 | 0.175 | 0.0500 |

| Month | Location | Species | Length | Total | Sex | Mass | GonadMass | GSI |
|---|---|---|---|---|---|---|---|---|
| 5 | Moku Manu | KYSP | 252 | 289 | M | 378 | 0.362 | 0.1000 |
| 6 | Moku Manu | KYSP | 252 | 290 | M | 387 | 0.174 | 0.0400 |
| 3 | Moku Manu | KYSP | 255 | 293 | M | 420 | 0.960 | 0.2300 |
| 5 | Moku Manu | KYSP | 257 | 294 | M | 348 | 0.316 | 0.0900 |
| 7 | K Bay | KYSP | 260 | 300 | M | 455 | 0.287 | 0.0600 |
| 1 | Makapuu | KYSP | 260 | 301 | M | 378 | 0.339 | 0.0900 |
| 10 | Moku Manu | KYSP | 261 | 304 | M | 385 | 0.302 | 0.0800 |
| 1 | Moku Manu | KYSP | 261 | 304 | M | 425 | 0.218 | 0.0500 |
| 8 | Moku Manu | KYSP | 264 | 306 | M | 357 | 0.176 | 0.0500 |
| 5 | Moku Manu | KYSP | 265 | 308 | M | 428 | 0.289 | 0.0700 |
| 1 | Makapuu | KYSP | 266 | 309 | M | 488 | 0.860 | 0.1800 |
| 3 | Moku Manu | KYSP | 266 | 312 | M | 432 | 0.720 | 0.1700 |
| 5 | Moku Manu | KYSP | 266 | 307 | M | 409 | 0.423 | 0.1000 |
| 5 | Moku Manu | KYSP | 267 | 308 | M | 419 | 0.450 | 0.1100 |
| 1 | Moku Manu | KYSP | 267 | 337 | M | 753 | 1.596 | 0.2100 |
| 1 | Makapuu | KYSP | 270 | 315 | M | 435 | 0.983 | 0.2300 |
| 5 | Moku Manu | KYSP | 270 | 313 | M | 445 | 0.292 | 0.0700 |
| 10 | Moku Manu | KYSP | 275 | 317 | M | 509 | 0.310 | 0.0600 |
| 5 | Moku Manu | KYSP | 275 | 322 | M | 456 | 0.416 | 0.0900 |
| 6 | Moku Manu | KYSP | 275 | 315 | M | 514 | 0.268 | 0.0500 |
| 5 | Moku Manu | KYSP | 276 | 316 | M | 507 | 0.480 | 0.0900 |
| 5 | Kaaawa | KYSP | 276 | 324 | M | 501 | 0.271 | 0.0500 |
| 1 | Makapuu | KYSP | 277 | 316 | M | 473 | 0.745 | 0.1600 |
| 1 | Makapuu | KYSP | 278 | 319 | M | 459 | 0.841 | 0.1800 |
| 6 | Moku Manu | KYSP | 279 | 318 | M | 500 | 0.343 | 0.0700 |
| 1 | Makapuu | KYSP | 282 | 322 | M | 575 | 0.910 | 0.1600 |
| 8 | Moku Manu | KYSP | 283 | 326 | M | 585 | 0.559 | 0.1000 |
| 3 | Moku Manu | KYSP | 284 | 322 | M | 490 | 1.109 | 0.2300 |
| 1 | Makapuu | KYSP | 287 | 335 | M | 554 | 0.778 | 0.1400 |
| 6 | Moku Manu | KYSP | 287 | 333 | M | 572 | 0.353 | 0.0600 |
| 5 | Mokuleia | KYSP | 288 | 332 | M | 528 | 0.257 | 0.0500 |
| 4 | Uppers | KYSP | 290 | 335 | M | 494 | 0.160 | 0.0300 |
| 10 | Moku Manu | KYSP | 291 | 333 | M | 577 | 0.240 | 0.0400 |
| 5 | Kaaawa | KYSP | 296 | 339 | M | 641 | 0.480 | 0.0700 |
| 1 | Makapuu | KYSP | 297 | 343 | M | 584 | 2.210 | 0.3800 |
| 3 | Moku Manu | KYSP | 297 | 343 | M | 678 | 1.774 | 0.2600 |
| 7 | Kaena Pt | KYSP | 303 | 351 | M | 650 | 0.468 | 0.0700 |
| 3 | Moku Manu | KYSP | 305 | 349 | M | 572 | 0.773 | 0.1400 |
| 3 | Moku Manu | KYSP | 306 | 353 | M | 685 | 1.677 | 0.2400 |

