# Size Structure and Reproductive Status of Exploited Reef-Fish Populations at Kamiali Wildlife Management Area, Papua New Guinea

Ken Longenecker, Ross Langston, Holly Bolick, and Utula Kondio

**Honolulu, Hawaii**
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COVER

Eight-year-old John Giamsa (center), helps Ross Langston (left), prepare histological sections of fish gonads for rapid reproductive analysis.

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Ken Longenecker[1],
Ross Langston[1],
Holly Bolick[1],
and
Utula Kondio[2]

(1) Pacific Biological Survey
Bishop Museum
Honolulu, Hawaii 96817, USA

(2) Kamiali Wildlife Management Area
Lababia, Morobe Province, PNG

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## EXECUTIVE SUMMARY

The Kamiali Initiative is a Bishop-Museum-led project to develop a self-sustaining cycle of environmental conservation, scientific research, and economic development in the coastal community of Kamiali, Papua New Guinea. The area includes approximately 120,000 acres of terrestrial and marine habitat, and is larger than most state parks in California. The success of the Kamiali Initiative is contingent upon Kamiali residents preserving the natural environment such that biological field researchers are motivated to work in the area. This project is arguably the most successful and is the only fully sustainable large-scale terrestrial/marine biodiversity conservation project in Papua New Guinea.

The most-challenging conservation issues at Kamiali center on coral-reef fishes. Fish are the source of the overwhelming majority of dietary protein for this coastal village, and coral-reefs are preferred fishing sites. To be successful, conservation practices must balance the conflicting needs of protecting fish populations (to attract researchers) against the cultural value of and dietary need for subsistence fishing.

Here we describe the status of Kamiali's exploited reef-fish populations to help guide and evaluate conservation efforts. We conducted rapid, histology-based reproductive analysis on four species to generate parameters necessary for life-history-based management of fisheries, described catch characteristics of the most common of these species and evaluate the sustainability of the fishery, used a combination of advanced diving technology and laser videogrammetry to augment our 2009 – 2011 descriptions of the size structure of exploited species (a total 74 species are covered in this report), expanded a literature review of reproductive parameters, estimated the percentage of reproductive individuals in each population (when sufficient information existed), and plotted a time series of average length for the most-consistently abundant species to examine long-term trends in fish size.

Results of reproductive analysis of *Lutjanus fulvus* (*iyayaŋ kurĩ naba*) are presented in Longenecker *et al.* (in review). To summarize, male and female $L_{50}$ is 13.5 and 18.8 cm FL, respectively. Sex ratios are not significantly different from 1:1, and do not vary predictably with size. The species does not change sex. Batch fecundity was not significantly related to female length, but weight is ($Wt = 0.0134(FL)^{3.1001}$). $L_m$ of *Kyphosus cinerascens* (*italawe*) is 18.1 cm FL for males and 25.3 cm for females. $Wt = 0.0413(TL)^{2.8250}$. $L_m$ of *Myripristis adusta* (*imbilĩ tombo gabo*) is 16.5 cm FL for males and 16.8 cm for females. $Wt = 0.0112(FL)^{3.3113}$. All *Plectropomus oligacanthus* (*ikula su tatalõ*) specimens were ≤ 41.9 cm FL, female, and immature. $Wt = 0.0060(FL)^{3.2294}$.

Harvest of *Lutjanus fulvus* (*iyayaŋ kurĩ naba*) at KWMA appears biased toward smaller individuals. A catch of 123 fish yielded 10.64 kg. The same yield can be obtained by harvesting only 80 fish distributed from 19 – 21 cm size classes. Under the latter scenario, more individuals would grow to reproductive size and promote population growth.

A total 632 individuals were captured on video during 2012, yielding a combined total 3,278 individuals representing 74 reef-associated species from 19 families (inclusive of 2009 – 2011 data). An exploited reef fish swimming in Kamiali Wildlife Management Area is likely to be about ½ its potential maximum length, and 20% shorter than the length at which maximum yield can be obtained. Size-at-maturity is known for 49% of the species studied. Of these, mean individual length was 92% of female $L_{50}$. Sex-ratios are known for 23 species. Considering only these species, an average 26% of individuals are mature females.

For the five most-consistently abundant species, 3-year moving averages of length suggest the size of four species is relatively stable. The fifth species may be decreasing in size, but more monitoring is needed to evaluate the trend.

Based on the apparent ease with which residents are able to catch fish, overfishing does not currently appear to be a threat to the majority of the exploited reef-fish species we examined. We propose that the population characteristics of species we studied at Kamiali Wildlife Management Area (average size ½ of maximum length and nearly equal to female reproductive length) can be used as indicators of robust populations of exploited fishes.

These aspects of exploited fish populations are apparently maintained by several characteristics of the village and its fishery, such as: customary tenure, distance (and relatively high cost of transport) to commercial markets, a subsistence economy, lack of refrigeration, and environmental cycles. Ongoing and anticipated changes related to economic modernization may threaten these aspects of village life. The Kamiali Initiative, by establishing a pathway to economic development that starts with environmental conservation, should help reduce the environmental impact of socioeconomic transformation.

## INTRODUCTION

### *Kala Words and a Pronunciation Guide for English Speaker*s

At the request of our target audience (residents of Kamiali Wildlife Management Area and neighboring communities), this report features local (Kala) names for fishes. Kala is the native language (or mother tongue) of approximately 2,000 people from six villages along the Huon Coast of Papua New Guinea, and the use of local fish names in this report makes it easier for Kala speakers to understand which species are being discussed.

The use of Kala herein is significant. Remarkably, there was no writing system for the language until 2010, thus this report is the first published documentation of many Kala fish names.

English speakers will recognize most Kala letters. Consonants shared with the English language are pronounced the same way (although the English speakers may hear the Kala “l” as an English “r”). The Kala language has ten vowels. It also has a consonant not used in English. The following pronunciation guide is paraphrased from DeVolder *et al*. 2012:

- a is pronounced “a” as in apple.
- e is pronounced “ay” as in way.
- i is pronounced “ee” as in see.
- o is pronounced “oa” as in boat.
- u is pronounced “oo” as in boot.
- The diacritical mark ~, called a *titi* (meaning wave) in Kala, may appear with any vowel (ã, ẽ, ĩ, õ, ũ) and indicates the vowel is nasalized. That is, air is let into the nasal cavity during pronunciation.
- ŋ is pronounced “ng” as in song.

### *General Background*

This report presents the results of research focused on exploited reef fishes at Kamiali Wildlife Management Area, Morobe Province, Papua New Guinea in 2012, and discusses the work in the context of previous, related work in the area (Longenecker *et al*. 2009, 2010, 2011). Our descriptions of population characteristics are crucial for the success of the Kamiali Initiative, a project to develop a self-sustaining cycle of environmental conservation, economic development, and scientific research. The foundation of this initiative is the residents of Kamiali, who hold title to their territory and traditional tenure over their natural resources.

Kamiali residents established the Kamiali Wildlife Management Area (KWMA) in 1996. It contains 32,000 hectares of terrestrial habitat and 15,000 hectares of adjacent marine habitat. KWMA is remote, located about 65 kilometers south of the port town of Lae. There are no roads to (or in) the village. Its approximately 600 residents obtain most of life’s needs from the surrounding environment.

Gardening and subsistence fishing form the basis of the Kamiali economy and are a focus of village life; however, residents need money for basic supplies and services (*e.g.*, medicine, education, and clothing). These needs, combined with a lack of income, have made exploitation of natural resources (*e.g.*, logging, mining) a tempting short-term source of money elsewhere in Papua New Guinea (PNG). However, logging and mining in PNG often result in disastrous long-term environmental and social impacts. In the interest of conserving their natural resources, and thus preserving their traditional lifestyle, Kamiali leaders signed, in 2006, a Memorandum of Understanding with Bishop Museum outlining the development of a world-class remote scientific research station at KWMA. Visiting researchers pay fees for research permits, field assistance, lodging, and meals. This revenue will help fund educational costs and community-development projects. The Kamiali Initiative thus creates a link between economic benefit and environmental conservation, and provides a strong incentive for villagers to protect their land and water in perpetuity (Figure 1).

For the Kamiali Initiative to succeed, village residents must conserve their natural environment such that it continues to attract biological field researchers. Fishing for coral-reef fishes may be the biggest challenge to the Kamiali Initiative; the vast majority of dietary protein for this coastal village is fish, and coral reefs are preferred fishing sites. Thus, the village must balance the conflicting needs of marine conservation to attract research revenue against fishing for food.

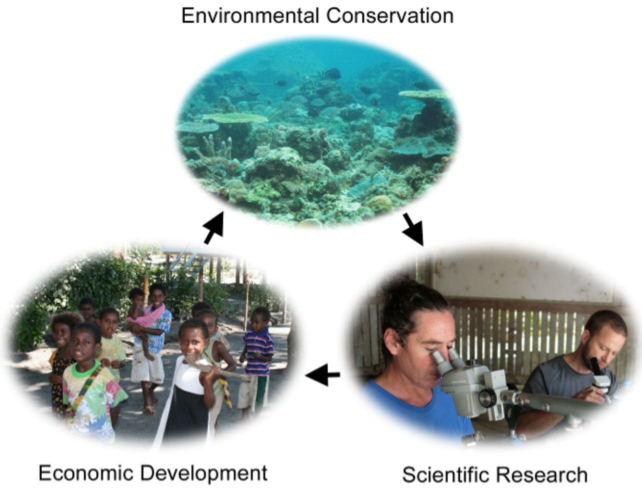


**Figure 1. Conceptual model of the Kamiali Initiative: A well-managed environment attracts biological research, providing a means of economic development to pay for school and medicine, thus providing incentive for continued environmental conservation.**

### *Fishery Surveys*

The most productive starting point to help the village balance conservation and fishing is a baseline description of the size structure of exploited fish populations (*i.e.*, length-frequency or the number of fish that have reached a given length). This information has intuitive appeal; Kamiali residents understand that shrinking average fish size may indicate unsustainable fishing practices. Length-frequency information is also the basis for science-based fishery management and conservation. When combined with life history information, a description of population size structure enables researchers to make predictions about the outcome of various management and conservation actions.

We now have size-structure data covering a span of four years. These data enable us to plot a time-series of average fish length for some of the more abundant species. The time-series plots will help identify long-term trends in exploited fish populations (*e.g.*, whether average is length shrinking, stable, or increasing). This long-term baseline information will permit evaluation of any management and conservation efforts that are enacted at KWMA.

### *Reproductive Analysis*

#### Size-at-maturity

Although detailed descriptions of size structure are the foundation of fishery management and conservation, one of the biggest challenges to converting those data into resource management and conservation action is a lack of basic life history information about the majority of exploited fish species. Remarkably little is known about reproductive parameters for Kamiali's exploited reef fishes. Size at maturity is unknown for nearly 60% of the 57 species examined by Longenecker *et al*. (2011). This problem is not restricted to Papua New Guinea; Longenecker *et al*. (2008a) report that size at maturity is unknown for 38% of the 13 most heavily exploited reef fishes in Hawaii. Worldwide, this information is missing for ~83% of exploited species (Froese & Binohlan 2000). It is impossible to evaluate the reproductive status of a population when this information is missing.

The sheer diversity of coral-reef fishes, and the supposed cost associated with the reproductive analysis of each species are often cited as barriers to obtaining this important information (Roberts & Polunin 1993, Johannes 1998). An additional challenge is the lack of basic infrastructure (*e.g.*, electrical service needed to operate laboratory equipment) in many parts of the developing countries where most of the world's coral reefs are located.

Given the scarcity of reproductive information, Froese & Binohlan (2000) developed empirically derived equations to estimate reproductive size. The equation for minimum female size-at-maturity ($L_m$) is highly predictive ($r^2 = 0.905$) for the subset of species used to develop the regression. However, Longenecker *et al.* (2011) demonstrated that the relationship overestimated female $L_m$ for exploited fishes at KWMA. Further, the degree of overestimation increased with increasing maximum length. We fully recognize the value of Froese & Binohlan's equations; it is far better to have an approximate reproductive size, based on empirical evidence, than to devise fishery management and conservation plans without reference to reproductive biology. However, the results of Longenecker *et al.* (2011) highlight the need for continued life history work. Marine resource management and conservation outcomes are more likely to match expectations when the latter are based on accurate information rather than approximations with known biases.

To address the above problems, we developed a method for rapid, low-cost, on-site, histology-based reproductive analysis that does not require electrical service (Longenecker *et al.* in press). With this method, reproductive information can be generated quickly, and its low cost eliminates one of the arguments against broad-scale reproductive analysis.

We focus on histological examination because gross (macroscopic) examination of gonads is known to introduce excessive error when describing reproductive parameters (Vitale *et al.* 2006). Longenecker *et al.* (in press) compared results from macroscopic and histological reproductive analysis and found that reproductive status and/or sex was misclassified in 47% of specimens examined (Longenecker *et al.* in press). This level of error appears consistent; in a later study, 43% of specimens were misclassified (Longenecker *et al.* in review). Importantly, in both studies gross (macroscopic) examinations led to overestimates of the number of mature females and underestimates of the number of mature males. These systematic errors underestimate female and overestimate male size-at-maturity. For instance, macroscopic examination of *godobo manibarã* and *godobo tarõ* (*Diagramma pictum*) gonads (Grandcourt *et al.* 2006) underestimated female size-at-maturity by 11% compared to results of histological examination of the same population (Grandcourt *et al.* 2011).

Providing accurate reproductive information will allow resource owners in developing countries (*i.e.*, Kamiali residents) to determine how their fishing practices may be impacting the marine environment. For instance, villagers can evaluate whether fish on the dinner table have had the chance to reproduce. Combining reproductive information with descriptions of size structure will allow communities to judge whether there are there enough adult (*i.e.*, reproductively active) fish to insure an adequate food supply for future generations.

Batch Fecundity and Sex-ratios

Helping village residents understand the value of various fishery conservation and management measures may be most simply done by generating estimates of reproductive output. One approach is to describe batch fecundity: the number of eggs shed in a single spawning event. Typically, there is an exponential (approximately cubic) relationship between fish length and batch fecundity. Thus, it is generally expected that an increase in average fish size will result in vast increases in reproductive output (and the number of young fish available to replace those harvested). For instance, Froese (2004) argues that that large fish play important roles in the long-term survival of a population partly because large females produce many more eggs than small females. However, this argument may not hold if the sex ratios change with size. If larger size-classes are male dominated, there may be so few females that population-level egg production drops. If species reach a length at which individuals are exclusively male, egg production can stop.

Longenecker *et al*. (2011) report that for six of 12 species at KWMA for which sex ratios are known, the proportion of males in a population increases with length. In Hawai‘i, the same pattern was found in three additional species (a damselfish, angelfish and surgeonfish; see Longenecker & Langston 2008, Langston *et al*. 2009). Loubens (1980) found that 12 species from New Caledonia (a triggerfish, a monocle bream, a wrasse, groupers, emperors, and snappers) reach a size where only males are present, and nine species (groupers and emperors) become increasingly male-biased with length. The same trend would be expected for protogynous fishes (*e.g.*, Scaridae, Serranidae, and Labridae). Some species from the above areas have stable or increasingly female-biased sex ratios (see Loubens 1980, Longenecker *et al*. 2008b, Longenecker *et al*. 2011). However, the majority of species studied (71%) become male-biased as size increases. Further, these species represent a broad range (9 families) of reef fishes.

If the goal of fishery management and conservation is to ensure an adequate number of adults of both sexes, size-specific sex ratios must be known before useful management policies can be formulated. This information will also help evaluate whether conservation and management actions designed to increase average fish length will result in more adults of either sex. Given the results summarized above, increases in average length do not necessarily lead to increases in mature individuals of both sexes. Thus, a combination of reproductive parameters must be considered so that village residents do not have unreasonable expectations when considering various fishery conservation and management actions.

### ***Catch Characteristics***

The above discussion of fish length focused on at-large individuals (*i.e.*, the free-swimming population). However, fishing gear, time, and location can result in catches that differ significantly from the characteristics of a free-swimming population. A detailed description of fish catch can help village residents understand how their fishing practices may impact their marine resources. For instance, Froese (2004) proposed three easily understood indicators to help evaluate the status of fish populations. The two simplest measurements are percent of reproductively mature individuals in the catch and percent of individuals within 10% of optimum length ($L_{opt}$, the length where, for an unexploited population, the number of fish of a given age multiplied by mean weight at that age is maximized and thus maximum yield can be obtained). Applying Froese’s indicators to fish catch at Kamiali will allow residents to evaluate whether fishing practices at KWMA are sustainable.

The value of reproductive information is further demonstrated by our ability to model the outcome of fishery management/conservation proposals relative to current fishing practices. These models allow us to explore ways that subsistence fishers can maintain their current harvest levels while simultaneously promoting larger fish populations. Longenecker *et al*. (2011) presented this information in terms of weight (important to villagers that depend on fish for their primary source of protein) and number of eggs released in a single spawning event (likely to influence the size of future fish populations). Most importantly, this information can be easily understood by non-specialists (*e.g.*, village residents who control marine resources at KWMA and will ultimately be responsible for any conservation/management decisions). For instance, harvest of *ikula sa* (*Cephalopholis cyanostigma*) at KWMA appears non-selective (average size of the catch was the same as that of the free-swimming population), and a catch of 44 fish yielded 5.62 kg. However, residents can obtain the same 5.62 kg by harvesting only 25 fish equally distributed among 23 – 25 cm size classes. Under this scenario, a hypothetical population would produce an additional 30,105 eggs per spawning event. On the other hand, harvest of *iwaŋgale* (*Parupeneus barberinus*) at KWMA appears to select larger individuals; all fish had reached adult size (but no fish was within 10% of $L_{opt}$). A catch of 123 fish yielded 11.08 kg. Residents can obtain the same 11.08 kg by harvesting only 26 fish equally distributed among 26 – 32 mm size classes. Under this scenario, a hypothetical population would produce an additional 543,442 eggs per spawning event. These numbers can be a powerful motivator for subsistence fishers attempting to balance immediate dietary needs with longer term goals of marine conservation.

### *Purpose*

The purpose of this study is to generate more-robust descriptions of the population size-structure of Kamiali's exploited reef fishes by augmenting, with a series of *in situ* surveys, demographic information gathered from 2009 – 2011. Length-frequency information will be examined in light of estimated length at optimum yield and life-history parameters such as maximum length, reproductive size, and sex ratios. For five of the most-abundant species at KWMA (as indicated by our fishery surveys), we will present a time-series of average fish length. These size-structure analyses will provide important baseline information that will allow Kamiali residents to detect changes in fish populations and, when necessary, take action to improve their fish stocks. To address the scarcity of reproductive information on exploited fishes at KWMA, we will describe the reproductive biology of four species. We will also examine the catch characteristics of the most frequently caught of these species to help evaluate whether current fishing practices are sustainable. Providing this information in the context of life history parameters will allow Kamiali residents to more-precisely define their conservation goals (*e.g.*, from "we want more fish" to "we will fish in a manner consistent with increasing the number of reproductive females"). Combined, the size-structure and life-history information will also serve as the basis for evaluating the effectiveness of conservation efforts enacted by the Kamiali community.

## METHODS

### *Study Area*

Kamiali is one of six Kala-speaking villages in Papua New Guinea and is located on the Huon Coast, approximately 64 km SSE of the port city, Lae. Approximately 600 residents hold title to and control the use of land, adjacent marine water, and the resources contained therein. The northern boundary of the Kamiali Wildlife Management Area (KWMA) is the mouth of the Bitoi River, whereas the Sela River is the southern limit. Nassau and Saschen Bays are wholly contained within the management area, as are Lababia and Jawani Islands and Capes Dinga and Roon. The northern part of Hessen Bay is also contained within the management area.

The terrestrial portion of the KWMA is remarkably undeveloped and characterized by lush vegetation. Kamiali Village is concentrated along the northern portion, where the shoreline is exclusively sandy beach. South of the village, the shoreline is dominated by fringing reefs on Capes Dinga and Roon. Fringing reefs also surround the islands of Lababia and Jawani. These reef flats transition abruptly to a fore reef which is steep, typically descending 20 to 30 meters. At their bases, the reefs give way to sandy sediment that is believed to occupy the majority of the marine area. Some coral outcroppings, patch reefs and pinnacles are interspersed throughout this presumably sedimentary area. The combined horizontal and vertical area (on reef flats and fore reefs, respectively) occupied by coral is approximately 248 ha.

### *Rapid Reproductive Analysis*

We chose four species for rapid reproductive analysis, based on the following criteria: 1) all are an important part of village fish catch; 2) village residents expressed an interest in learning more about each species; 3) published reproductive information was lacking or incomplete; and 4) each species is distinctive enough that the chance of misidentification was low. We analyzed *italawe* (the kyphosid, or sea chub, *Kyphosus cinerascens*), *iyayaŋ kurĩ naba* (the lutjanid, or snapper, *Lutjanus fulvus*), *imbilĩ tombo gabo* (the holocentrid, or soldierfish, *Myripristis adusta*), and *ikula su tatalõ* (the serranid, or coral trout, *Plectropomus oligacanthus*). Images of each species are presented in Figure 2.

*Italawe* (*Kyphosus cinerascens*) is widespread in the Indo-Pacific, ranging from the Red Sea and east coast of Africa to the Hawaiian Islands, Line Islands, and Tuamotu Archipelago; and from Japan to New South Wales, Australia (Randall 2005). *Iyayaŋ kurĩ naba* (*Lutjanus fulvus*) is also widespread in the Indo-Pacific, its natural range is from East Africa to the Marquesas and Line islands; and from southern Japan to Australia. It has also been introduced to and become established in Hawai‘i. (Anderson & Allen 2001). *Imbilĩ tombo gabo* (*Myripristis adusta*) is found throughout the Indo-Pacific with the following exceptions: Red Sea, Arabian Sea, Persian Gulf, Hawai‘i, and the Pitcairn Group (Randall & Greenfield 1999). *Ikula su tatalõ* (*Plectropomus oligacanthus*) is known only from the western Pacific Ocean, including the Philippines, Indonesia, New Guinea, northeastern Australia from Cape York to the northern Great Barrier Reef, Palau, Chuuk, the Caroline Islands, Marshall Islands, and Solomon Islands (Heemstra & Randall 1999).

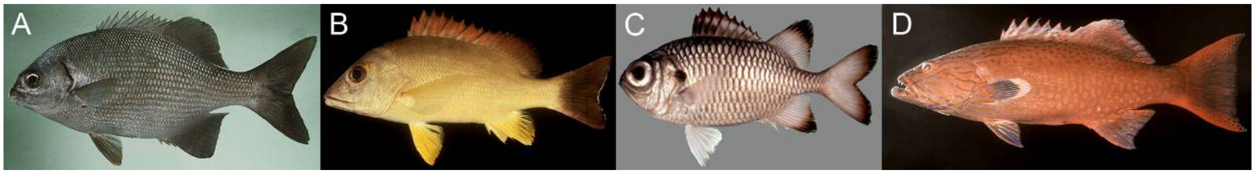


**Figure 2. Species chosen for reproductive analysis. A) *italawe* (*Kyphosus cinerascens*), B) *iyayaŋ kurĩ naba* (*Lutjanus fulvus*), C) *imbilĩ tombo gabo* (*Myripristis adusta*), D) *ikula su tatalõ* (*Plectropomus oligacanthus*). Images courtesy of J. Randall.**

All specimens used for reproductive analysis were caught by village residents between February and June 2012. They delivered their fish to our processing station and allowed us to obtain the length and weight, and remove the gonads of each fish. Fishers received a modest bounty (3.00 kina) for each specimen and the fish were returned to them for consumption.

From 23 May - 2 June 2012 we used methods modified from Longenecker et al. (in press) for size-at-maturity and sex-ratio analyses. Briefly, for each specimen we measured fork length (FL) to the nearest mm, and estimated whole body weight with a hanging spring-scale. We then removed and fixed gonads in a modified Dietrich’s solution for at least 24 h. Whole gonads were weighed to 0.001 g on a battery-powered jeweler’s scale. For each ovary that appeared to be at or nearing maturity, an approximately 1-cm thick transverse section was removed from one lobe, weighed to 0.001 g, and transferred to Gilson’s fluid for later batch fecundity analysis (below). For all gonads, we embedded an approximately 8 mm$^3$ section in plastic (JB4, Electron Microscopy Sciences). We mounted on a microscope slide at least five tissue sections from each specimen, stained them with Toluidine Blue, and examined them at 40X on a dissecting microscope for evidence of reproductive maturity. We classified ovaries according to Wallace and Sellman (1981) and testes according to Nagahama (1983). We considered females mature with the onset of vitellogenesis (appearance of yolk protein in the oocytes), and males mature when the testes contained visible spermatozoa. We report size at sexual maturity ($L_{50}$) as the size at which a regression (3-parameter, sigmoidal) of percent mature individuals in each 2-cm size class versus fork length (the average length of individuals within a size class) indicates 50% of individuals are mature.

To estimate batch fecundity, we used methods modified from Agger et al. (1974). Ovarian samples reserved for batch-fecundity analysis (above) were stored in Gilson's fluid for at least six weeks. We analyzed those that, based on the histological examination above, had reached at least late vitellogenesis (≥ stage 3b). Oocytes were liberated from the stroma by agitation in an ultrasonic cleaner. Samples were diluted with water to a total volume of 400 ml, stirred to distribute oocytes, and a Stempel pipette was used to obtain ten 1-ml subsamples. We counted the largest size-class of oocytes in each subsample (oocytes ≥ stage 3b were ≥ 400 µm in diameter, thus oocyte size was used as an indicator for oocyte maturity). Batch fecundity was estimated with the following equation:

Batch fecundity = (mean # oocytes/ml)(400 ml)(total ovary weight/sample weight)

Regression analysis (2-parameter power function) was used to describe the relationship between fork length and batch fecundity.

### *Catch Characteristics*

We used the specimens obtained for reproductive analysis to describe length-weight relationships. We constructed a fishery-dependent length-frequency histogram for *iyayaŋ kurĩ naba* (*Lutjanus fulvus*). We evaluated fishery selectivity with a two-sample t-test comparing mean fish lengths in the harvested and free-swimming populations. We used one-sample t-tests to compare mean catch size with empirically derived estimates of $L_{opt}$ (Froese & Binohlan 2000) and our estimate of $L_{50}$ (Longenecker *et al.* in review). We also calculated the percent mature individuals and the percent of individuals within 10% of $L_{opt}$ in the catch.

### *Fishery Surveys*

From 25 May – 3 June 2012, we conducted 10 laser-videogrammetry surveys to describe the size distribution of exploited reef fishes in Kamiali Wildlife Management Area. These surveys were performed at preferred fishing sites, most of which are beyond the depth limits of conventional open-circuit SCUBA. As such, we used closed-circuit rebreathers with 10/50 trimix diluent as life support to reach depths to 92 m. Due to the lengthy decompression obligations incurred while working at these depths (*e.g.*, 3 hours for a 20-minute dive to 92 m), the work was performed in areas with bathymetric profiles that permitted work to continue while ascending. Thus, surveys are concentrated at offshore pinnacles and near fringing reefs (Table 1, Figure 3).

A high-definition video camera fitted with parallel laser pointers was used to capture images of individual fish when they were oriented perpendicular to the laser beam axes. We used editing software to review the video and capture still frames where both lasers appeared on the fish. Because the beams are parallel, the lasers superimpose a reference scale on the side of the fish, allowing length estimates by solving for equivalent ratios. Our length estimates were calculated using ImageJ software (Rasband 2009). Longenecker & Langston (2008) have demonstrated a nearly 1:1 relationship between estimated and actual fish lengths. Further, a prediction interval suggested 95% of estimates will be within 0.5 cm of the actual fish length (Longenecker & Langston 2008).

The species included in the fishery survey met the following four criteria: 1) they are reef fishes; 2) exploited by local fishers; 3) common enough to have been captured at least several times on video; and 4) can be reliably identified from still images. A total 74 species representing 19 families (Acanthuridae, Balistidae, Caesionidae, Carangidae, Carcharhinidae, Ephippidae, Haemulidae, Holocentridae, Kyphosidae, Labridae, Lethrinidae, Lutjanidae, Mullidae, Nemipteridae, Priacanthidae, Scaridae, Scombridae, Serranidae, and Siganidae) met these criteria.

A systematic literature review was conducted using the methods of Longenecker *et al.* (2008a) to obtain estimates of maximum length ($L_{max}$), size at maturity, size-specific sex ratios, spawning season, and reproductive mode. Briefly, we: 1) searched electronic resources (*e.g.*, Google Scholar, FishBase) using key-word combinations of species names plus “reproduction” or “maturity”; 2) upon obtaining these publications, we identified and obtained additional relevant literature listed in their reference section; 3) we then searched these publications and obtained any additional references.

In summarizing life history information, preference was given to studies specific to Papua New Guinea (*e.g.*, maximum length information of Allen & Swainston 1993). Preference was also given to length at 50% maturity ($L_{50}$) over other estimates of size at maturity (*e.g.*, minimum size-at-maturity or $L_m$). Results from studies outside the southern hemisphere were included only when data for southern populations were not available (*e.g.*, reproductive size for *imaŋalẽ talã* or *Caranx melampygus*). Conversely, information on spawning seasonality was included only for southern hemisphere populations.

We applied the empirically derived equations of Froese & Binohlan (2000) to estimate fishery and, when necessary, reproductive parameters. Published maximum lengths ($L_{max}$, see Results) were used to generate estimates of $L_\infty$. The latter were then used to generate estimates of $L_{opt}$. If published values of $L_{50}$ were not available, we also used $L_\infty$ estimates to generate ♀$L_m$ estimates.

**Table 1. List of marine sites surveyed at Kamiali Wildlife Management Area during 2012. Latitude and longitude were estimated by GPS using the WGS84 datum. FR = Fringing Reef, OP = Offshore Pinnacle.**

| Survey | Date | Latitude (ºS) | Longitude (ºE) | Habitat | Max Depth (m) |
|---|---|---|---|---|---|
| 1 | 25-May-12 | 7.30314 | 147.15393 | FR | 31 |
| 2 | 26-May-12 | 7.29080 | 147.20840 | OP | 30 |
| 3 | 27-May-12 | 7.30036 | 147.13283 | FR | 20 |
| 4 | 28-May-12 | 7.34815 | 147.15633 | FR | 32 |
| 5 | 28-May-12 | 7.32087 | 147.20534 | OP | 33 |
| 6 | 30-May-12 | 7.32857 | 147.20650 | OP | 65 |
| 7 | 31-May-12 | 7.34375 | 147.16573 | OP | 51 |
| 8 | 01-Jun-12 | 7.30434 | 147.15421 | FR | 92 |
| 9 | 02-Jun-12 | 7.30776 | 147.16628 | OP | 31 |
| 10 | 03-Jun-12 | 7.30044 | 147.13452 | FR | 17 |

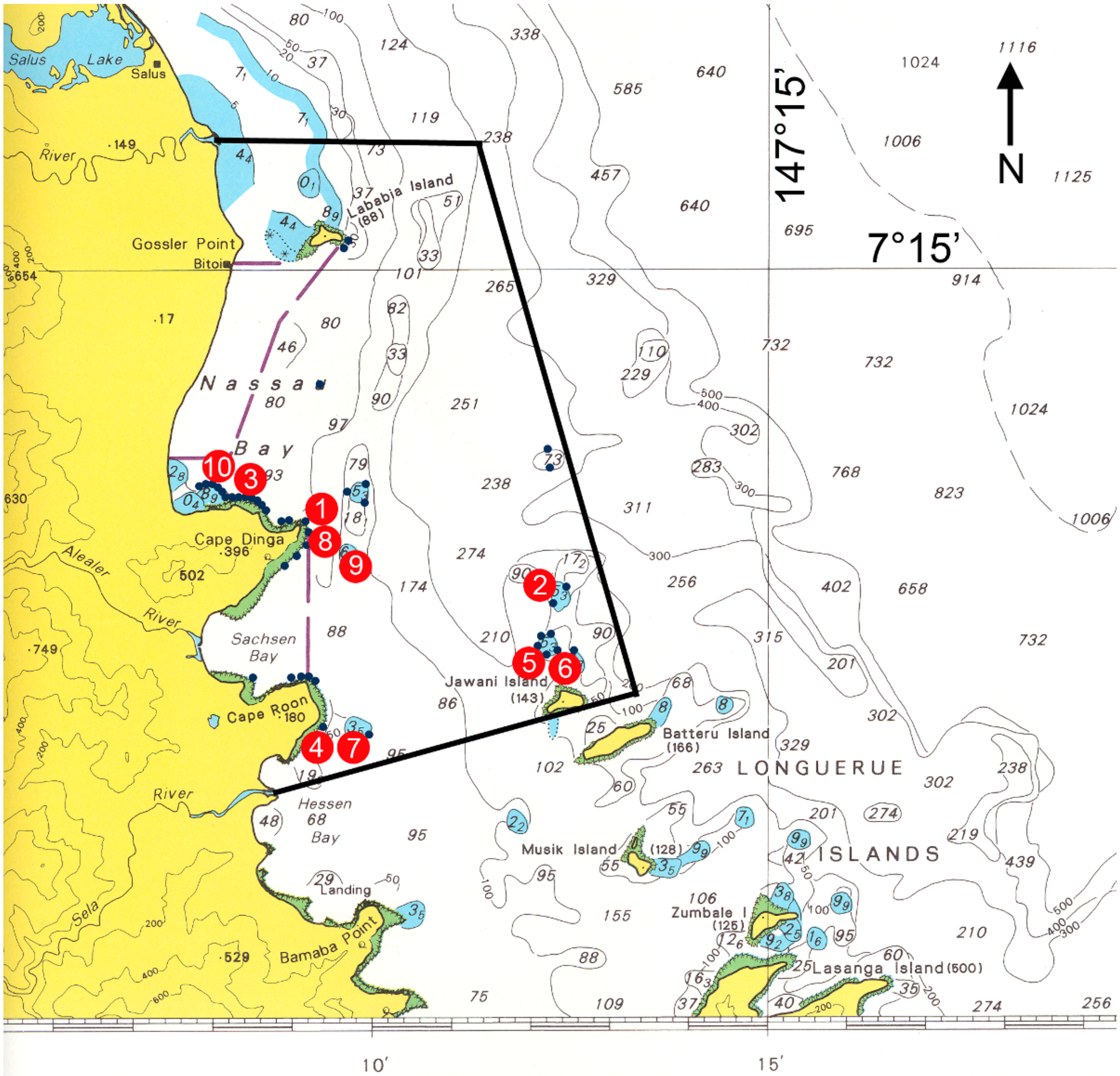


**Figure 3. The marine portion of Kamiali Wildlife Management Area (outlined in black). Red circles indicate locations of 2012 survey sites (coordinates are given in Table 1). Smaller blue circles indicate 2009 - 2011 survey sites (coordinates in Longenecker *et al.* 2009, 2010, 2011). Adapted from chart Aus 523, published by the Australian Hydrographic Service. Depths are in meters.**

We constructed length-frequency histograms for each species for which at least 15 individuals were captured on video from 2009 – 2012. A still frame captured from video must have been of suitable quality for length estimation to be included in the count of total number of individuals. Mean length was compared to $L_{max}$, $L_{opt}$, and female $L_m$ or $L_{50}$. When sex ratios were available, we estimated the percentage of reproductive females in each population. The length information presented below is the distance between the front of the head and the end of the middle caudal ray.

### *Time Series*

We plotted a time-series of average length by year for species that were most-frequently and consistently captured on video. To examine longer-term trends, we also plotted 3-year moving averages. Species we analyzed were represented by at least 10 specimens each of the last four years. Five species met this criterion: *luduŋ ŋai* or *mai* (the caesionid, or fusilier, *Caesio cuning*), *ikula sa* (the serranid, or grouper, *Cephalopholis cyanostigma*), *itale* (the lutjanid, or snapper, *Lutjanus biguttatus*), *iwaŋgale* (the mullid, or goatfish, *Parupeneus barberinus*), and another goatfish, *iwaŋgale bote* (*P. multifasciatus*). Images of each are presented in figure 4.

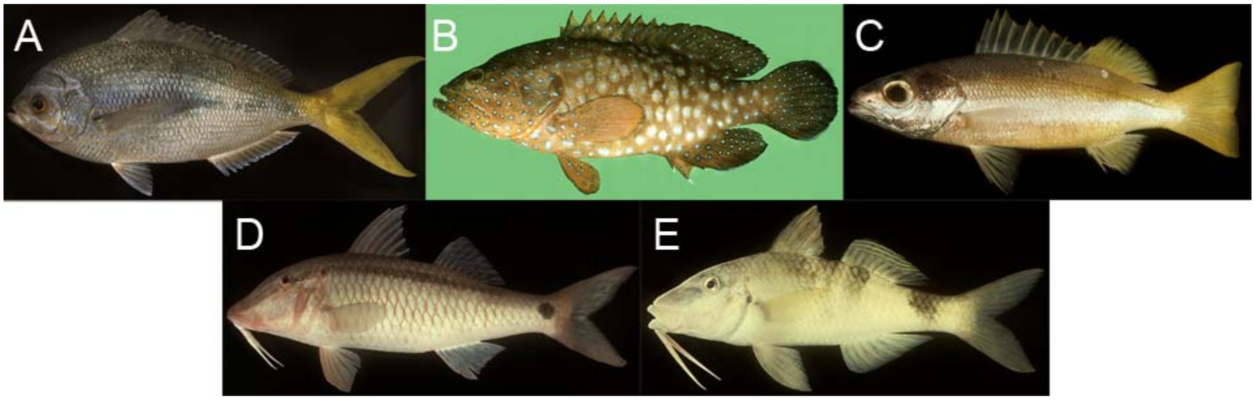


**Figure 4. Species used for time-series plots. A) *luduŋ ŋai* or *mai* (*Caesio cuning*), B) *ikula sa* (*Cephalopholis cyanostigma*), C) *itale* (*Lutjanus biguttatus*), D) *iwaŋgale* (*Parupeneus barberinus*), E) *iwaŋgale bote* (*P. multifasciatus*). Images courtesy of J. Randall.**

## RESULTS

### *Reproductive Analysis*

Results for *iyayaŋ kurĩ naba* (*Lutjanus fulvus*) are presented in Longenecker *et al*. (in review). To summarize, we histologically examined 114 gonads and found male and female $L_{50}$ is 13.5 and 18.8 cm FL, respectively. Sex ratios are 1♂:1.38♀, are not significantly different from 1:1, and do not vary predictably with size. The species does not change sex. On average, females from 17.8 to 21.7 cm FL (mean = 19.4) produce 35,305 ± 29,141 (mean ± SD) eggs per spawning event.

We histologically examined 16 gonads from *imbilĩ tombo gabo* (*Myripristis adusta*). Specimen lengths ranged from 10.4 to 20.0 cm FL, average length was 16.5 cm. All gonads were differentiated. The single immature male was 16.3 cm FL. Three mature males ranged from 16.5 to 19.9 cm (average = 16.5 cm). Five immature females ranged from 10.4 to 16.3 cm. Seven mature females ranged from 16.8 to 20.0 cm (average = 18.6 cm). Fish length was not predictive of batch fecundity, which ranged from 11,834 – 28,955 eggs (average = 20,024).

We histologically examined gonads from 20 *italawe* (*Kyphosus cinerascens*). Specimen lengths ranged from 14.1 to 32.6 cm FL, average length was 23.3 cm. Undifferentiated gonads were seen in two fish (14.1 and 15.1 cm). Three immature males ranged from 15.8 to 20.1 cm. Seven mature males ranged from 18.1 to 29.9 cm (average = 26.6 cm). Five immature females ranged from 17.8 to 24.1 cm. Three mature females ranged from 25.3 to 32.6 cm (average = 29.7 cm). We had too few specimens to explore the relationship between length and batch fecundity. However, batch fecundity ranged from 76,226 – 141,891 eggs (average = 113,596).

We histologically examined gonads from eight *ikula su tatalõ* (*Plectropomus oligacanthus*). Specimen lengths ranged from 29.4 to 41.9 cm FL, average length was 36.5. All were immature females.

### *Length-Weight Relationships*

Length is highly predictive of total body weight for the four species selected for reproductive analyses. For all species, weight is an approximately cubic function of length (Table 2).

**Table 2. Length-weight relationships for five exploited fishes based on fishery catch. Wt = total body weight (g), FL = fork length (cm). Information for *L. fulvus* from Longenecker *et al.* in review.**

| Species | Equation | N | Range (cm) | $r^2$ |
|---|---|---|---|---|
| *Kyphosus cinerascens* (*italawe*) | $Wt = 0.0413(TL)^{2.8250}$ | 20 | 14.1 – 32.6 | 0.988 |
| *Lutjanus fulvus* (*iyayaŋ kurĩ naba*) | $W = 0.0134(FL)^{3.1001}$ | 123 | 8.6 – 23.3 | 0.977 |
| *Myripristis adusta* (*imbilĩ tombo gabo*) | $Wt = 0.0112(FL)^{3.3113}$ | 19 | 10.4 – 20.0 | 0.959 |
| *Plectropomus oligacanthus* (*ikula su tatalõ*) | $Wt = 0.0060(FL)^{3.2294}$ | 8 | 29.4 – 41.8 | 0.974 |

### *Fishery Surveys*

In 2012, we captured an additional 632 specimens on video suitable for length estimation, yielding a combined total 3,278 individuals analyzed from 2009 to 2012. These specimens include 16 species not analyzed in the 2009 - 2011 surveys (Longenecker *et al*. 2012). Mean length, along with known information on maximum length, size at maturity, size-specific sex ratios, spawning season, and reproductive mode is presented for each of 74 species in Table 3. Species and family names follow the taxonomy of FishBase (Froese and Pauly 2012). A tilde (~) preceding values in Table 3 indicates uncertainty. These typically occur before maximum length and size-at-maturity values. For maximum length, a lack of published total length to fork length equations prevented accurate determination of fork length. For size-at-maturity values, only minimum size-at-maturity ($L_m$) values were available. These would be expected to be smaller than the preferred size at 50% maturity ($L_{50}$).

Weighted percent maximum length of all individuals captured on video was 52%. That is, an exploited reef fish swimming in Kamiali Wildlife Management Area is likely to be about ½ its potential maximum length.

Weighted percent estimated optimum length of all individuals captured on video was 80%. In other words, an exploited fish is likely to be about 20% shorter than the length at which the empirical equation of Froese & Binohlan (2000) suggests maximum yield per recruit can be obtained.

Information about reproduction in these species is remarkably scant. Size at maturity is known for about half (49%) of the species studied. Of this subset, an individual *imaŋalẽ babaura* (*Carangoides bajad*), *Plectorhinchus vittatus*, *imbilĩ tombo gabo* (*M. adusta*), *imbilĩ sa* (*Neoniphon sammara*), *italawe* (*K. cinerascens*), *Cheilinus fasciatus*, *babaura* (*Lutjanus carponotatus*), *ina suwi* (*Lutjanus gibbus*), *babaura yumi yayã* (*Lutjanus kasmira*), *kawasi ŋasiŋa* (*Lutjanus russelli*), *itale yumi yayã* (*Mulloidichthys vanicolensis*), *iwaŋgale* (*Parupeneus barberinus*), *walia* (*Parupeneus trifasciatus*), *Priacanthus hamrur*, *Rastrelliger kanagurta*, *itaŋgi* (*Scomberomorus commerson*), *ikula bobo* (*Cephalopholis boenak*), *ikula tumi* (*Cephalopholis sexmaculata*), *yula* (*Plectropomus leopardus*), or *yulawe* (*Siganus lineatus*) in Kamiali Wildlife Management Area was more likely than not to be reproductively mature. These represent 56%

of the species for which reproductive information is available. On the other hand, an individual *biaŋgawe suwi* (*Naso hexacanthus*), *imaŋalẽ talã* (*Caranx melampygus*), *Carcharhinus amblyrhynchos*, *Triaenodon obesus*, *illĩ* (*Lutjanus argentimaculatus*), *itale* (*Lutjanus biguttatus*), *Lutjanus bohar*, *iyayaŋ kurĩ naba* (*Lutjanus fulvus*), *baniŋga* (*Lutjanus monostigma*), *imawe* (*Lutjanus semicinctus*), *isale* (*Lutjanus vitta*), *iwaŋgale bote* (*Parupeneus multifasciatus*), *itaŋgi talaloŋa* (*Gymnosarda unicolor*), or *ikula sa* (*Cephalopholis cyanostigma*) were more likely to be immature. Further, no individual *godobo manibarã /tarõ* (*Diagramma pictum*), or *ikula su mani balã* (*Plectropomus areolatus*) had reached maturity.