| Month | Location | Species | Length | Total | Sex | Mass | GonadMass | GSI |
|---|---|---|---|---|---|---|---|---|
| 5 | Moku Manu | KYSP | 307 | 356 | M | 635 | 0.744 | 0.1200 |
| 7 | Market | KYSP | 308 | 355 | M | 690 | 0.326 | 0.0500 |
| 4 | Sunset Beach | KYSP | 308 | 335 | M | 653 | 0.688 | 0.1100 |
| 8 | Moku Manu | KYSP | 311 | 354 | M | 641 | 0.531 | 0.0800 |
| 5 | Moku Manu | KYSP | 314 | 362 | M | 654 | 0.489 | 0.0700 |
| 1 | Makapuu | KYSP | 315 | 363 | M | 722 | 1.280 | 0.1800 |
| 1 | Moku Manu | KYSP | 317 | 348 | M | 744 | 1.890 | 0.2500 |
| 5 | Moku Manu | KYSP | 319 | 370 | M | 655 | 0.611 | 0.0900 |
| 7 | Market | KYSP | 325 | 383 | M | 778 | 0.741 | 0.1000 |
| 3 | Moku Manu | KYSP | 330 | 381 | M | 855 | 1.667 | 0.1900 |
| 1 | Makapuu | KYSP | 332 | 385 | M | 911 | 3.606 | 0.4000 |
| 6 | Moku Manu | KYSP | 334 | 368 | M | 939 | 0.687 | 0.0700 |
| 4 | Sunset Beach | KYSP | 335 | 386 | M | 930 | 0.673 | 0.0700 |
| 5 | Moku Manu | KYSP | 337 | 394 | M | 899 | 0.889 | 0.1000 |
| 10 | Moku Manu | KYSP | 347 | 397 | M | 776 | 0.403 | 0.0500 |
| 6 | Markets | KYSP | 405 | 467 | M | 1730 | 1.786 | 0.1000 |
| 8 | Moku Manu | KYSP | 245 | 286 | U | 311 | 1.045 | 0.3400 |
| 8 | Moku Manu | KYSP | 284 | 333 | U | 559 | NA | NA |
| 10 | Moku Manu | KYSP | 235 | 266 | M | 323 | 0.182 | 0.0600 |
| 10 | Moku Manu | KYSP | 239 | 274 | M | 311 | 0.093 | 0.0300 |
| 10 | Moku Manu | KYSP | 268 | 299 | M | 536 | 0.157 | 0.0300 |
| 11 | MOKU MANU | KYSP | 288 | 326 | M | 493 | 0.393 | 0.0800 |
| 10 | Moku Manu | KYSP | 295 | 333 | M | 633 | 0.085 | 0.0100 |
| 11 | MOKU MANU | KYSP | 302 | 346 | M | 622 | 0.295 | 0.0500 |
| 11 | MOKU MANU | KYSP | 312 | 351 | M | 783 | 0.227 | 0.0300 |
| 11 | MOKU MANU | KYSP | 314 | 371 | M | 824 | 0.184 | 0.0200 |
| 11 | MOKU MANU | KYSP | 306 | 347 | U | 688 | NA | NA |




A Principal Component analysis is conducted on body mass and gonad mass (which together are the GSI), using R package sizeMat (Josymar Torrejon-Magallanes). This separates the population into two groups with different slopes of gonad mass vs. body mass, where the mature individuals have a steeper slope. This occurs because prior to the onset of maturity an individual is a allocating energy to somatic growth, whereas after onset of maturity it allocates a portion to reproductive development/output.