Given the scarcity of reproductive information, we compared average length relative to minimum size at female maturity (♀$L_m$), and observed size at which 50% of females are mature (♀$L_{50}$). For all ♀$L_m$ values combined (observed and estimated), the weighted-mean length of 51 species suggests an exploited fish was 80% of minimum size at maturity. Published ♀$L_{50}$ values were available for 23 species. For these, average length was 92% of female $L_{50}$.

For eight of the 24 species for which information on sex ratios has been published, larger size classes are increasingly male dominated [*babaura* (*Lutjanus carponotatus*), *ina suwi* (*Lutjanus gibbus*), *isale* (*Lutjanus vitta*), *iwaŋgale* (*Parupeneus barberinus*), *iwaŋgale bote* (*Parupeneus multifasciatus*), *ikula sa* (*Cephalopholis cyanostigma*), *ikula su mani balã* (*Plectropomus areolatus*), yula (*Plectropomus leopardus*)]. Size-specific sex ratios were not examined in two serranid species with overall female biases [*ikula bobo* (*Cephalopholis boenak*), and ikula karu guŋ-guŋ (*Cephalopholis urodeta*)]. However, all serranids are classified as protogynous hermaphrodites (Heemstra & Randall 1993). Because individuals typically mature as females, then change sex with further growth, these species should also be expected to have male-biased sex ratios with increasing size [this assertion is true for *ikula sa* (*Cephalopholis cyanostigma*), *ikula su mani balã* (*Plectropomus areolatus*) and yula (*Plectropomus leopardus*)]. Seven species occur in an approximately 1:1 sex ratio [*imaŋalẽ tombo gabo* (*Carangoides plagiotaenia*), *godobo manibarã* and *godobo tarõ* (*Diagramma pictum*), *illĩ* (*Lutjanus argentimaculatus*), *itale* (*Lutjanus biguttatus*), *iyayaŋ kurĩ naba* (*Lutjanus fulvus*), *imawe* (*Lutjanus semicinctus*), and yulawe (*Siganus lineatus*)]. Overall sex ratios are female-biased for six species [*imaŋalẽ talã* (*Caranx melampygus*), *Plectorhinchus vittatus*, *imbilĩ sa* (*Neoniphon sammara*), *babaura yumi yayã* (*Lutjanus kasmira*), *walia* (*Parupeneus trifasciatus*), and *Priacanthus hamrur*]; however, the possibility of predictable size-specific sex ratios has not been evaluated for any of these species. *Itaŋgi* (*Scomberomerus commerson*) is female-biased at larger sizes. When published sex-ratio information is considered, the size structure data generated from laser-videogrammetry surveys study suggest, on average, 26% of the exploited reef fish population is composed of mature females.

Demographic information for each of 74 species is presented below. When at least 15 individuals were captured on video suitable for length estimates, these accounts also include size-frequency histograms, with arrows indicating maximum length ($L_{max}$), optimum length ($L_{opt}$) and female reproductive length. The reader is cautioned that, depending on information available, reproductive length may be minimum size at maturity ($L_m$) or size at 50% maturity ($L_{50}$). Also, note that arrows may be solid for published values, or dashed for estimated values.

**Table 3. Size and reproductive information for common, exploited fishes in Kamiali Wildlife Management Area (updated from Longenecker *et al*. 2010). Values bridging female and male $L_{50}$ columns (*Naso hexacanthus*, *Neoniphon sammara*, *Lutjanus monostigma*, *Gymnosarda unicolor,* and *Scomberomorus commerson*) indicate no sex-specific size-at-maturity values were provided.**

| Taxon (Kala name, if recorded) | N | Mean length (cm) | $L_{max}$ (cm) | Female $L_{50}$ (cm) | Male $L_{50}$ (cm) | Sex ratio | Spawning season | Sex change? |
|---|---|---|---|---|---|---|---|---|
| ACANTHURIDAE | | | | | | | | |
| *Ctenochaetus tominiensis* | 6 | 15 | 19[a,b] | | | | | No[c] |
| *Naso hexacanthus* (*biaŋgawe suwi*) | 88 | 43 | 71[a,b] | ~50[b,d] | | | | No[c] |
| *Naso lopezi* (*biaŋgawe talõ*) | 3 | 59 | 48[a,b] | | | | | No[c] |
| *Naso vlamingii* (*biaŋgawe tumi*) | 10 | 36 | 51[a,b] | | | | | No[c] |
| BALISTIDAE | | | | | | | | |
| *Canthidermis maculata* (*labaikã suwi*) | 13 | 33 | 35[a] | | | | | No[c] |
| CAESIONIDAE | | | | | | | | |
| *Caesio cuning* (*luduŋ ŋai* or *mai*) | 1065 | 16 | 42[a,b] | | | | | No[e] |
| CARANGIDAE | | | | | | | | |
| *Carangoides bajad* (*imaŋalẽ babaura*) | 41 | 41 | 51[a,b] | ~25[f] | | ~1:1[f] | Jun-Sep[f] | |
| *Carangoides plagiotaenia* (*imaŋalẽ tombo gabo*) | 30 | 26 | 38[a,b] | | | | | |

|  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|
| *Caranx melampygus* (*imaŋalẽ talã*) | 35 | 26 | 72[a,g] | 36[g] |  | 1♂:1.48♀[g] |  | No[g] |
| *Caranx papuensis* (*imaŋalẽ labrã kulĩ*) | 13 | 62 | 66[b,h] |  |  |  |  |  |
| CARCHARHINIDAE |  |  |  |  |  |  |  |  |
| *Carcharhinus amblyrhynchos* | 8 | 78 | 217[a,b] | 118[b,i] | 114[b,i] |  | May-Oct (biennial)[i] |  |
| *Triaenodon obesus* | 7 | 71 | 177[a,b] | 97[b,i] | 94[b,i] |  | May-Oct (biennial)[i] |  |
| EPHIPPIDAE |  |  |  |  |  |  |  |  |
| *Platax pinnatus* (*ibuŋgi tarõ*) | 11 | 25 | 30[a] |  |  |  |  |  |
| *Platax teira* (*ibuŋgi*) | 4 | 36 | 60[a] |  |  |  |  |  |
| HAEMULIDAE |  |  |  |  |  |  |  |  |
| *Diagramma pictum* (*godobo manibarã* & *godobo tarõ*) | 8 | 25 | 90[a] | 36[j] | 27[j] | ~1:1[j] | Apr-May & Nov[j] | No[j] |
| *Plectorhinchus lineatus* (*iyabua sa*) | 22 | 36 | 50[a] |  |  |  |  |  |
| *Plectorhinchus vittatus* | 3 | 30 | 50[a] | 23[b,k] | 29[b.k] | 1♂:1.75♀[k] | Dec-May[k] |  |
| HOLOCENTRIDAE |  |  |  |  |  |  |  |  |
| *Myripristis adusta* (*imbilĩ tombo gabo*) | 16 | 18 | 28[a,l] | 17[m] | 17[m] |  |  | No[c] |
| *Myripristis berndti* | 4 | 12 | 26[a,n] |  |  |  |  | No[c] |

| **Taxon (Kala name, if recorded)** | **N** | **Mean length (cm)** | **$L_{max}$ (cm)** | **Female $L_{50}$ (cm)** | **Male $L_{50}$ (cm)** | **Sex ratio** | **Spawning season** | **Sex change?** |
|---|---|---|---|---|---|---|---|---|
| *Myripristis kuntee* (*imbilĩ godõ nambĩ*) | 65 | 12 | 16$^{a,o}$ | | | | | No$^{c}$ |
| *Myripristis pralinia* | 3 | 12 | 17$^{a,n}$ | | | | | No$^{c}$ |
| *Myripristis violacea* (*imbilĩ yakẽ bumbu*) | 69 | 13 | 17$^{a,n}$ | | | | | No$^{c}$ |
| *Myripristis vittata* (*imbilĩ yakẽ suwi*) | 20 | 11 | 17$^{a,l}$ | | | | | No$^{c}$ |
| *Neoniphon sammara* (*imbilĩ sa*) | 16 | 14 | ~27$^{a,l}$ | ~8$^{k,p}$ (SL) | | 1♂:2.56♀$^{k}$ | Nov-May$^{k}$ | No$^{c}$ |
| *Sargocentron caudimaculatum* (*imbilĩ yasai*) | 7 | 15 | 19$^{a,b}$ | | | | | No$^{c}$ |
| KYPHOSIDAE | | | | | | | | |
| *Kyphosus cinerascens* (*italawe*) | 67 | 30 | 41$^{b,h}$ | 25$^{m}$ | 18$^{m}$ | | | |
| *Kyphosus vaigiensis* (*italawe talabopia*) | 5 | 21 | 56$^{b,h}$ | | | | | |
| LABRIDAE | | | | | | | | |
| *Choerodon anchorago* | 4 | 22 | 38$^{a}$ | | | | | |
| *Cheilinus fasciatus* | 12 | 17 | ~36$^{a,p}$ (TL) | ~12$^{b,p,q}$ | ~20$^{b,p,q}$ | | | ♀→♂$^{q}$ |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Oxycheilinus celebicus* | 6 | 14 | 20[a] | | | | | |
| *Oxycheilinus digramma* | 4 | 18 | 30[a] | | | | | |
| LETHRINIDAE | | | | | | | | |
| *Lethrinus erythropterus* (*kada maba*) | 5 | 22 | 48[a,b] | | | | | |
| *Monotaxis grandoculis* (*labaikã taloŋ* & *labaikã*) | 64 | 25 | ~56[a,l] | | | | | |
| LUTJANIDAE | | | | | | | | |
| *Lutjanus argentimaculatus* (*illĩ*) | 4 | 48 | 118[a,b] | 53[r] | 47[r] | 1♂:1.18♀[r] | Oct-Nov[s], Dec[r] | No[t] |
| *Lutjanus biguttatus* (*itale*) | 427 | 14 | 19[a,u] | 17[u] | 13[u] | 1:1[u] | | No[u] |
| *Lutjanus bohar* | 4 | 17 | 71[a,b] | 43[v] | <30[v] | | Aug-Apr[v] | No[v] |
| *Lutjanus boutton* (*iyayaŋ*) | 160 | 14 | 28[a,b] | | | | | No[t] |
| *Lutjanus carponotatus* (*babaura*) | 30 | 20 | 38[a,b] | 19[w] | | Increasingly male-biased with length[x] | Oct-Dec[w] | No[y] |
| *Lutjanus fulvus* (*iyayaŋ kurĩ naba*) | 39 | 18 | 39[a,b] | 19[z] | 14[z] | 1:1[z] | Year round[t,aa] | No[z] |
| *Lutjanus gibbus* (*ina suwi*) | 22 | 20 | 42[a,b] | 18[b,k]-23[bb] | 14[b,k] | Increasingly male-biased with length[cc] | Jan-Apr[k] | No[t] |

| Taxon (Kala name, if recorded) | N | Mean length (cm) | $L_{max}$ (cm) | Female $L_{50}$ (cm) | Male $L_{50}$ (cm) | Sex ratio | Spawning season | Sex change? |
|---|---|---|---|---|---|---|---|---|
| *Lutjanus kasmira*<br>(*babaura yumi yayã*) | 4 | 16 | 33[a,dd] | 12[k,dd] | 14[k,dd] | 1♂:1.33♀[k] | Year round[t] | No[t] |
| *Lutjanus monostigma*<br>(*baniŋga*) | 4 | 21 | 48[a,b] | ~32[ee] | | | Feb & Nov[t] | No[t] |
| *Lutjanus rivulatus*<br>(*isina*) | 4 | 31 | 63[a,b] | | | | | No[t] |
| *Lutjanus russellii*<br>(*kawasi ŋasiŋa*) | 75 | 22 | 43[a,b] | 22[ff] | | | Aug-Feb[gg] | No[t] |
| *Lutjanus semicinctus*<br>(*imawe*) | 49 | 20 | 34[a,b] | 21[hh] | 18[hh] | Varies unpredictably with length (~1:1)[hh] | | No[hh] |
| *Lutjanus vitta*<br>(*isale*) | 19 | 14 | 37[a,b] | 15[ii] | | Increasingly male-biased > 29 cm[jj] | Sep-Apr[jj,kk] | No[t] |
| *Macolor macularis*<br>(*labaikã tewe yayã*) | 17 | 31 | 55[a,b] | | | | | |
| *Macolor niger*<br>(*labaikã yasai*) | 5 | 28 | ~60[a,p] (TL) | | | | | |
| MULLIDAE | | | | | | | | |
| *Mulloidichthys vanicolensis*<br>(*itale yumi yayã*) | 7 | 21 | 34[a,b] | 17[ll] | | | Oct-Nov[mm] | |
| *Parupeneus barberinus*<br>(*iwaŋgale*) | 135 | 15 | 44[a,l] | ~12[hh] | ~14[hh] | Increasingly male-biased with length[hh] | Oct-May[k] | No[hh] |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Parupeneus cyclostomus* (*iwaŋgale bokole*) | 20 | 18 | 44[a,nn] | | | | | |
| *Parupeneus multifasciatus* (*iwaŋgale bote*) | 99 | 14 | 26[a,oo] | 15[oo] | 15[oo] | Increasingly male-biased with length[oo] | | No[oo] |
| *Parupeneus trifasciatus* (*walia*) | 35 | 19 | 30[a,pp] | 11[k,pp] | 16[k,pp] | 1♂:1.67♀[k] | Sep-Apr[k] | |
| NEMIPTERIDAE | | | | | | | | |
| *Scolopsis bilineata* | 8 | 13 | ~23[a,p] (TL) | | | | | ♀→♂[qq] |
| PRIACANTHIDAE | | | | | | | | |
| *Priacanthus hamrur* | 3 | 23 | ~40[a,p] (TL) | 20[rr] | 18[rr] | 1♂:1.77♀[rr] | Apr-Jul[rr] | |
| SCARIDAE | | | | | | | | |
| *Chlorurus bleekeri* | 5 | 18 | 30[a] | | | | | |
| *Chlorurus bowersi* | 3 | 22 | 31[ss] | | | | | |
| *Scarus flavipectoralis* (*iŋga talaŋ* & *iŋga tali lau*) | 27 | 19 | 29[a,b] | | | | | |
| SCOMBRIDAE | | | | | | | | |
| *Gymnosarda unicolor* (*itaŋgi talaloŋa*) | 18 | 59 | 137[a,b] | ~70[tt] | | | Dec-Feb[uu] | No[uu] |
| *Rastrelliger kanagurta* | 4 | 23 | 33[a,b] | 19[vv] | 18[vv] | | Oct-Jul[vv] | No[uu] |

| Taxon (Kala name, if recorded) | N | Mean length (cm) | $L_{max}$ (cm) | Female $L_{50}$ (cm) | Male $L_{50}$ (cm) | Sex ratio | Spawning season | Sex change? |
|---|---|---|---|---|---|---|---|---|
| *Scomberomorus commerson*<br>(*itaŋgi*) | 5 | 95 | 218[a,ww] | ~65[xx] | | Female biased >90 cm[xx] | Jul-Dec[uu] | No[uu] |
| SERRANIDAE | | | | | | | | |
| *Anyperodon leucogrammicus*<br>(*ikula damasã*) | 15 | 25 | 52[a] | | | | | ♀→♂[yy] |
| *Cephalopholis boenak*<br>(*ikula bobo*) | 10 | 16 | 24[a] | 15[zz] | 16[zz] | 1♂:5.30♀[aaa] | Apr-Oct[zz] | ♀→♂[zz] |
| *Cephalopholis cyanostigma*<br>(*ikula sa*) | 76 | 19 | 35[a] | 23[hh] | 20[hh] | Increasingly male-biased with length[hh] | | ♀→♂[hh] |
| *Cephalopholis microprion*<br>(*ikula yuyeŋ*) | 22 | 13 | 23[a] | | | | | ♀→♂[yy] |
| *Cephalopholis sexmaculata*<br>(*ikula tumi*) | 4 | 24 | 47[a] | ~24[bbb] | | | Mar-May[bbb] | ♀→♂[yy] |
| *Cephalopholis urodeta*<br>(*ikula karu guŋ-guŋ*) | 6 | 18 | 27[a] | | | 1♂:28.50♀[aaa] | | ♀→♂[yy] |
| *Plectropomus areolatus*<br>(*ikula su mani balã*) | 15 | 18 | 70[a] | 40[b,ccc] | 48[b,ccc] | Increasingly male-biased with length[ddd] | Jan-May[ccc] | ♀→♂[yy] |
| *Plectropomus leopardus*<br>(*yula*) | 10 | 32 | 68[a,b] | 32[eee] | 37[zz] | Increasingly male-biased > 44 cm[eee] | Sep-Dec[fff] | ♀→♂[fff] |
| *Plectropomus oligacanthus*<br>(*ikula su tatalõ*) | 54 | 33 | 65[a] | | | | Sep-Dec[ggg] | ♀→♂[yy] |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| SIGANIDAE | | | | | | | | |
| *Siganus javus*<br>(*yulawe kokoranawa*) | 33 | 25 | ~53[h,p]<br>(TL) | | | | | |
| *Siganus lineatus*<br>(*yulawe*) | 66 | 26 | 41[a,b] | 24[hh] | ~19[hh] | ~1:1[hh] | Year round[hhh] | No[hh] |
| *Siganus puellus*<br>(*indaŋa*) | 3 | 22 | ~38[a,p]<br>(TL) | | | | | |
| *Siganus vulpinus* | 4 | 16 | 30[a] | | | | | |

(a) Allen & Swainston 1993; (b) FL estimated using length-length relationship from Froese & Pauly 2012; (c) Thresher 1984; (d) Choat & Robertson 2002 (authors do not describe how estimate was obtained); (e) Carpenter 1998; (f) Grandcourt *et al*. 2003; (g) Sudekum *et al*. 1991; (h) Randall *et al*. 1990; (i) Robbins 2006; (j) Grandcourt *et al*. 2011; (k) Anand & Pillai 2002 (authors report minimum size at maturity based on a combination of gross and histological examination of individuals in variable size classes, above lengths are the mean of minimum and maximum class limits); (l) Longenecker *et al*. 2010; (m) Present study; (n) FL estimated from a general *Myripristis* length relationship (C.J. Bradley, unpublished data) based on Hawaiian specimens of at least three species: *M. berndti*, *M. chryseres*, *M. kuntee*: FL = -0.4139 + 0.8919(TL); $r^2$ = 0.993; n = 50; (o) FL estimated from Hawaiian specimens (Longenecker 2008 and C.J. Bradley, unpublished data) FL = 0.4314 + 0.8288(TL), $r^2$ = 0.993, n = 13; (p) no relationship available to estimate fork length; (q) Hubble 2003; (r) Russell & McDougall 2008; (s) Pakoa 1998; (t) Allen 1985; (u) Longenecker *et al*. in press; (v) Marriott et al 2007; (w) Kritzer 2004; (x) authors' interpretation of data in Heupel *et al*. 2010: %♀ = 146.986 – 3.735(FL); (y) Evans *et al*. 2008; (z) Longenecker *et al*. in review; (aa) Caillart *et al*. 1994; (bb) Heupel *et al*. 2009 (all females > 23 cm FL were mature); (cc) results from Heupel *et al*. 2009 suggest the proportion of females is inversely related to size; (dd) Friedlander *et al*. 2002; (ee) Munro & Williams 1985 (length at first maturity); (ff) Kritzer in Williams *et al*. 2002; (gg) authors' interpretation of GSI and developmental stages in Sheaves 1995; (hh) Longenecker *et al*. 2011; (ii) Davis & West 1993; (jj) authors' interpretation of data in Davis & West 1992: sex ratio is 1:1 to 29 cm, then %♀ = 1.986 – 0.00534(FL); (kk) Loubens 1980; (ll) Cole 2008; (mm) Jehangeer 2003; (nn) FL estimated from Hawaiian specimens (Longenecker 2008): FL = 0.3132 + 0.8657(TL), $r^2$ = 0.998, n = 14; (oo) Longenecker & Langston 2008, %♀ = 141.3 – 0.6167(FL in mm) with all individuals male above 225 mm; (pp) FL estimated from relationships for Hawaiian specimens: FL = 0.827 + 0.840(TL), $r^2$ = 0.99, n = 3; FL = 1.029 + 1.044(SL), $r^2$ = 0.97, n = 3; (qq) Russell 1990; (rr) Sivakami *et al*. 2001; (ss) Bellwood; (tt) Sivadas & Anasukoya 2005 report that all individuals < 70 cm were immature; (uu) Collette & Nauen 1983; (vv) Abdussamad *et al*. 2010; (ww) Mackie *et al.* 2003; (xx) Lewis *et al*. 1974 (length at first maturity, sex ratio was ~1:1 in specimens <90 cm, but larger size classes were female biased, 4♂:38♀); (yy) Heemstra & Randall 1993; (zz) Chan & Sadovy 2002; (aaa) Were 2009; (bbb) Shakeel & Ahmed 1996 report the smallest mature female was 24 cm; (ccc) Rhodes & Tupper 2007; (ddd) authors' interpretation of data in Williams *et al*. 2008: %♀ = 285.0 – 4.346(FL); (eee) authors' interpretation of data in Ferreira 1995: sex ratio is ~1♂:4♀ to 44 cm, then %♀ = 333 – 5.6(FL), maximum female size is 56 cm; (fff) Ferreira 1995; (ggg) Pet & Muljadi 2001; (hhh) Hamilton *et al*. 2004 report year-round spawning aggregations during the first quarter of the moon phase.

## Species Accounts

### Acanthuridae

***Ctenochaetus tominiensis*** **Randall, 1955**; Kala name not yet recorded. Figure 5.

**Figure 5.** ***Ctenochaetus tominiensis*****. Laser dots are separated by 31.5 mm.**

A total six (6) specimens were captured on video from 2009 to 2012. Average fork length was 15 cm. Due to low sample size, a size distribution is not presented. However, mean fork length is 79% of the maximum reported length of 19 cm, 125% of estimated optimum length of 12 cm, and 115% of the estimated female $L_m$ of 13 cm.

***Naso hexacanthus*** **(Bleeker, 1855)** or ***biaŋgawe suwi***. Figure 6.

**Figure 6.** ***Biaŋgawe suwi*** **(*****Naso hexacanthus*****). Laser dots are separated by 36 mm.**

An additional nine (9) specimens were added to our data set in 2012, yielding a combined total 88 individuals captured on video suitable for length estimation. The additional data shifted the mean fork length estimate to 43 cm from our 2011 estimate of 44 cm. The updated mean length is 61% of the estimated maximum length of 71 cm, 91% of estimated optimum length of 47 cm, and 86% of the estimated female $L_{50}$ of 50 cm (Figure 7). Results suggest approximately 12% of the individuals had attained female reproductive size; however we were not able to evaluate the reliability of the size-at-maturity estimate.

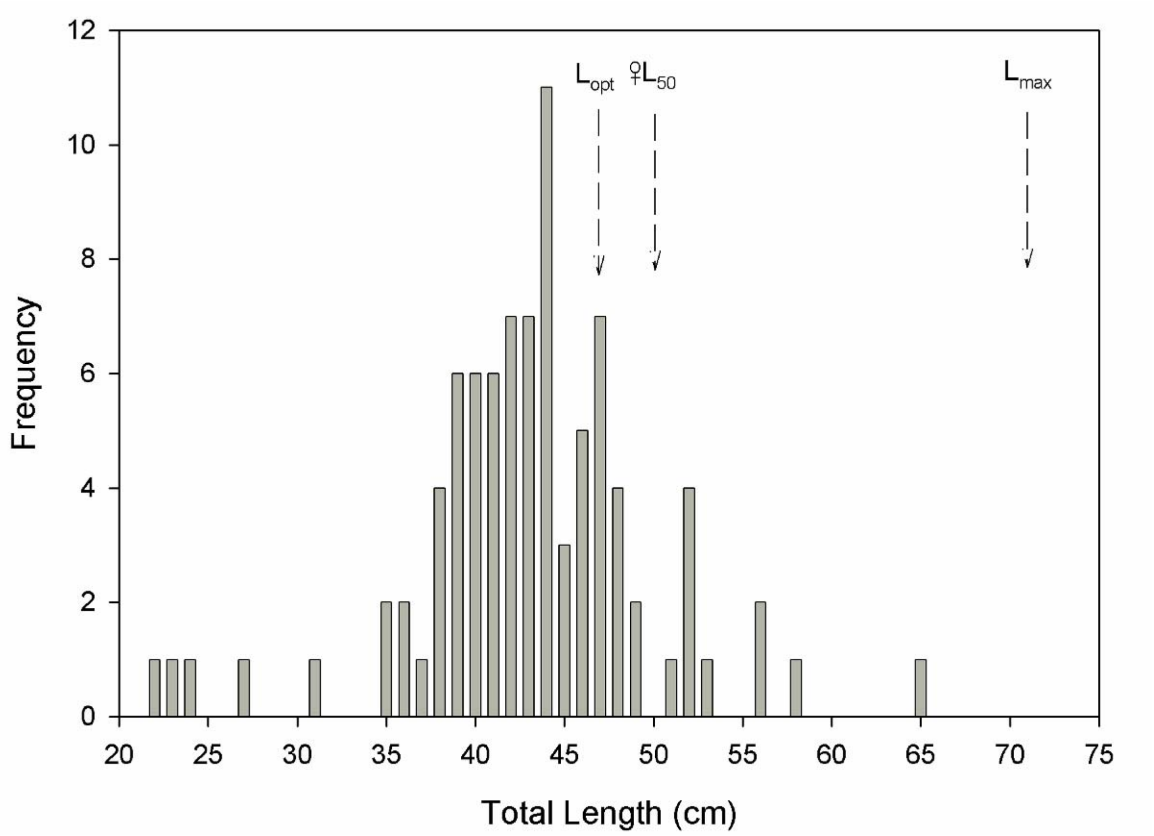


**Figure 7. Size structure of *Naso hexacanthus*.**

***Naso lopezi*** **Herre, 1927** or ***biaŋgawe talõ***. Figure 8.

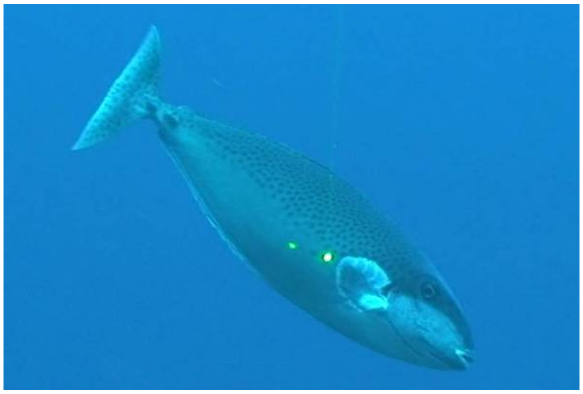


**Figure 8. *Biaŋgawe talõ* (*Naso lopezi*). Laser dots are separated by 36 mm.**

No new specimens were added to our data set in 2012, leaving a total three (3) individuals captured on video suitable for length estimation. Due to low sample size, a size distribution is not presented. However, mean fork length was 59 cm, which is 123% of the estimated maximum length of 48 cm, and 190% of estimates of optimum length and female $L_m$, both 31 cm. The largest specimen captured on video was 85 cm, or 177% of estimated maximum length.

***Naso vlamingii*** **(Valenciennes, 1835)** or ***biaŋgawe tumi***. Figure 9.

No new specimens were added to our data set in 2012, leaving a total 10 individuals captured on video suitable for length estimation. Due to low sample size, a size distribution is not presented. The mean fork length of 36 cm is 71% of the estimated maximum length of 51 cm, and 109% of estimates of optimum length and female $L_m$, both 33 cm.

**Figure 9. *Biaŋgawe tumi* (*Naso vlamingii*).**

## Balistidae

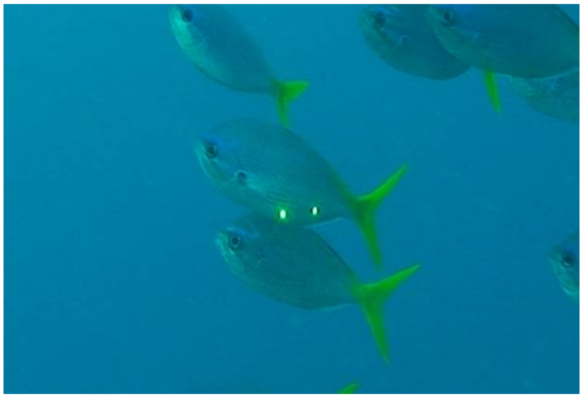
***Canthidermis maculata*** **(Bloch, 1786)** or ***labaikã suwi***. Figure 10.

No new specimens were added to our data set in 2012, leaving a total 13 individuals captured on video suitable for length estimation. Due to low sample size, a size distribution is not presented. However, the mean total length was 33 cm, which is 94% of the maximum reported length of 35 cm, and 143% of estimates of optimum length and female $L_m$, both 23 cm.

**Figure 10. *Labaikã suwi* (*Canthidermis maculata*). Laser dots are separated by 36 mm.**

## Caesionidae

***Caesio cuning*** (Bloch, 1791) or ***luduŋ ŋai*** (***mai***). Figure 11.



An additional 269 specimens were added to our data set in 2011, yielding a combined total 1065 individuals captured on video suitable for length estimation. The additional data did not change the mean fork length estimate of 16 cm, which is 38% of the estimated maximum length of 42 cm, and 59% of estimates optimum length and female $L_m$, both 27 cm (Figure 12).

**Figure 11. *Luduŋ ŋai* (*mai*) or *Caesio cuning*. Laser dots are separated by 31.5 mm.**

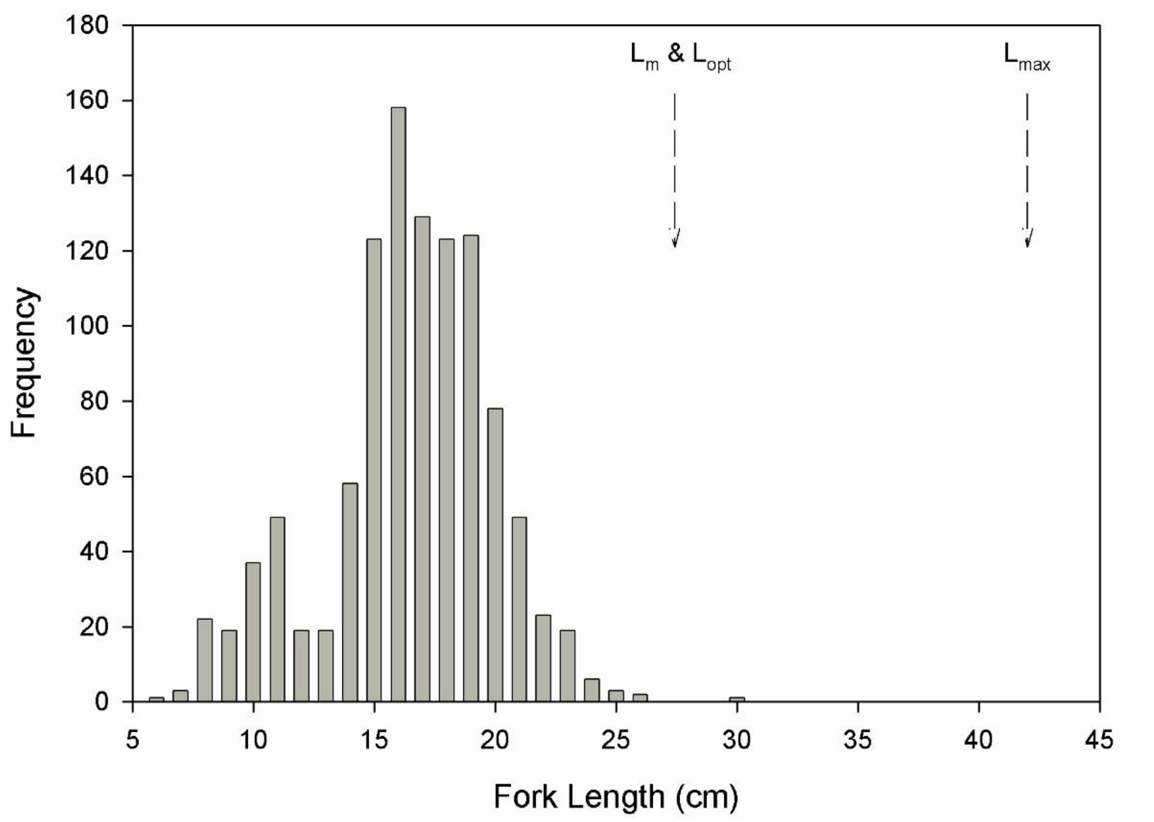


**Figure 12. Size structure of *Caesio cuning*.**

Carangidae

***Carangoides bajad* (Forsskål, 1775)** or ***imaŋalẽ babaura***. Figure 13.

**Figure 13. *Imaŋalẽ babaura* (*Carangoides bajad*). Laser dots are separated by 39 mm.**

Seven (7) new specimens were added to our data set in 2012, yielding a total 41 individuals captured on video suitable for length estimation. The additional data did not shift our mean fork length of 26 cm, which is 51% of the estimated maximum length of 51 cm, and 79% of the estimated optimum length of 33 cm and 104% of the published female $L_m$ of 25 cm (Figure 14). Size-at-maturity and sex-ratio information suggest 34% of the population captured on video is composed of mature females.

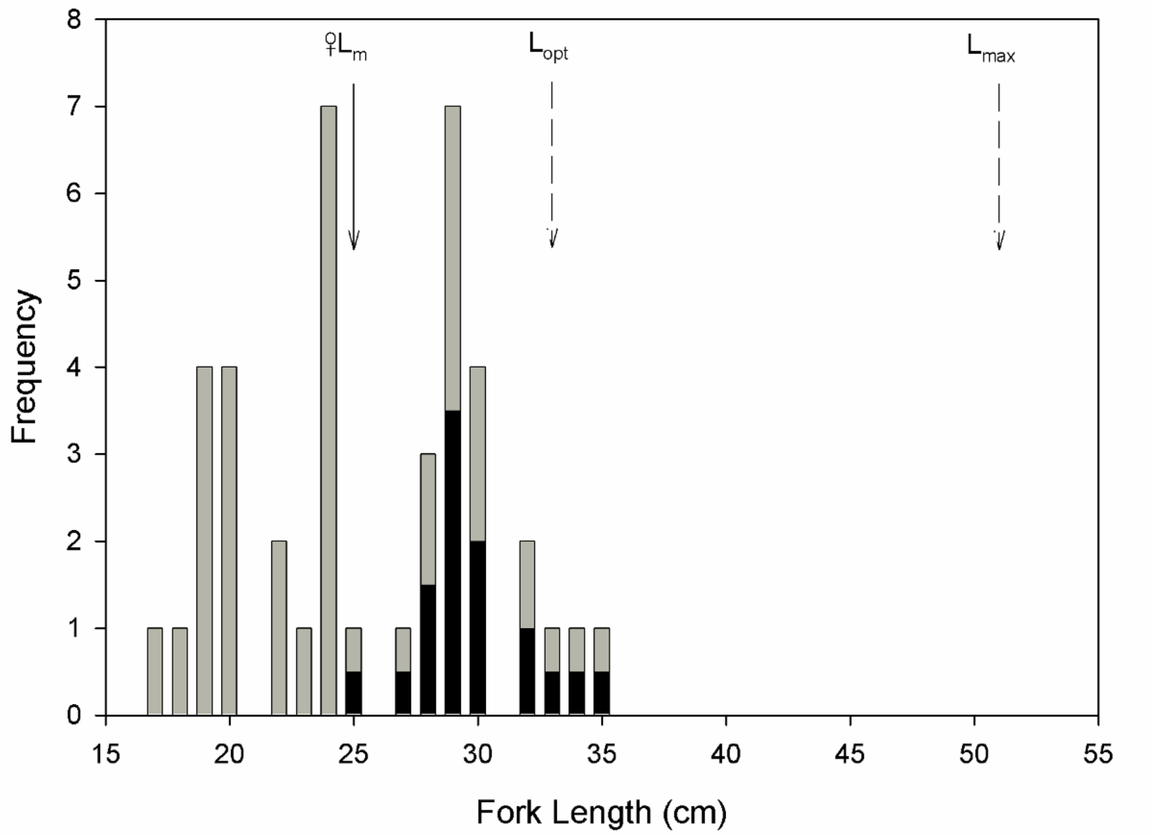


**Figure 14. Size structure of *Carangoides bajad*. The dark portion of bars represent estimated number of mature females, light portion represents all other individuals.**

***Carangoides plagiotaenia*** **Bleeker, 1857** or ***imaŋalẽ tombo gabo***. Figure 15.

**Figure 15. *Imaŋalẽ tombo gabo* (*Carangoides plagiotaenia*). Laser dots are separated by 36 mm.**

An additional four (4) specimens were added to our data set in 2012, yielding a combined total 30 individuals captured on video suitable for length estimation. The mean additional data did not shift our 2011 mean length estimate of 26 cm. Mean length is 68% of the estimated maximum length of 38 cm, and 104% of estimated optimum and female $L_m$, both 25 cm (Figure 16).

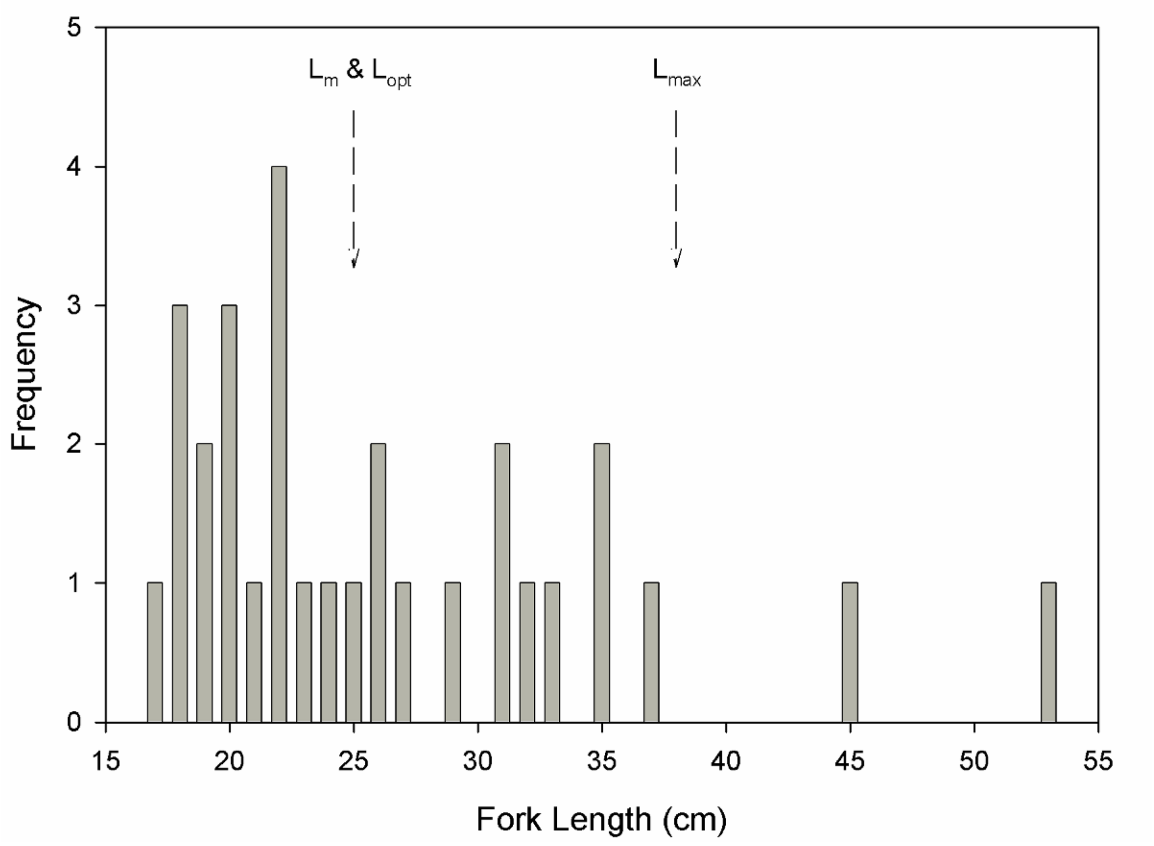


**Figure 16. Size structure of *Carangoides plagiotaenia*.**

***Caranx melampygus*** **Cuvier, 1833** or ***imaŋalẽ talã***. Figure 17.

**Figure 17. *Imaŋalẽ talã* (*Caranx melampygus*).**

An additional three (3) specimens were added to our data set in 2012, yielding a combined total 35 individuals captured on video suitable for length estimation. The additional data did not change our 2011 mean fork length of 26 cm, which is 36% of the reported maximum length of 72 cm, 55% of estimated optimum length of 47 cm and 84% of the published female $L_m$ of 36 cm (Figure 18). Size-at-maturity and sex-ratio information suggest 9% of the population captured on video is composed of mature females.