The method is used in other studies, e.g.,

Parvizi, E., Naderloo, R., Keikhosravi, A., and Schubart, C. D., 2017, Life history traits and patterns of sexual dimorphism in the freshwater crab Potamon ibericum (Bieberstein, 1809) (Decapoda: Brachyura: Potamidae) from the western Alborz Mountains, Iran: Journal of Crustacean Biology, v. 37, no. 3, p. 323-331.

Caill-Milly, N., Sanchez, F., Benito, D., Ruiz, P., Izagirre, U., and Briaudeau, T., 2023, Assessment of size at first maturity for Ruditapes philippinarum from Arcachon Bay (French Atlantic coast): New insights for fishery management: Estuarine, Coastal and Shelf Science, v. 285, p. 108321.

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## all individuals were used in the analysis
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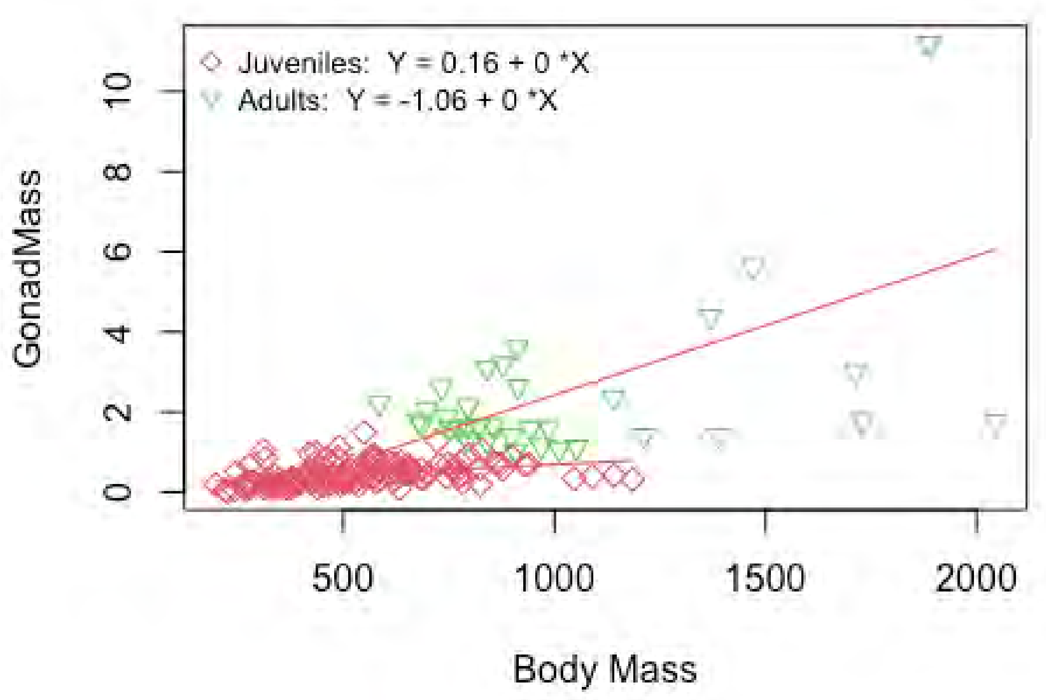
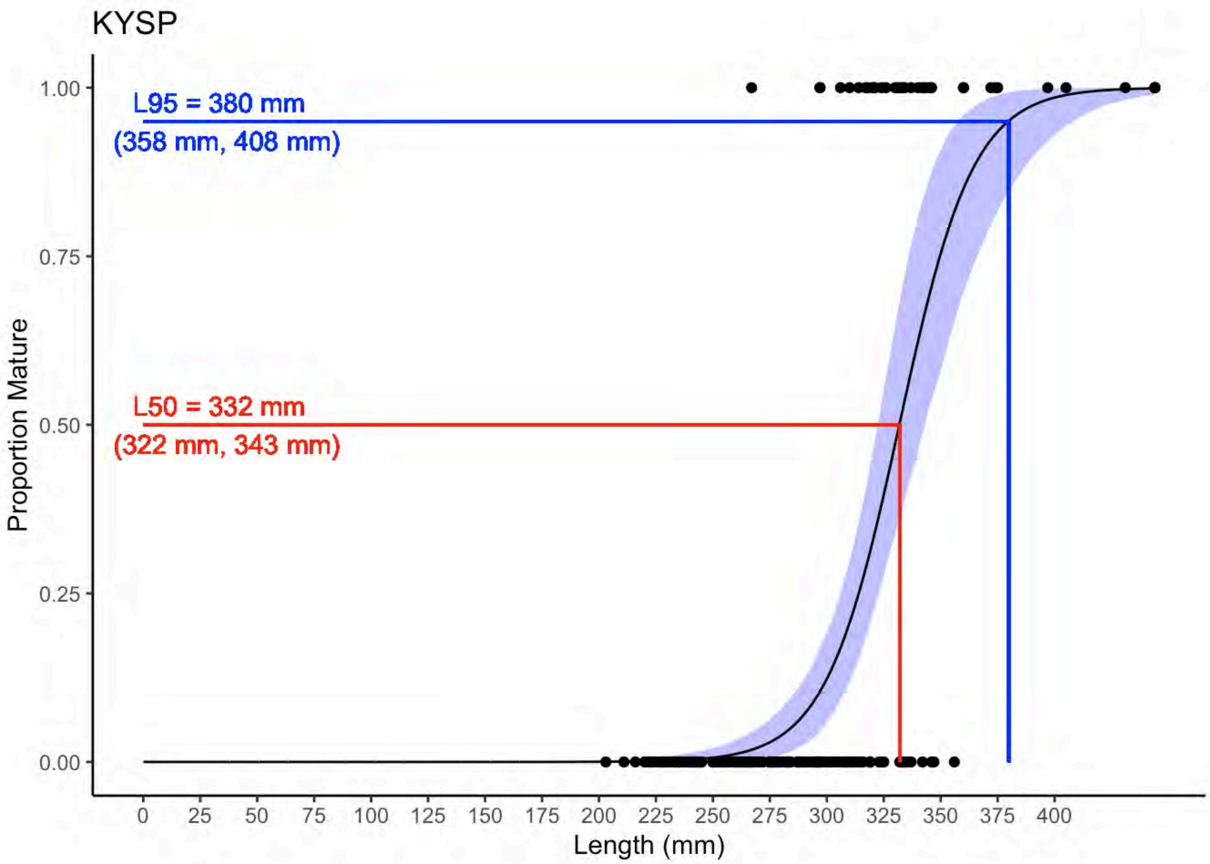
The plot below shows the results of the assignment with principal component analysis. The Red diamonds show individuals assigned as immature, while the green triangles show individuals assigned as mature. Body mass and gonad mass are both in grams.




The maturity ogive for males is shown below. Black line is the logistic estimate of the proportion of the population that as reached maturity at each fork length. Purple shading shows the 95% confidence envelope. Red line shows the length where 50% of the population is mature (L50), with the 95% confidence range of values given in parentheses. Blue line shows the same information for the L95. Black dots show each individual fish used for the input dataset.




## 7 DISCUSSION

This study has established life-history information for goatfish and chub species in Hawai'i based on sampled collected on O'ahu. Future research should include an analysis of age-length relationships using otoliths (Longenecker and Langston, 2008). In addition, analysis of diet from preserved digestive tracts may be helpful for understanding ecology.

### 7.1 Sexual dimorphis and L50 vs L95

The sexual dimorphism in Parupeneus goatfishes (males larger) means that the harvest is likely skewed towards males. In an effort to develop a size limit that is effective for the species, it may be most sensible to use the L95 for females or the L50 for males, which are similar. This would result in a size limit that prohibits take of nearly all females, which should be beneficial to reproductive output of the population.

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