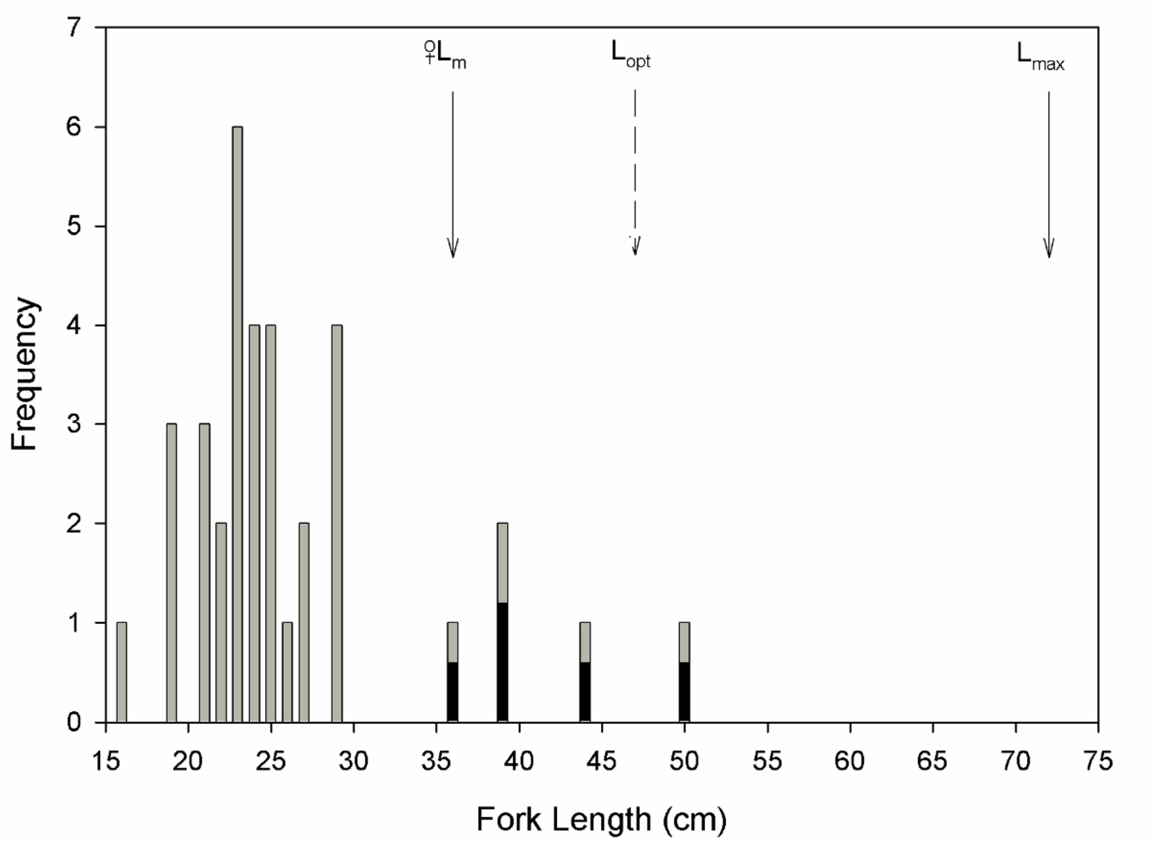


**Figure 18. Size structure of *Caranx melampygus*. The dark portion of bars represent estimated number of mature females, light portion represents all other individuals.**

## ***Caranx papuensis*** **Alleyne & MacLeay, 1877** or ***imaŋalẽ labrã kulĩ***. Figure 19.

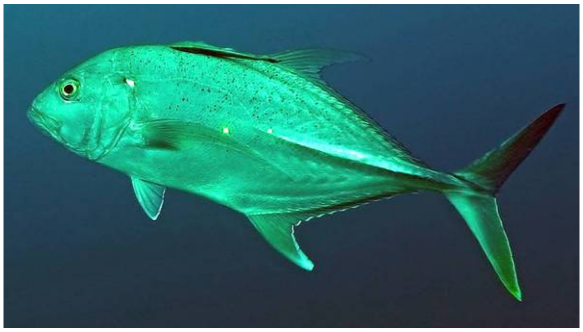


**Figure 19. *Imaŋalẽ labrã kulĩ* or *Caranx papuensis* (with a remora attached near the origin of the first dorsal fin). Laser dots are separated by 39 mm.**

No new specimens were added to our data set in 2012, leaving a combined total 13 individuals captured on video suitable for length estimation. Due to low sample size, a size distribution is not presented. The mean fork length estimate remains 59 cm which is 89% of the estimated maximum length of 66 cm, 137% of the estimated optimum length of 43 cm, and 140 % of the estimated female $L_m$ of 42 cm.

### Carcharhinidae

***Carcharhinus amblyrhynchos* (Bleeker, 1856)**; Kala name not yet recorded. Figure 20.

**Figure 20. *Carcharhinus amblyrhynchos*.**

A total eight (8) specimens were captured on video from 2009 to 2012 (none in 2012). Due to low sample size, a size distribution is not presented. Mean fork length is 78 cm, which is 36% of the estimated maximum length of 217 cm, 53% of the estimated optimum length of 147 cm, and 66% of the published female $L_{50}$ of 118 cm.

***Triaenodon obesus* (Rüppell, 1837)**; Kala name not yet recorded. Figure 21.

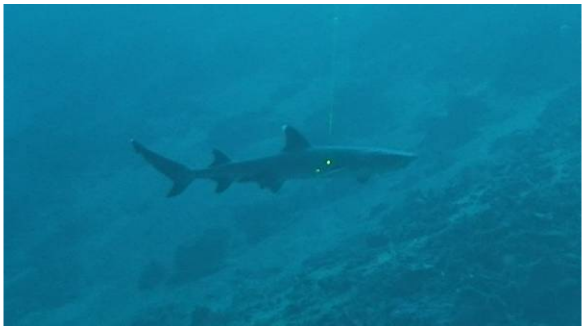


**Figure 21. *Triaenodon obesus*. Laser dots are separated by 35.5 mm.**

A total seven (7) specimens were captured on video from 2009 to 2012. Due to low sample size, a size distribution is not presented. Mean fork length is 71 cm, which is 40% of the maximum reported length of 177 cm, 60% of the estimated optimum length of 119 cm, and 73% of the published female $L_{50}$ of 97 cm.

### Ephippidae

***Platax pinnatus* (Linneaus, 1758)** or ***ibuŋgi tarõ***. Figure 22.

**Figure 22. *Ibuŋgi tarõ* (*Platax pinnatus*). Laser dots are separated by 36 mm.**

A total two (2) specimens were added to our data set in 2012, yielding a total 11 individuals captured on video suitable for length estimation. Due to low sample size, a size distribution is not presented. However, the additional data shifted mean total length to 25 cm from our 2011 estimate of 26 cm. The updated mean length is 83% of the maximum reported length of 30 cm, 132% of the estimated optimum length of 19 cm, and 125% of the estimated female $L_m$ of 20 cm.

***Platax teira* (Forsskål, 1775)** or ***ibuŋgi***. Figure 23.

**Figure 23. *Ibuŋgi* (*Platax teira*). Laser dots are separated by 39 mm.**

A total four (4) individuals were captured on video suitable for length estimation from 2009-2012. Due to low sample size, a size distribution is not presented. However, mean total length was 36 cm, which is 60% of the maximum reported length of 60 cm, 92% of the estimated optimum length of 39 cm, and 95% of the estimated female $L_m$ of 38 cm.

Haemulidae

***Diagramma pictum* (Thunberg, 1792)** or ***godobo manibarã*** (juvenile) and ***godobo tarõ*** (adult). Figure 24.

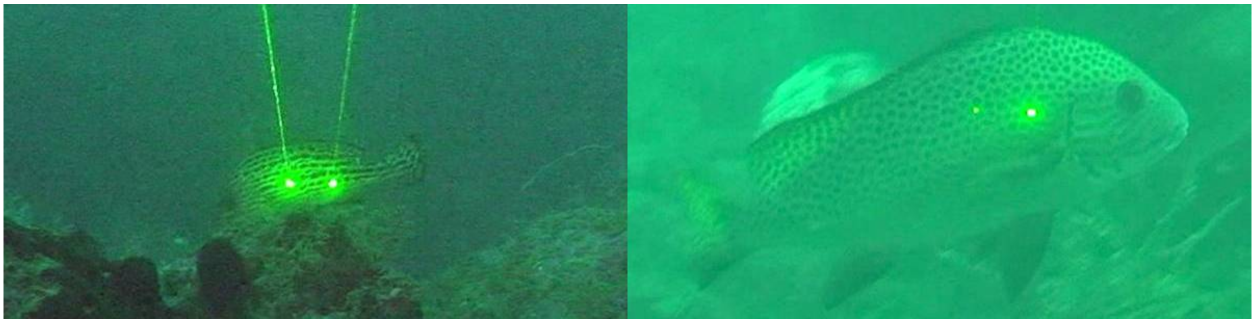


**Figure 24. *Godobo manibarã* (left) and *godobo tarõ* (right) or *Diagramma pictum* juvenile (left) and adult (right). Laser dots are separated by 31 and 36 mm, respectively.**

No new specimens were recorded on 2012, leaving a total eight (8) individuals captured on video suitable for length estimation. Due to low sample size, a size distribution is not presented. However, the mean total length was 25 cm, which is 28% of the maximum reported length of 90 cm, 57% of the published optimum length of 44 cm, and 69% of the published female $L_{50}$ of 36 cm. None of the individuals captured on video had reached female $L_{50}$.

***Plectorhinchus lineatus (Linnaeus, 1758)*** or ***iyabua sa***. Figure 25.

**Figure 25. *Iyabua sa* (*Plectorhinchus lineatus*). Laser dots are separated by 39 mm.**

An additional three (3) specimens were added to out data set in 2012, yielding a combined total 22 individuals captured on video suitable for length estimation. The additional data did not change our 2011 mean total length estimate of 36 cm. Mean size is 72% of the maximum reported length of 50 cm, 109% of the estimated optimum length of 33 cm and 113% of the estimated female $L_m$ of 32 cm (Figure 26).

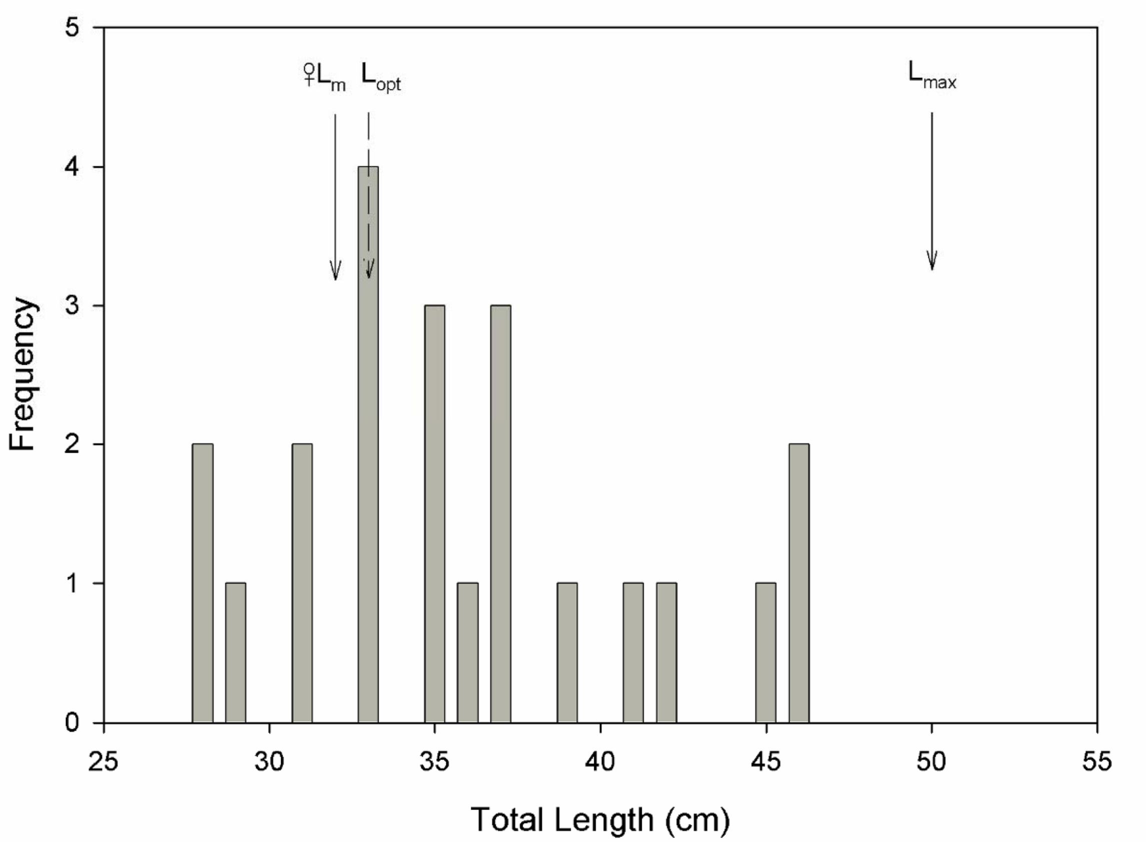


**Figure 26. Size structure of *Plectorhinchus lineatus*.**

***Plectorhinchus vittatus*** **(Linnaeus, 1758)**; Kala name not yet recorded. Figure 27.

**Figure 27. *Plectorhinchus vittatus*. Laser dots are separated by 31.5 mm.**

A total three (3) specimens were captured on video from 2009 to 2012. Due to low sample size, a size distribution is not presented. However, the mean length of 30 cm is 60% of the maximum reported length of 50 cm, 91% of the estimated optimum length of 33 cm and 143% of the published female $L_m$ of 23 cm. Based on published size-at-maturity and sex-ratio information, approximately 64% of the population captured on video is composed of mature females.

Holocentridae

***Myripristis adusta*** **Bleeker, 1853** or ***imbilĩ tombo gabo***. Figure 28.

S. Talbot

**Figure 28. *Imbilĩ tombo gabo* (*Myripristis adusta*).**

An additional one (1) specimen was added to our data set in 2012, yielding a combined total 16 individuals captured on video suitable for length estimation. The additional data did not change the mean fork length estimate of 18 cm, which is 64% of the maximum reported length of 28 cm, 100% of the estimated optimum length of 18 cm, and 106% of the observed female $L_m$ of 17 cm (Figure 29).

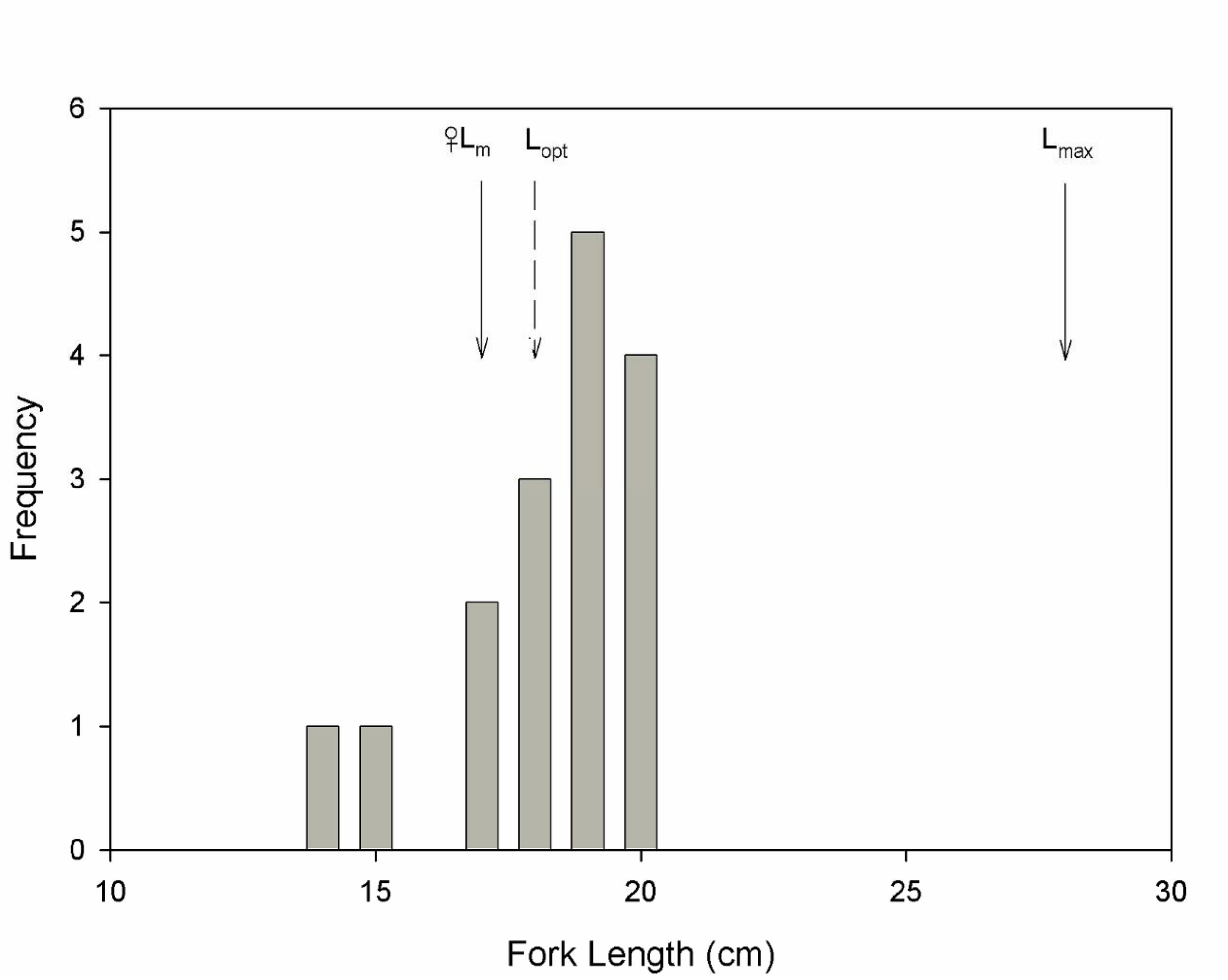


**Figure 29. Size structure of *Myripristis adusta*.**

***Myripristis berndti* (Jordan & Evermann, 1903)**; Kala name not yet recorded. Figure 30.

**Figure 30. *Myripristis berndti*.**

A total four (4) specimens were captured on video from 2009 to 2012. Due to low sample size, a size distribution is not presented. However, mean fork length is 12 cm, which is 46% of the maximum reported length of 26 cm, 71% of the estimated optimum length of 17 cm, and 67% of the estimated female $L_m$ of 18 cm.

***Myripristis kuntee* Valenciennes, 1831** or ***imbilĩ godõ nambĩ***. Figure 31.

**Figure 31. *Imbilĩ godõ nambĩ* (*Myripristis kuntee*). Laser dots are separated by 39 mm.**

An additional seven (7) specimens were added to our data set in 2012, yielding a combined total 65 individuals captured on video suitable for length estimation. The additional data did not change the mean fork length estimate of 12 cm. Mean size is 75% of the maximum reported length of 16 cm (two individuals were larger than 16 cm), 109% of the estimated optimum length of 11 cm, and 100% of the estimated female $L_m$ of 12 cm (Figure 32).

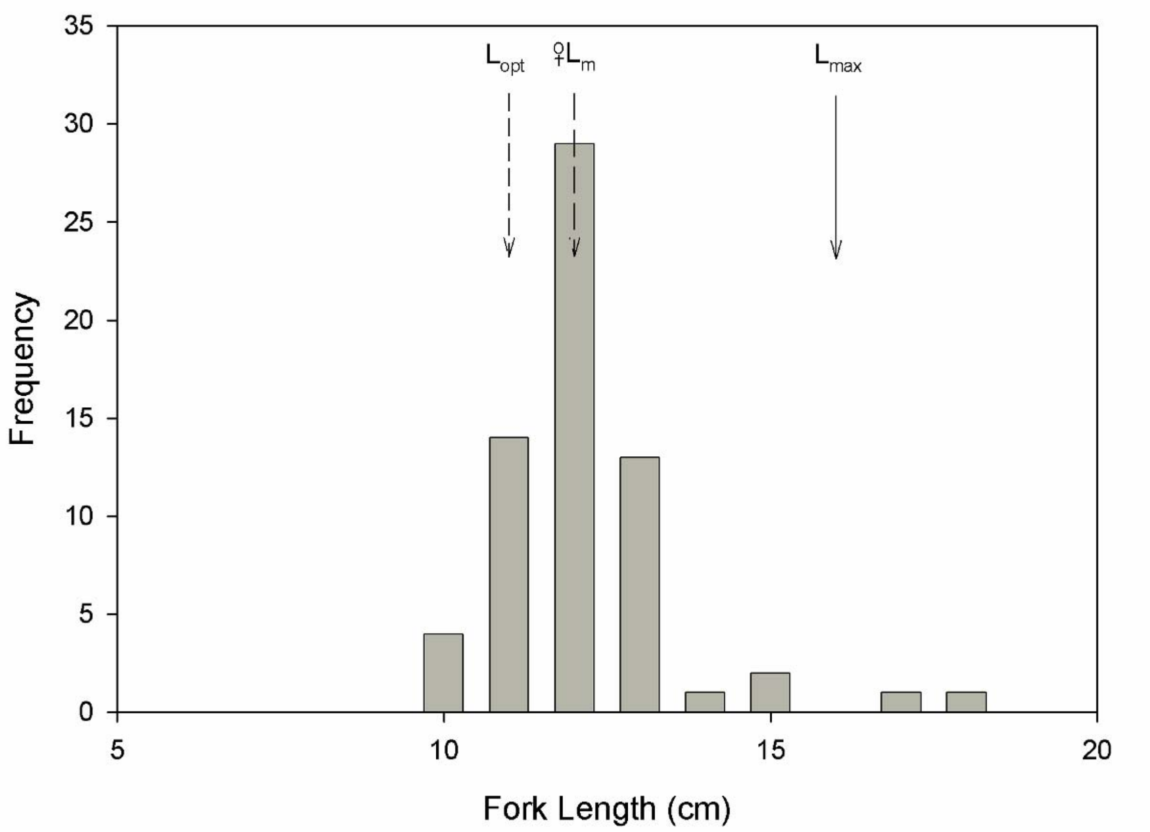


**Figure 32. Size structure of *Myripristis kuntee*.**

***Myripristis pralinia* Cuvier, 1829**; Kala name not yet recorded. Figure 33.

**Figure 33. *Myripristis pralinia*.**

A total three (3) specimens were captured on video from 2009 to 2012. Due to low sample size, a size distribution is not presented. However, the mean fork length of 12 cm is 86% of the maximum reported length of 17 cm, 109% of the estimated optimum length of 11 cm, and 100% of the estimated female $L_m$ of 12 cm.

***Myripristis violacea* Bleeker, 1851** or ***imbilĩ yakẽ bumbu***. Figure 34.

**Figure 34. *Imbilĩ yakẽ bumbu* (*Myripristis violacea*).**

An additional 17 specimens were added to our data set in 2012, yielding a combined total 69 individuals captured on video suitable for length estimation. The additional data did not change the mean fork length estimate of 13 cm. Mean size is 76% of the estimated maximum length of 17 cm, 118% of the estimated optimum length of 11 cm, and 108% of the estimated female $L_m$ of 12 cm (Figure 35).

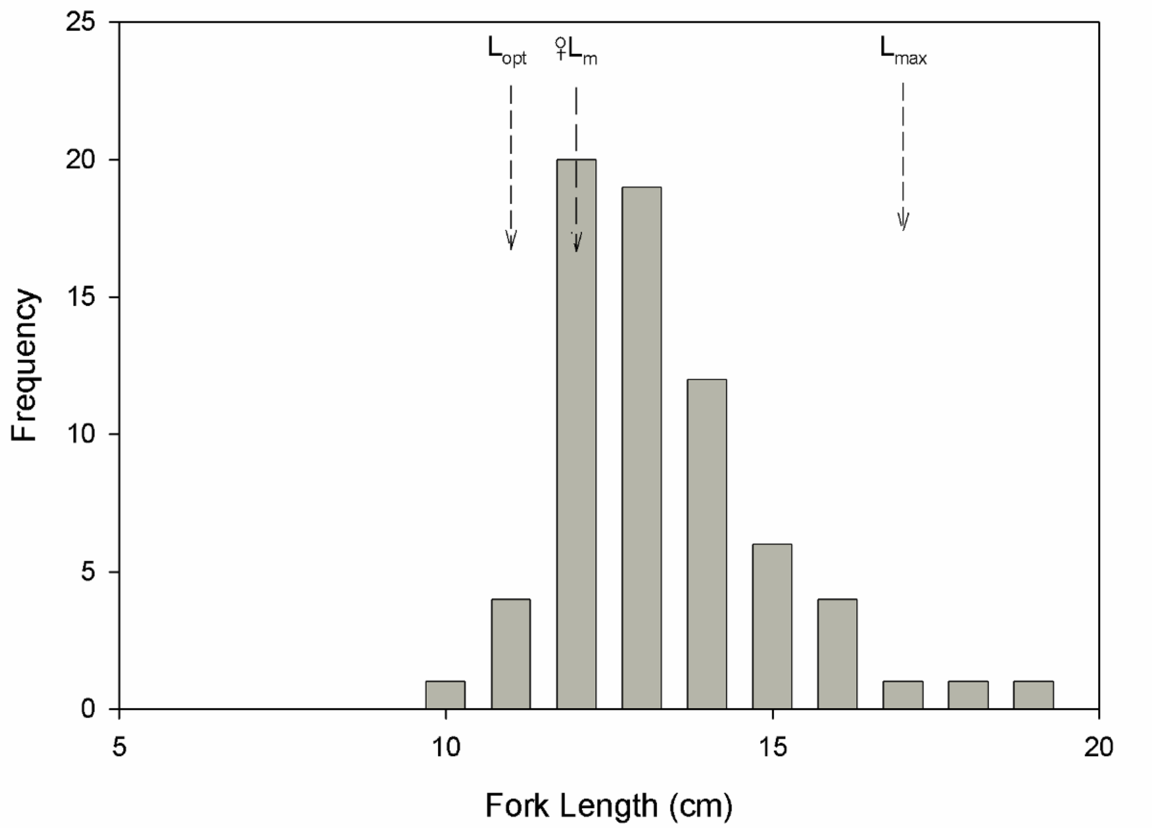


**Figure 35. Size structure of *Myripristis violacea.***

***Myripristis vittata* Valenciennes, 1831** or ***imbilĩ yakẽ suwi***. Figure 36.

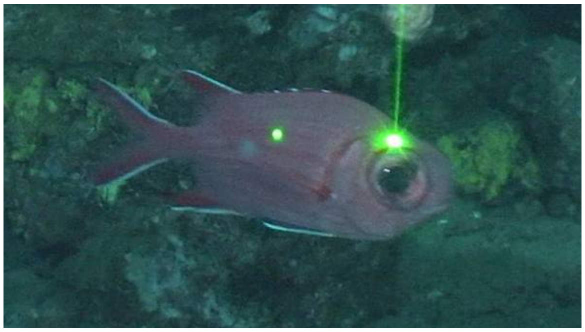


**Figure 36. *Imbilĩ yakẽ suwi* (*Myripristis vittata*). Laser dots are separated by 36 mm.**

No new specimens were added to our data set in 2012, leaving a combined total 20 individuals captured on video suitable for length estimation. The mean fork length estimate of 11 cm is 65% of the maximum reported length of 17 cm, 100% of the estimated optimum length of 11 cm and 92% of the estimated female $L_m$ of 12 cm (Figure 37).

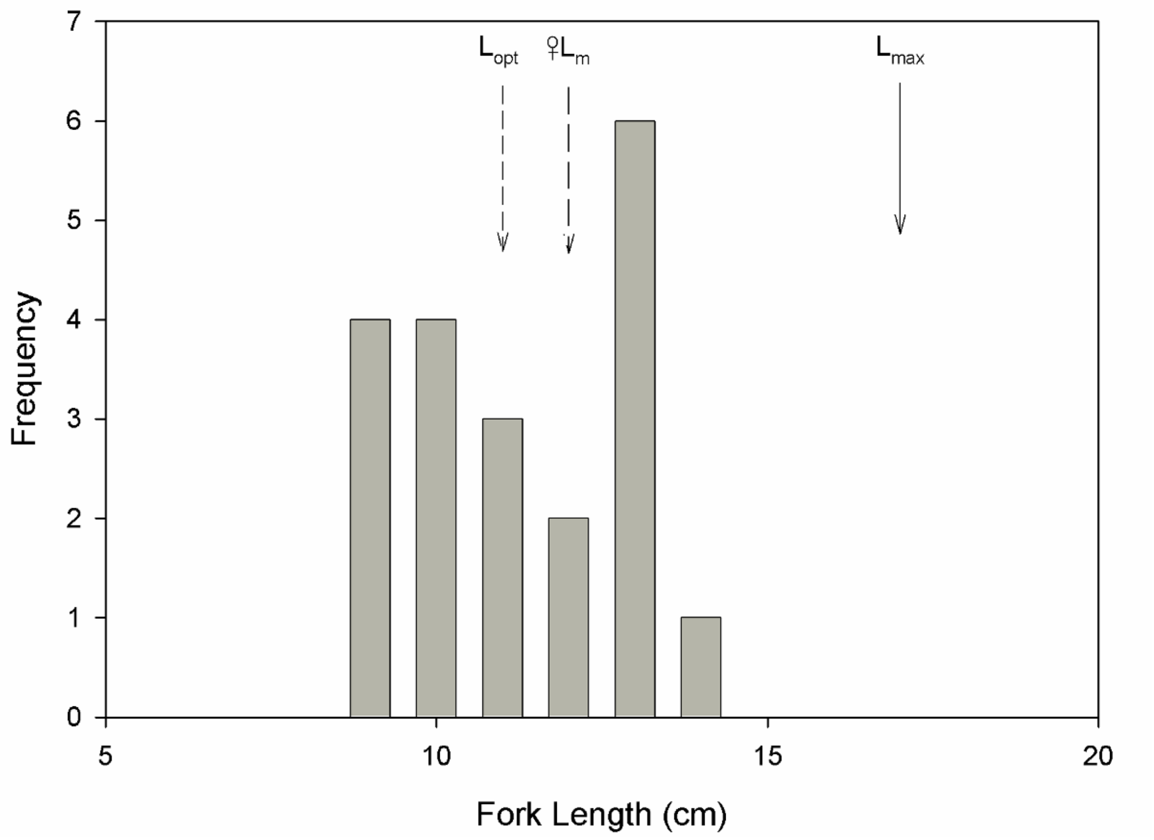


**Figure 37. Size structure of *Myripristis vittata*.**

***Neoniphon sammara* (Forsskål, 1775)** or ***imbilĩ sa***. Figure 38.

**Figure 38. *Imbilĩ sa* (*Neoniphon sammara*). Laser dots are separated by 39 mm.**

An additional two (2) specimens were added to our data set in 2012, yielding a total 16 individuals captured on video suitable for length estimation. However, the additional data did not change our 2011 the mean fork length estimate of 14 cm. Mean size is 52% of the estimated maximum length of 27 cm, 82% of the estimated optimum length of 17 cm, and 175% of the published female $L_m$ eight (8) cm. One-hundred percent of individuals had attained female $L_m$ (Figure 39). Size-at-maturity and sex-ratio information suggests 72% of the population captured on video is composed of mature females.

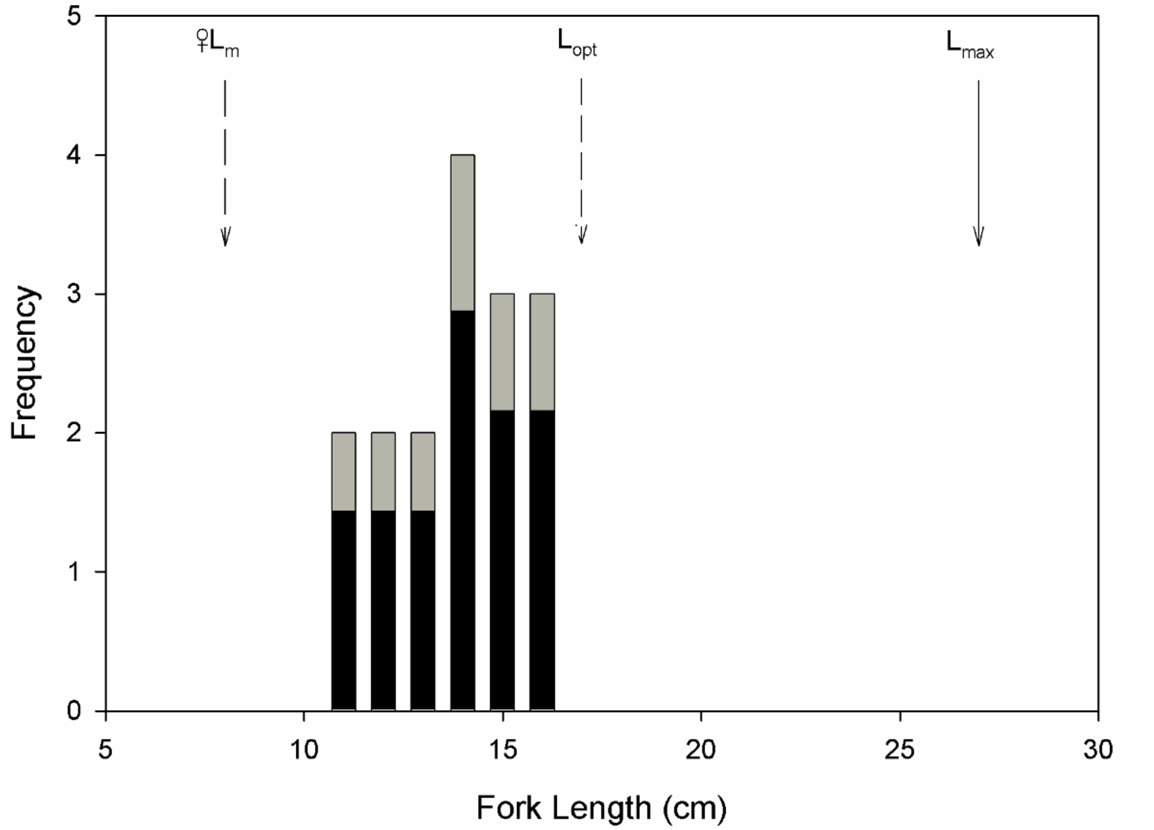


**Figure 39. Size structure of *Neoniphon sammara*. The dark portion of bars represent estimated number of mature females, light portion represents all other individuals.**

***Sargocentron caudimaculatum* (Rüppell, 1838)** or ***imbilĩ yasai***. Figure 40.

**Figure 40. *Imbilĩ yasai* (*Sargocentron caudimaculatum*). Laser dots are separated by 31 mm.**

An additional two (2) specimens were added to our data set in 2012, yielding a total seven (7) individuals captured on video suitable for length estimation. Due to low sample size, a size distribution is not presented. However, the additional data did not change our 2011 mean fork length estimate of 15 cm. Mean length is 79% of the maximum reported length of 19 cm, 125% of the estimated optimum length of 12 cm, and 115% of the estimated female $L_m$ of 13 cm.

## Kyphosidae

***Kyphosus cinerascens*** **(Forsskål, 1775)** or ***italawe***. Figure 41.

**Figure 41. *Italawe* (*Kyphosus cinerascens*). Laser dots are separated by 39 mm.**

One (1) new specimen was added to our data set in 2012, yielding a combined total 67 individuals captured on video suitable for length estimation. The additional data did not change the mean fork length estimate of 30 cm, which is 73% of the estimated maximum length of 41 cm, 111% of estimated optimum length of 27 cm, and 120% of observed female $L_m$ of 25 cm (Figure 42).

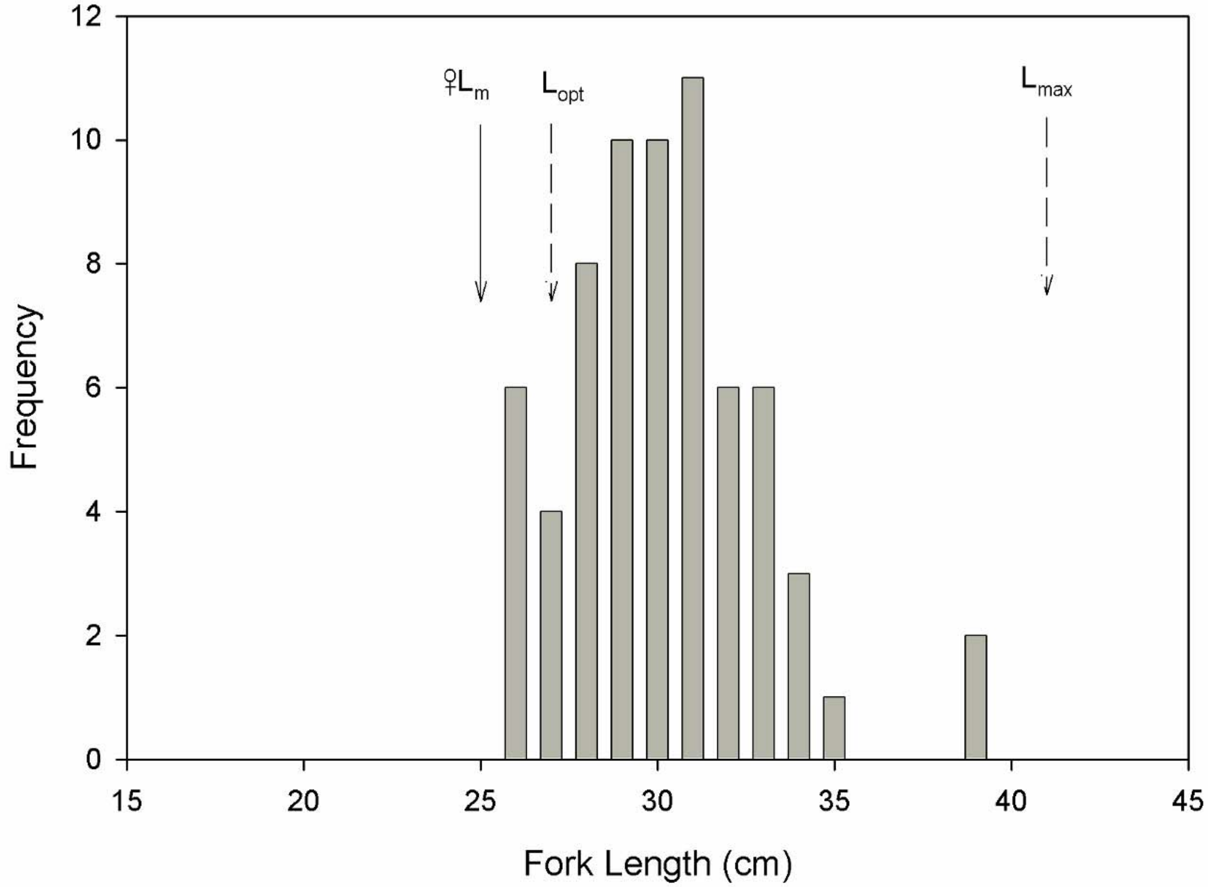


**Figure 42. Size structure of *Kyphosus cinerascens*.**

***Kyphosus vaigiensis* (Quoy & Gaimard, 1825)** or ***italawe talabopia***. Figure 43.

**Figure 43. *Italawe talabopia* (*Kyphosus vaigiensis*). Laser dots are separated by 39 mm.**

No new specimens were added to our data set in 2012, leaving a total five (5) individuals captured on video suitable for length estimation. Due to low sample size, a size distribution is not presented. However, mean fork length was 38 cm (not 21, as reported in 2011), which is 68% of the estimated maximum length of 56 cm, 103% of the estimated optimum length of 37 cm and 106% of the estimated female $L_m$ of 36 cm.

Labridae

***Choerodon anchorago* (Bloch, 1791)**; Kala name not yet recorded. Figure 44.

**Figure 44. *Choerodon anchorago*. Laser dots are separated by 36 mm.**

A total four (4) specimens were captured on video from 2009 to 2012. Due to low sample size, a size distribution is not presented. However, mean total length was 22 cm, which is 58% of the published maximum length of 38 cm, and 88% of estimates of optimum length and female $L_m$, both 25 cm.

***Cheilinus fasciatus* (Bloch, 1791)**; Kala name not yet recorded. Figure 45.

**Figure 45. *Cheilinus fasciatus*. Laser dots are separated by 39 mm.**

A total 12 specimens were captured on video from 2009 to 2012. Due to low sample size, a size distribution is not presented. However, mean fork length was 17 cm, which is 47% of the estimated maximum total length of 36 cm, and 74% of the estimated optimum total length of 23 cm, and 142% of the published female $L_{50}$ of 12 cm (TL). The above estimates are presented as total length because no relationship between total and fork lengths is available. Therefore the above percentages are likely underestimates.

***Oxycheilinus celebicus* (Bleeker, 1853)**; Kala name not yet recorded. Figure 46.

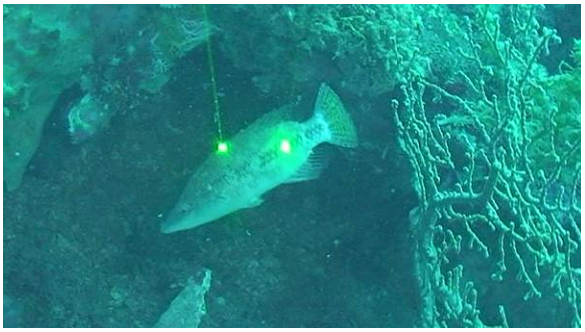


**Figure 46. *Oxycheilinus celebicus*. Laser dots are separated by 31 mm.**

A total six (6) specimens were captured on video from 2009 to 2012. Due to low sample size, a size distribution is not presented. However, mean total length was 14 cm, which is 70% of the published maximum length of 20 cm, 100% of the estimated optimum length of 14 cm, and 108% of the estimated female $L_m$ of 13 cm.

***Oxycheilinus digramma* (Lacepède, 1801)**; Kala name not yet recorded. Figure 47.

**Figure 47. *Oxycheilinus digramma*. Laser dots are separated by 36.5 mm.**

A total four (4) specimens were captured on video from 2009 to 2012. Due to low sample size, a size distribution is not presented. However, mean total length was 18 cm, which is 60% of the estimated maximum length of 30 cm, 95% of the estimated optimum length of 19 cm, and 90% of the estimated female $L_m$ of 20 cm.

Lethrinidae

***Lethrinus erythropterus* Valenciennes, 1830** or ***kada maba***. Figure 48.

**Figure 48. *Kada maba* (*Lethrinus erythropterus*). Laser dots are separated by 31 mm.**

No new specimens were added to our data set in 2012, leaving a total five (5) individuals captured on video suitable for length estimation. Due to low sample size, a size distribution is not presented. However, mean fork length was 22 cm, which is 46% of the estimated maximum length of 48 cm, and 71% of estimates of optimum length and female $L_m$, both 31 cm.

***Monotaxis grandoculis* (Forsskål, 1775)** or ***labaikã taloŋ*** (juvenile) and ***labaikã*** (adult). Figure 49.

**Figure 49. *Labaikã taloŋ* (left) and *labaikã* (right) or *Monotaxis grandoculis* juvenile (left) and adult (right).**

An additional three (3) specimens were added to our data set in 2011, yielding a combined total 64 individuals captured on video suitable for length estimation. The additional data did not change our 2010 mean fork length estimate of 25 cm. Mean length is 45% of the estimated maximum length of 56 cm, 68% of the estimated optimum length of 37 cm and 69% of the estimated female $L_m$ of 36 cm (Figure 50).

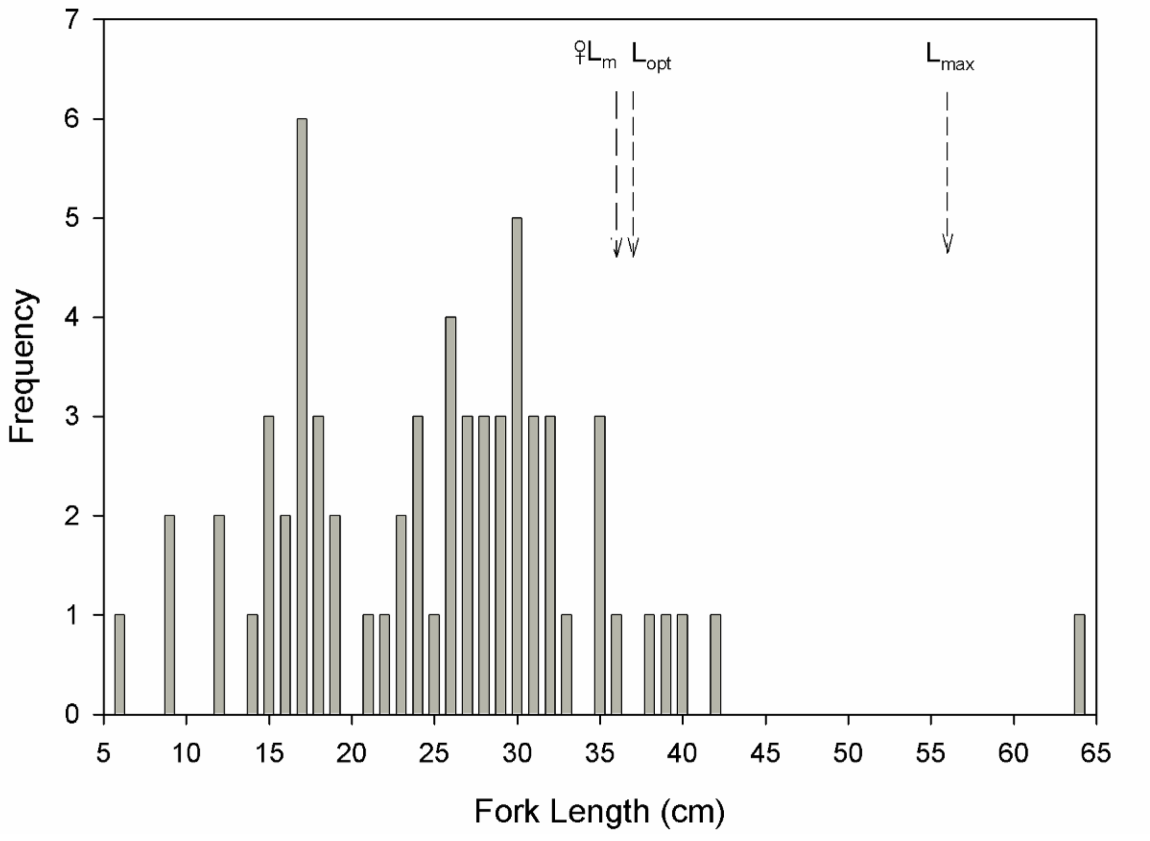


**Figure 50. Size structure of *Monotaxis grandoculis*.**

## Lutjanidae

### *Lutjanus argentimaculatus* **(Forsskål, 1775)** or ***illī***. Figure 51.

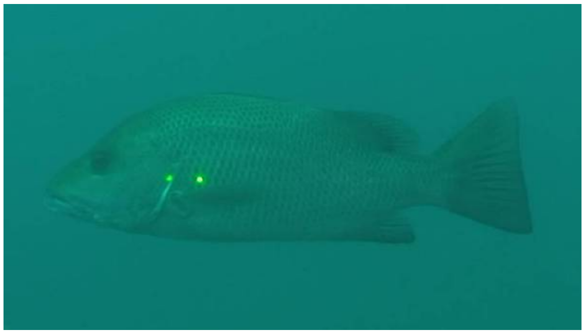


**Figure 51. *Illī* (*Lutjanus argentimaculatus*). Laser dots are separated by 36 mm.**

No new specimens were added to our data set in 2012, leaving a total four (4) individuals captured on video suitable for length estimation. Due to low sample size, a size distribution is not presented. Mean fork length is 48 cm, which is 41% of the estimated maximum reported length of 118 cm, 61% of the estimated optimum length of 79 cm and 91% of the published female $L_{50}$ of 53 cm. Size-at-maturity and-sex ratio information suggest that 27% of the population captured on video is composed of mature females.

### *Lutjanus biguttatus* **(Valenciennes, 1830)** or ***itale***. Figure 52.

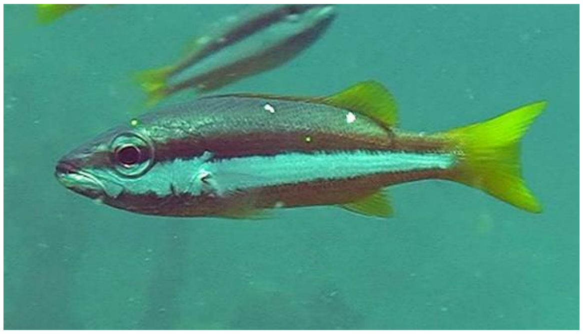


**Figure 52. *Itale* (*Lutjanus biguttatus*). Laser dots are separated by 39 mm.**

An additional 80 specimens were added to our data set in 2012, yielding a combined total 427 individuals captured on video suitable for length estimation. The additional data did not change our 2011 average fork length estimate of 14 cm. Mean size is 71% of the published maximum length of 19 cm, 117% of estimated optimum length of 12 cm and 88% of the published female $L_{50}$ of 17 cm (Figure 53). Given that sex ratios are not significantly different from 1:1, about 15% of the population is mature females.

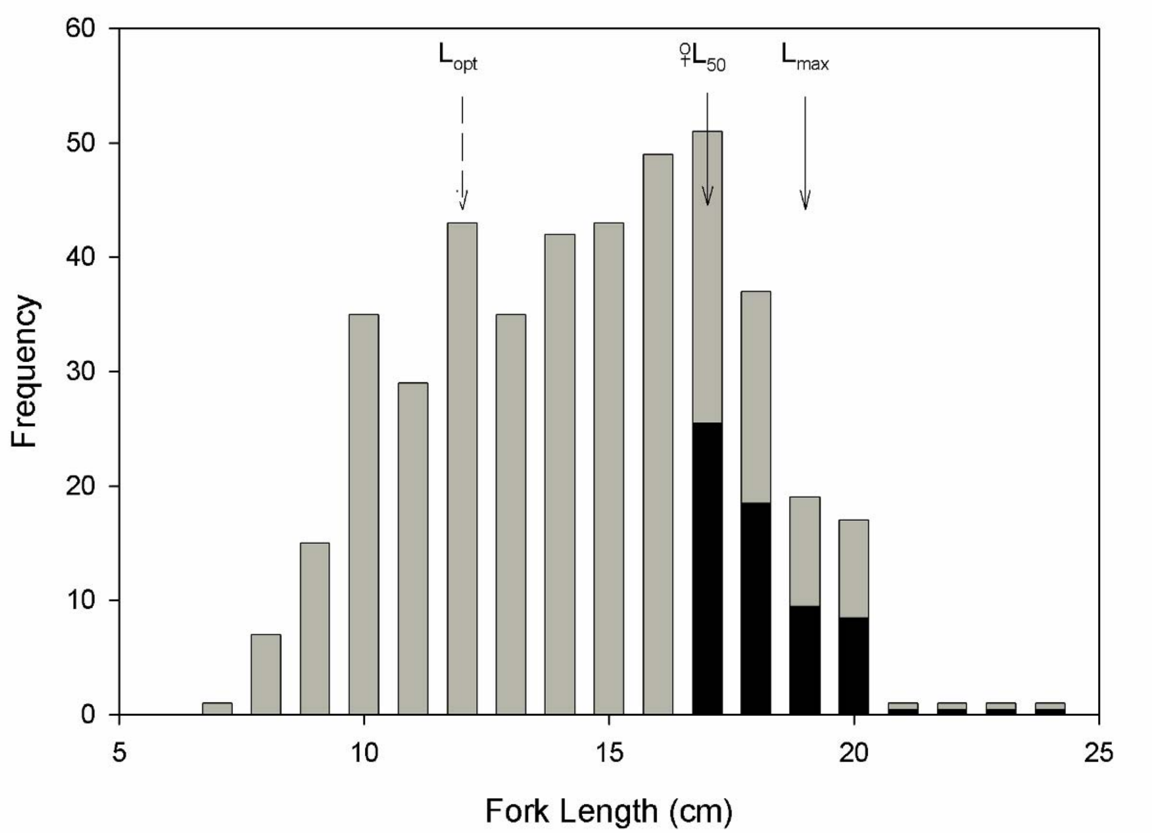


**Figure 53. Size structure of *Lutjanus biguttatus*. The dark portion of bars represent estimated number of mature females, light portion represents all other individuals.**

***Lutjanus bohar*** **(Forsskål, 1775)**; Kala name not yet recorded. Figure 54.

**Figure 54. *Lutjanus bohar*. Laser dots are separated by 31 mm.**

A total four (4) specimens were captured on video suitable for length estimation from 2009-2012. Due to low sample size, a size distribution is not presented. However, mean fork length is 17 cm, which is 24% of the estimated maximum reported length of 71 cm, 36% of the estimated optimum length of 47 cm and 40% of the published female $L_{50}$ of 43 cm. The small percentages presented above may be an artifact of our methods; each juvenile captured on video was counted because color patterns allow for accurate identification. However, adults are difficult to distinguish from *Lutjanus argentmaculatus* and may have been classified as unidentified individuals.

### ***Lutjanus boutton*** **(Lacepède, 1802)** or ***iyayaŋ***. Figure 55.

**Figure 55.** ***Iyayaŋ*** **(*Lutjanus boutton*). Laser dots are separated by 39 mm.**

An additional one (1) specimen was added to our data set in 2012, yielding a combined total 160 individuals captured on video suitable for length estimation. The additional datum did not change the 2011 mean fork length estimate of 14 cm, which is 50% of the estimated maximum length of 28 cm, 78% of the estimated optimum length of 18 cm and 74% of estimated female $L_m$ of 19 (Figure 56).

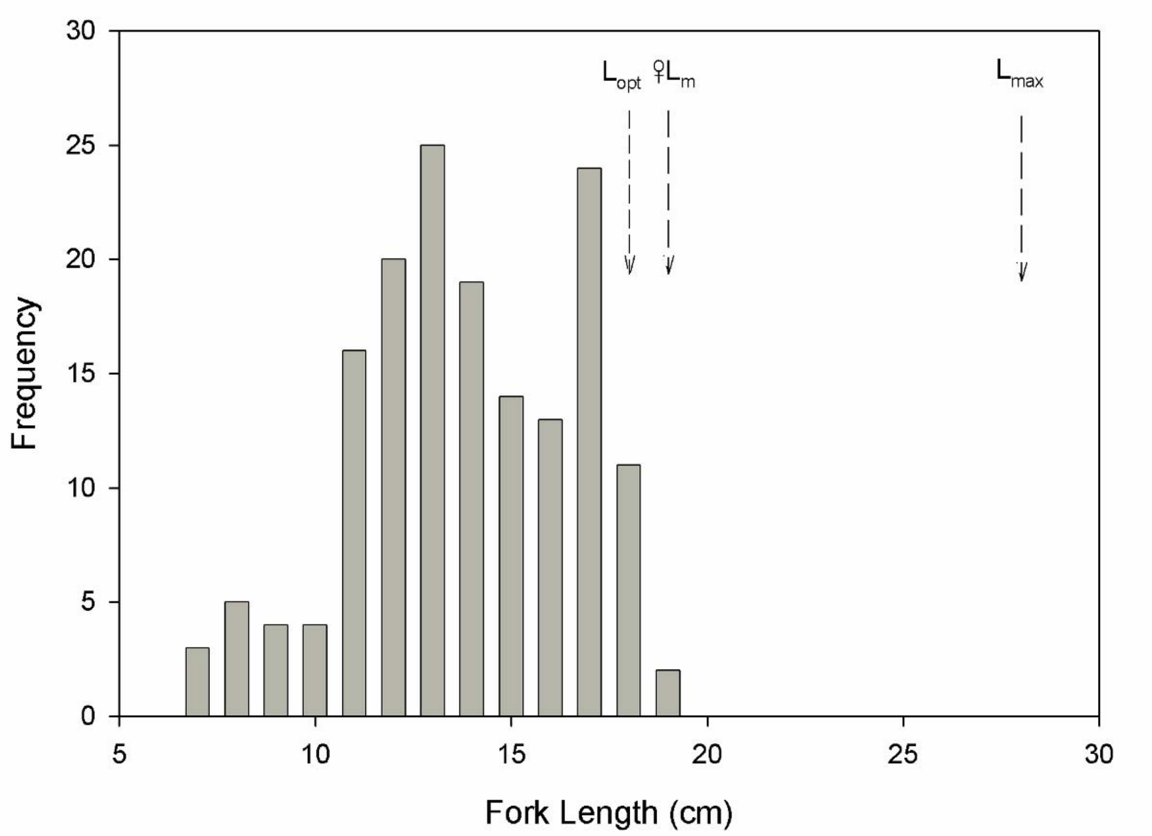


**Figure 56. Size structure of *Lutjanus boutton*.**

***Lutjanus carponotatus* (Richardson, 1842)** or ***babaura***. Figure 57.

**Figure 57. *Babaura* (*Lutjanus carponotatus*).**

An additional two (2) specimens were added to our data set in 2012, yielding a combined total 30 individuals captured on video suitable for length estimation. The additional data did not change our 2011 mean fork length estimate of 20 cm. Mean length is 52% of the maximum reported length of 38 cm, 80% of estimated optimum length of 25 cm and 108% of the published female $L_{50}$ of 19 cm (Figure 58). Size-at-maturity and size-specific sex-ratio information suggest that 24% of the population captured on video is composed of mature females.

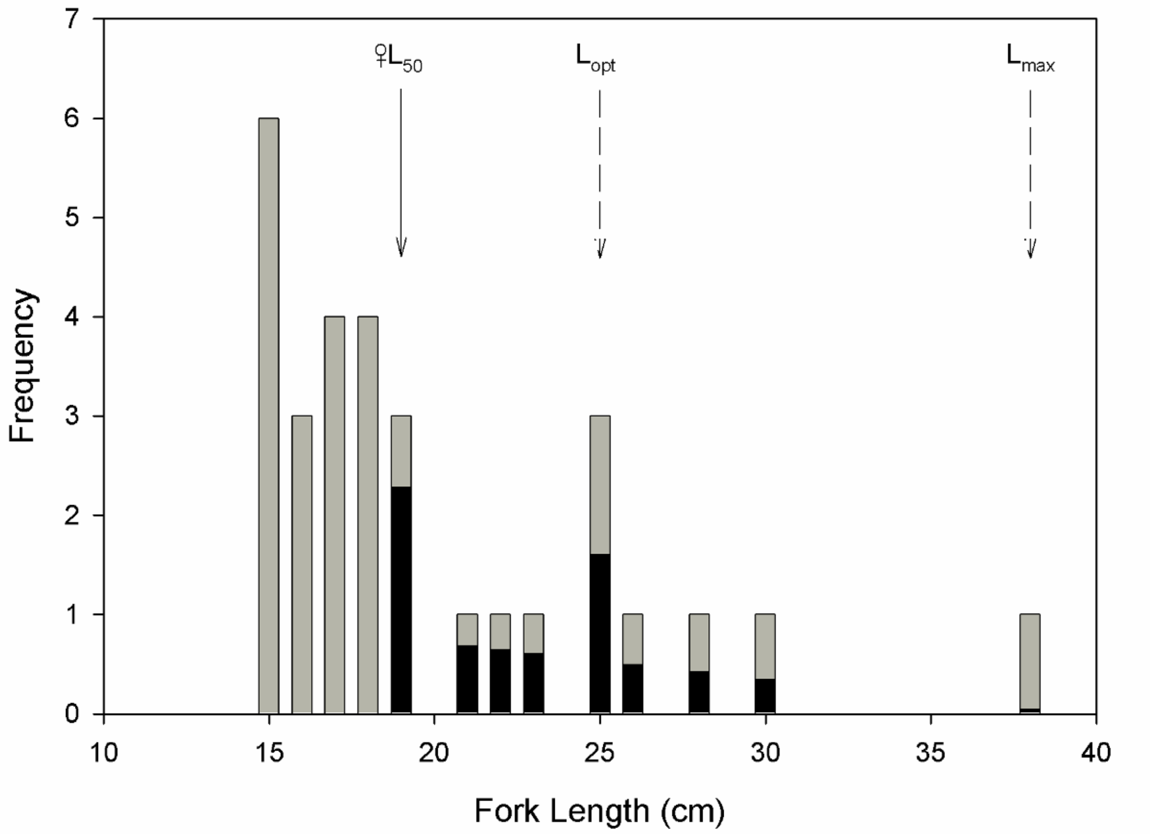


**Figure 58. Size structure of *Lutjanus carponotatus*. The dark portion of bars represent estimated number of mature females, light portion represents all other individuals.**

***Lutjanus fulvus* (Forster, 1801)** or ***iyayaŋ kurĩ naba***. Figure 59.

**Figure 59. *Iyayaŋ kurĩ naba* (*Lutjanus fulvus*).**

An additional two (2) specimens were added to our data set in 2012, yielding a combined total 41 individuals captured on video suitable for length estimation. The additional data did not change the 2011 mean fork length estimate of 18 cm, which is 46% of the estimated maximum reported length of 39 cm, 72% of the estimated optimum length of 25 cm and 95% of the observed female $L_{50}$ of 19 cm (Figure 60). The above information, when considered in light of the approximately 1:1 sex-ratio, suggests that about 22% of the population is mature females.

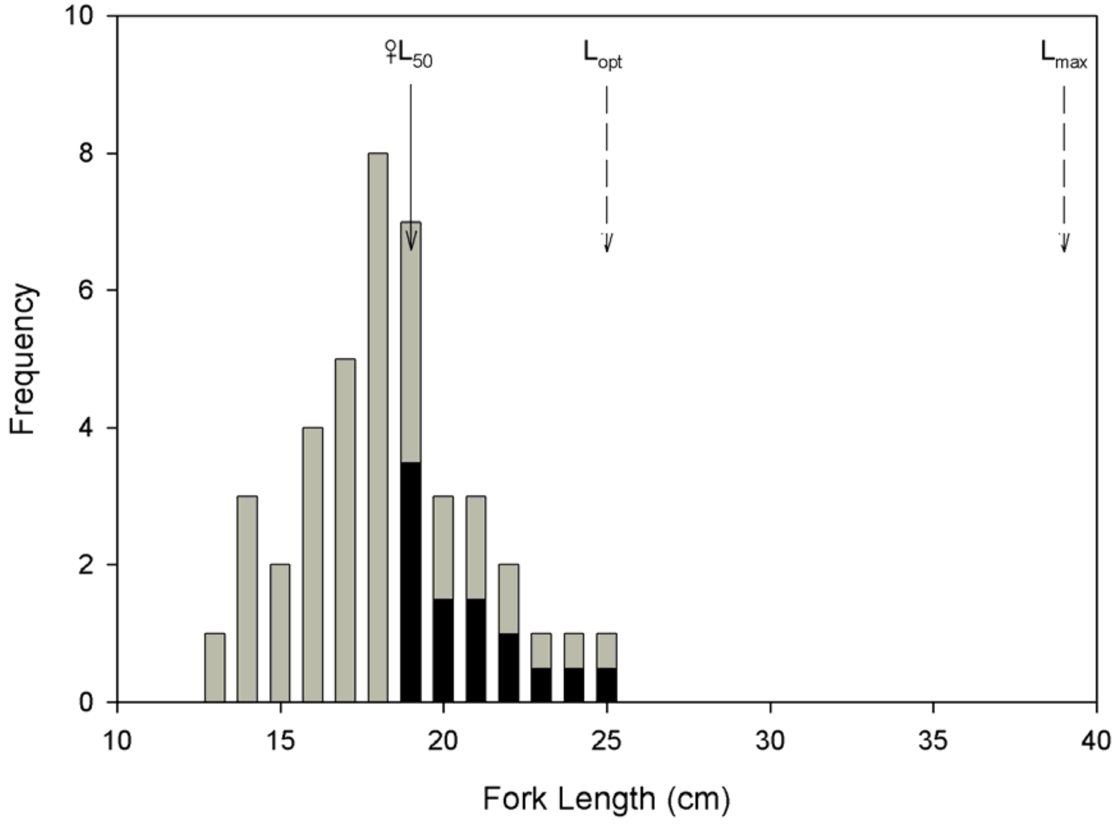


**Figure 60. Size structure of *Lutjanus fulvus*. The dark portion of bars represent estimated number of mature females, light portion represents all other individuals.**

***Lutjanus gibbus* (Forsskål, 1775)** or ***ina suwi***. Figure 61.

**Figure 61. *Ina suwi* (*Lutjanus gibbus*). Laser dots are separated by 39 mm.**

An additional two (2) specimens were added to our data set in 2012, yielding a combined total 22 individuals captured on video suitable for length estimation. The additional data shifted mean fork length to 20 cm from our 2011 estimated of 21 cm. The updated length estimate is 48% of the estimated maximum length of 42 cm, 74% of the estimated optimum length of 27 cm, and at least 111% of the published female $L_m$ of 18 cm (Figure 62). Because sex ratios have not been described in detail, the percentage of mature females cannot be estimated.

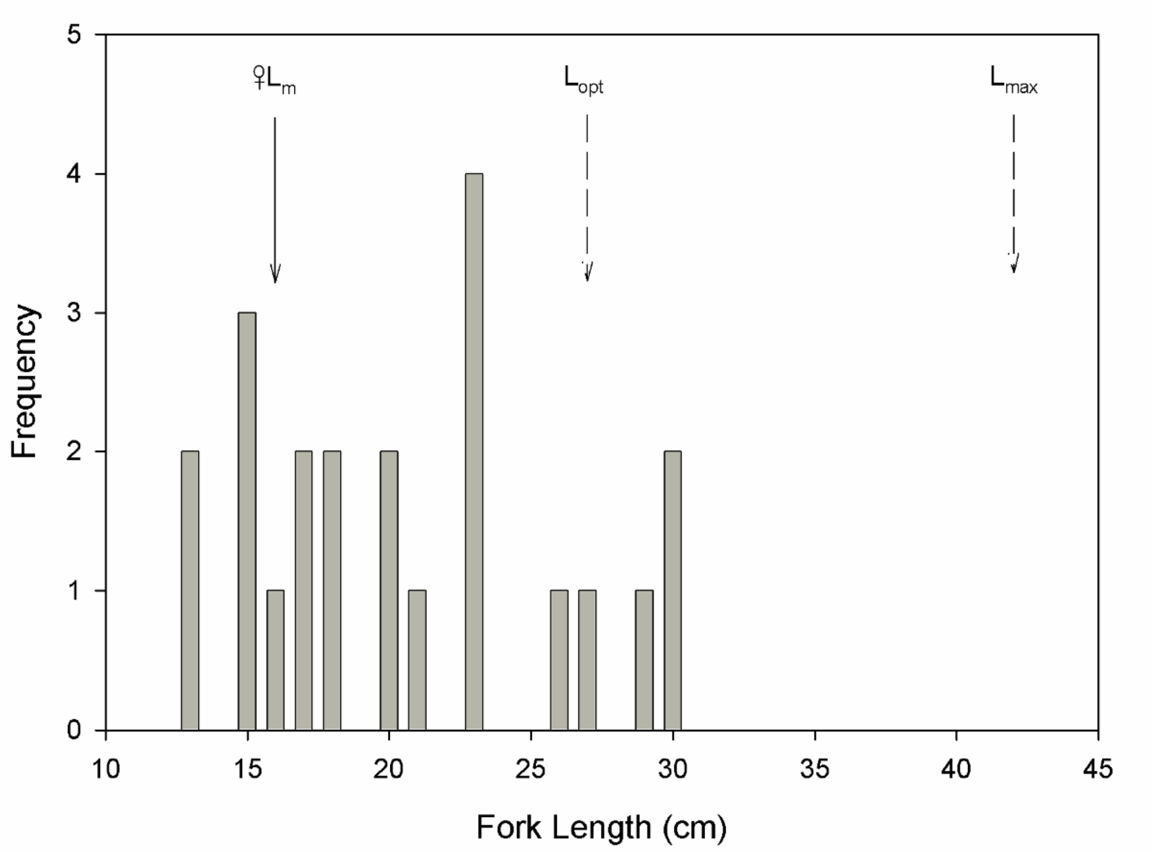


**Figure 62. Size structure of *Lutjanus gibbus*.**

***Lutjanus kasmira*** **(Forsskål, 1775)** or ***babaura yumi yayã***. Figure 63.

**Figure 63. *Babaura yumi yayã* (*Lutjanus kasmira*). Laser dots are separated by 36 mm.**

One (1) new specimen was added to our data set in 2012, yielding a combined four (4) individuals captured on video suitable for length estimation. Due to low sample size, a size distribution is not presented. However, the additional datum shifted our mean fork length estimate to 16 cm from our 2011 estimate of 15 cm. Updated mean length is 48% of the published maximum length of 33 cm, 76% of the estimated optimum length of 21 cm and 133% of the published female $L_m$ of 12 cm. Size-at-maturity and sex-ratio information suggest that 43% of the population captured on video is composed of mature females.

***Lutjanus monostigma*** **(Cuvier, 1828)** or ***baniŋga***. Figure 64.

**Figure 64. *Baniŋga* (*Lutjanus monostigma*). Laser dots are separated by 31 mm.**

No new specimens were added to our data set in 2012, leaving a total four (4) individuals captured on video suitable for length estimation. Due to low sample size, a size distribution is not presented. The mean fork length of 21 cm is 44% of the estimated maximum length of 48 cm, 68% of the estimated optimum length of 31 cm, and 66% of the published female $L_m$ of 32 cm.

***Lutjanus rivulatus*** **(Cuvier, 1828)** or ***isina***. Figure 65.

**Figure 65. *Isina* (*Lutjanus rivulatus*). Laser dots are separated by 39 mm.**

No new specimens were added to our data set in 2012, leaving a total four (4) individuals captured on video suitable for length estimation. Due to low sample size, a size distribution is not presented. Mean fork length of 31 cm is 49% of the estimated maximum length of 63 cm, 76% of the estimated optimum length of 41 cm and 78% of the estimated female $L_m$ of 40 cm.

***Lutjanus russellii* (Bleeker, 1849)** or ***kawasi ŋasiŋa***. Figure 66.

**Figure 66. *Kawasi ŋasiŋa* (*Lutjanus russellii*). Laser dots are separated by 39 mm.**

No new specimens were added to our data set in 2012, leaving a combined total 75 individuals captured on video suitable for length estimation. The mean fork length estimate of 22 cm is 51% of the estimated maximum length of 43 cm, 79% of the estimated optimum length of 28 cm, and 100% of the published female $L_{50}$ of 22 cm (Figure 67).

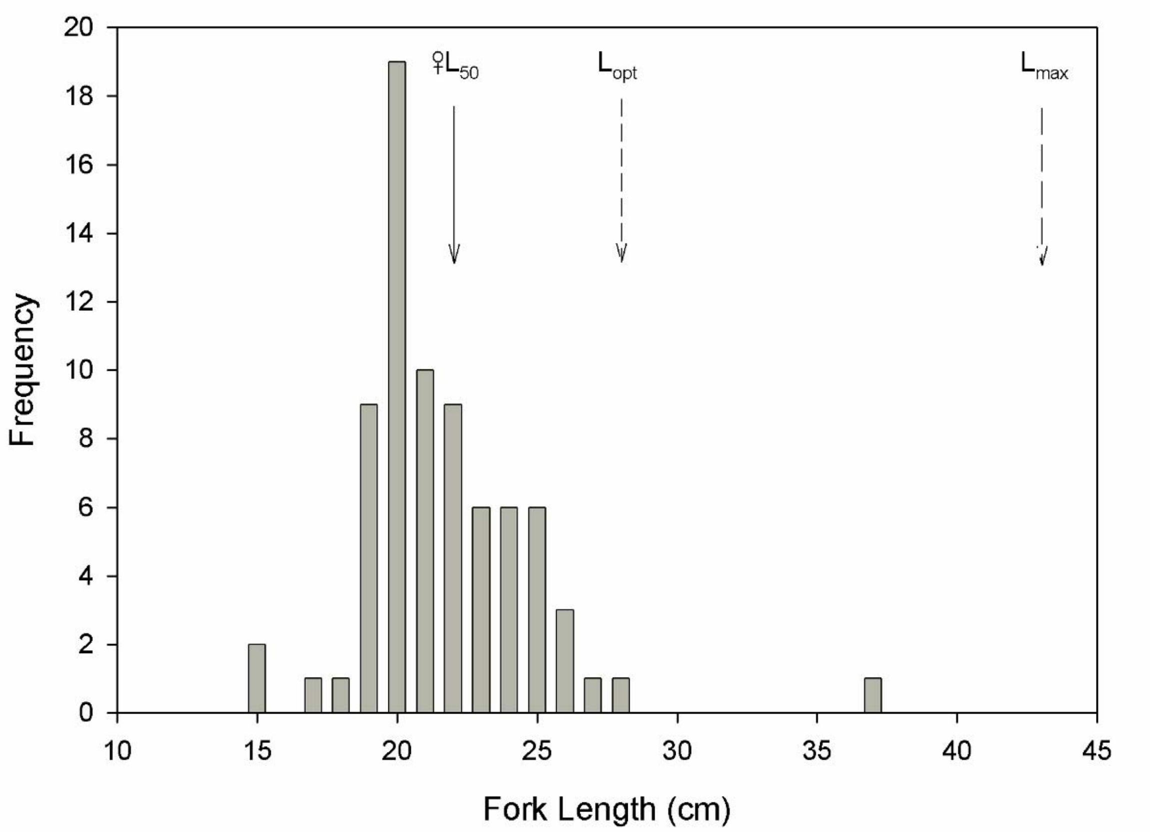


**Figure 67. Size structure of *Lutjanus russellii*.**

***Lutjanus semicinctus* Quoy & Gaimard, 1824** or ***imawe***. Figure 68.

**Figure 68. *Imawe* (*Lutjanus semicinctus*). Laser dots are separated by 39 mm.**

An additional seven (7) specimens were added to our data set in 2012, yielding a combined total 49 individuals captured on video suitable for length estimation. The additional data did not change the mean fork length estimate from our 2011 value of 20 cm. Mean size is 59% of the estimated maximum length of 34 cm, 91% of the estimated optimum length of 22 cm, and 95% of published female $L_{50}$ of 21 cm. When the above information is considered in light of size-specific sex ratios (which could not be described with a regression equation, and may underestimate the number of mature females in large size classes, see Longenecker *et al*. 2011), approximately 14% of the individuals captured on video are mature females (Figure 69).

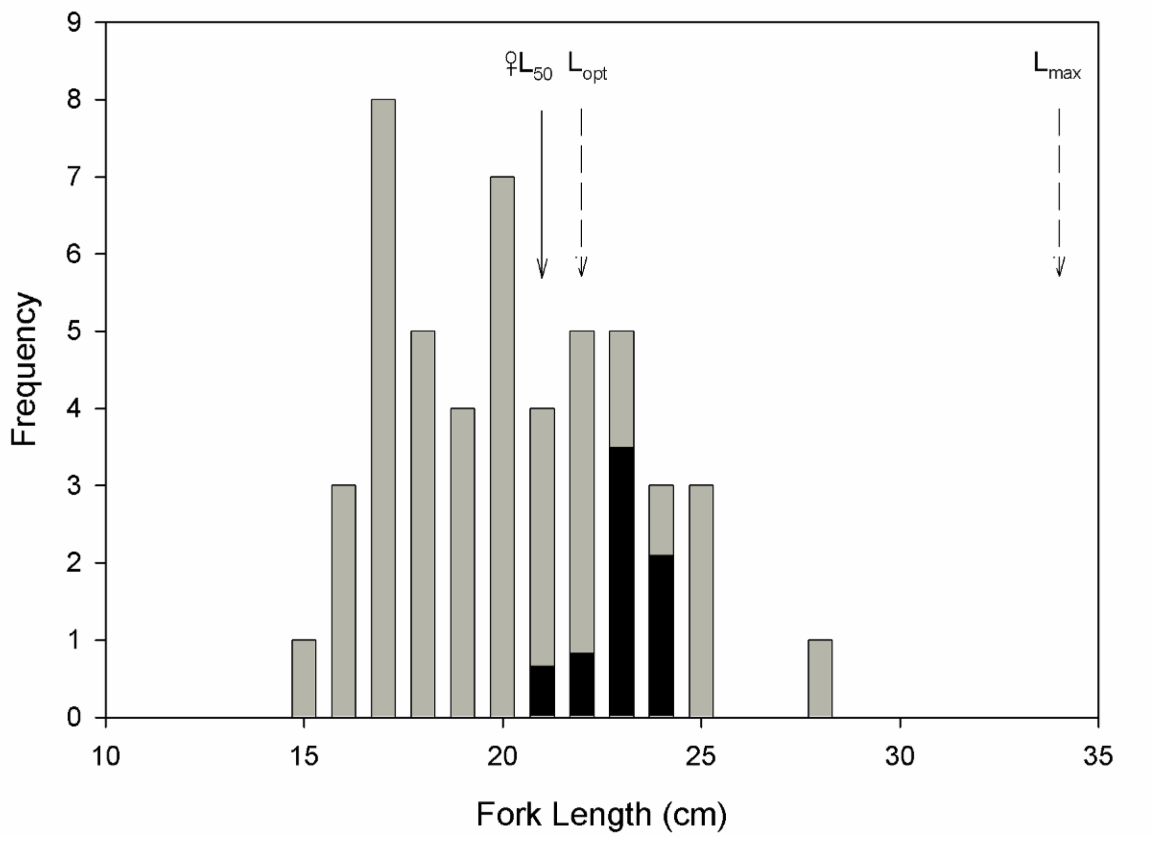


**Figure 69. Size structure of *Lutjanus semicinctus*. The dark portion of bars represent estimated number of mature females, light portion represents all other individuals.**

***Lutjanus vitta*** **(Quoy & Gaimard, 1824)** or ***isale***. Figure 70.

**Figure 70. *Isale* (*Lutjanus vitta*). Laser dots are separated by 39 mm.**

No new specimens were added to our data set in 2012, leaving a total 19 individuals captured on video suitable for length estimation. The mean fork length estimate remains at 14 cm. Mean length is 38% of the estimated maximum length of 37 cm, 58% of estimated optimum length of 24 cm and 93% of the published female $L_{50}$ of 15 cm (Figure 71). Size-at-maturity and size-specific sex ratio information suggest that 24% of the population captured on video is composed of mature females.

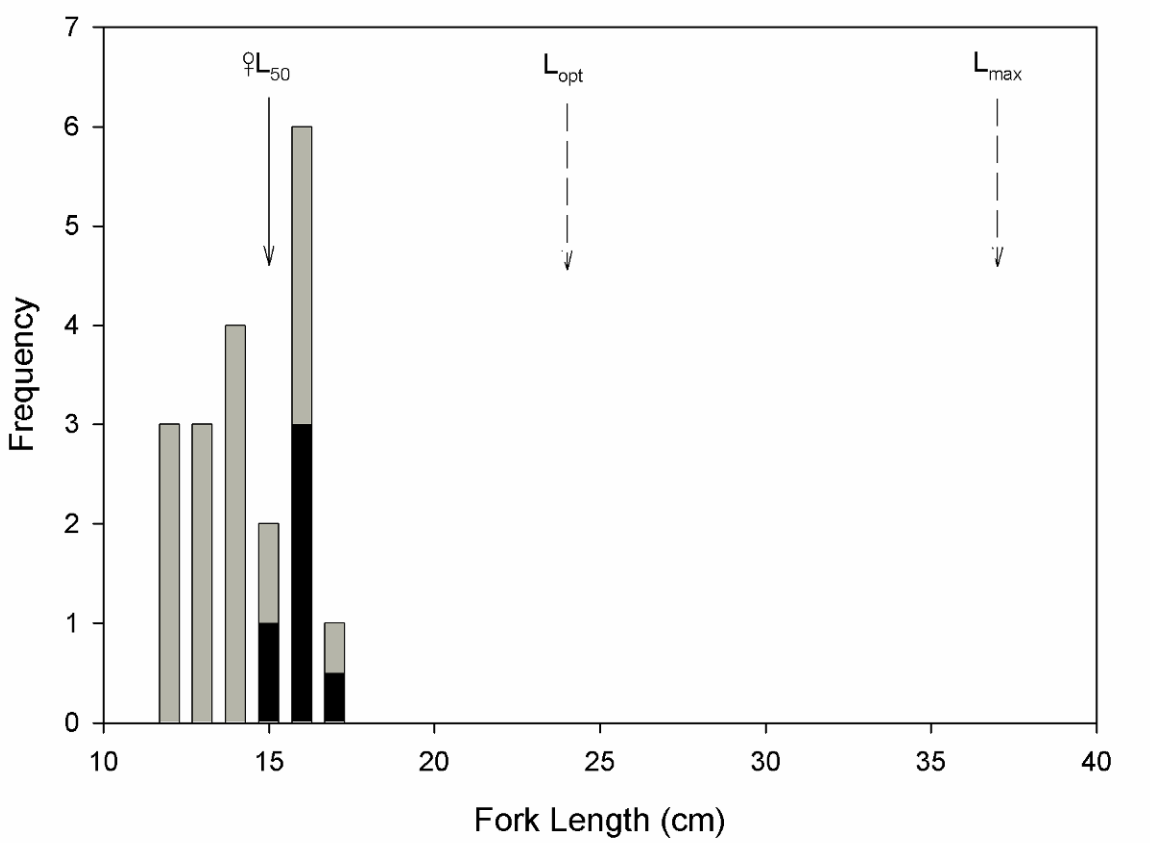


**Figure 71. Size structure of *Lutjanus vitta*. The dark portion of bars represent estimated number of mature females, light portion represents all other individuals.**

***Macolor macularis*** **Fowler, 1931** or ***labaikã tewe yayã***. Figure 72.

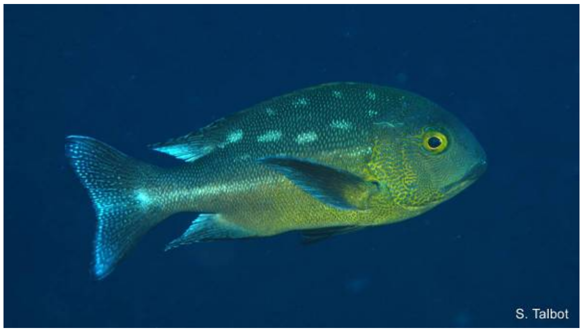


**Figure 72.** ***Labaikã tewe yayã*** **(*Macolor macularis*).**

No new specimens were added to our data set in 2012, leaving a total 17 individuals captured on video suitable for length estimation. The mean fork length estimate of 31 cm is 56% of the estimated maximum length of 55 cm, 86% of the estimated optimum length of 36 cm, and 89% of the estimated female $L_m$ of 35 cm (Figure 73).

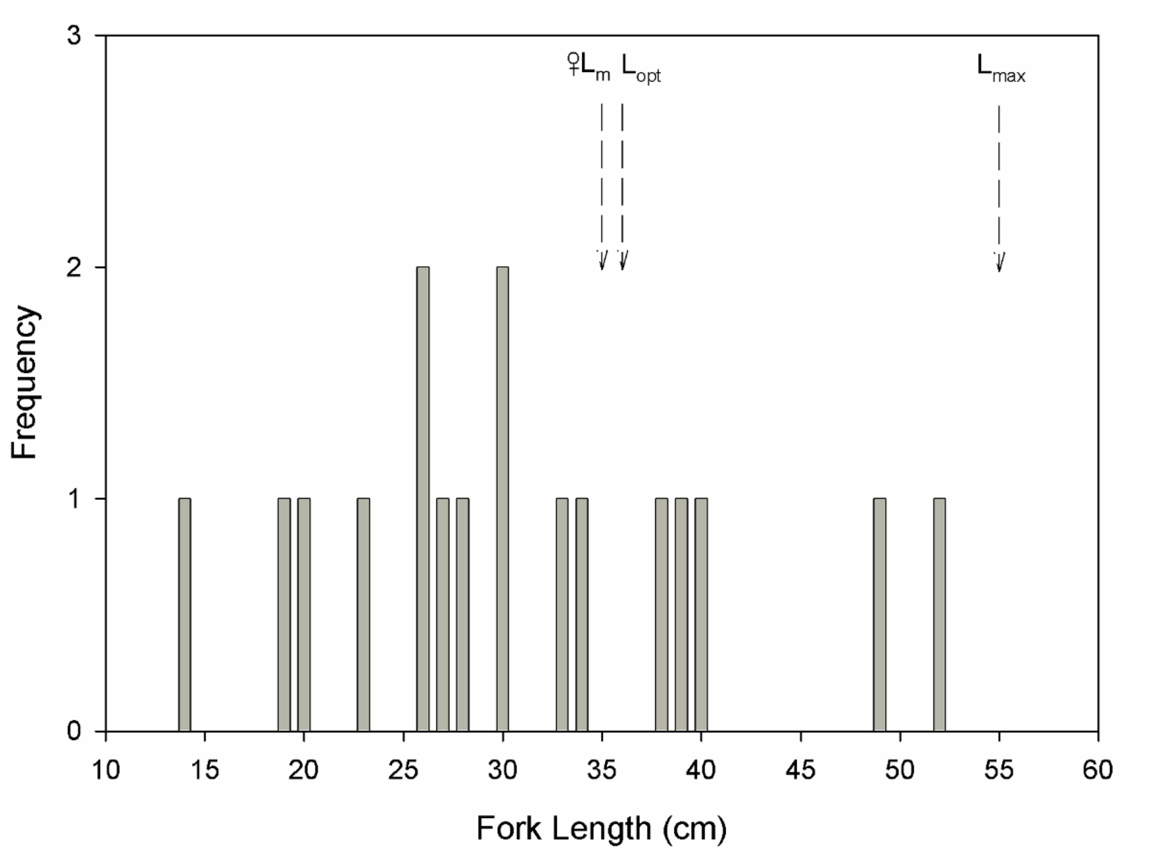


**Figure 73. Size structure of *Macolor macularis*.**

***Macolor niger*** **(Forsskål, 1775)** or ***labaikã yasai***. Figure 74.

**Figure 74. *Labaikã yasai* (*Macolor niger*). Laser dots are separated by 31 mm.**

No new specimens were added to our data set in 2012, leaving a total five (5) individuals captured on video suitable for length estimation. Due to low sample size, a size distribution is not presented. However, mean fork length is 28 cm, which is 47% of the estimated maximum total length of 60 cm, 72% of the estimated optimum total length of 39 cm and 74% of the estimated female $L_m$ of 38 cm (TL). The above estimates are presented as total length because no relationship between total and fork lengths is available. Therefore the above percentages are likely underestimates.

Mullidae

***Mulloidichthys vanicolensis*** **(Valenciennes, 1831)** or ***itale yumi yayã***. Figure 75.

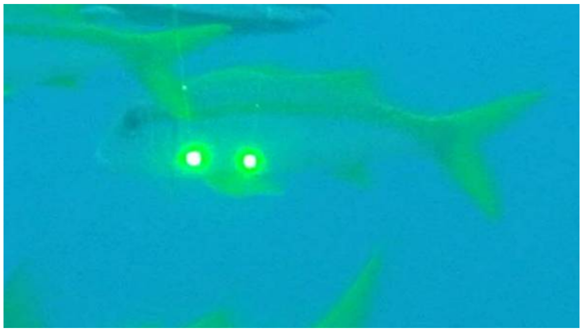


**Figure 75. *Itale yumi yayã* (*Mulloidichthys vanicolensis*). Laser dots are separated by 31 mm.**

No new specimens were added to our data set in 2012, leaving a total seven (7) individuals captured on video suitable for length estimation. Due to low sample size, a size distribution is not presented. However, mean fork length is 21 cm, which is 62% of the estimated maximum length of 34 cm, 95% of the estimated optimum length of 22 cm, and 124% of the published female $L_{50}$ of 17 cm.

***Parupeneus barberinus*** **(Lacepède, 1801)** or ***iwaŋgale***. Figure 76.

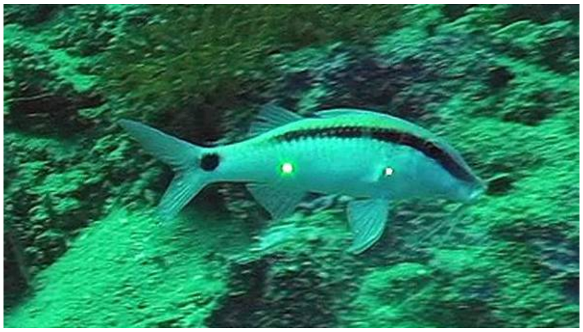


**Figure 76. *Iwaŋgale* (*Parupeneus barberinus*). Laser dots are separated by 39 mm.**

An additional 14 specimens were added to our data set in 2012, yielding a combined total 135 individuals captured on video suitable for length estimation. The additional data did not change our 2011 mean fork length estimate of 15 cm. Mean size is 34% of the estimated maximum length of 44 cm, 52% of the estimated optimum size of 29 cm and 125% of reported female $L_m$ of 12 cm. Size-at-maturity and size-specific sex ratio information suggest that 43% of the population captured on video is composed of mature females (Figure 77).

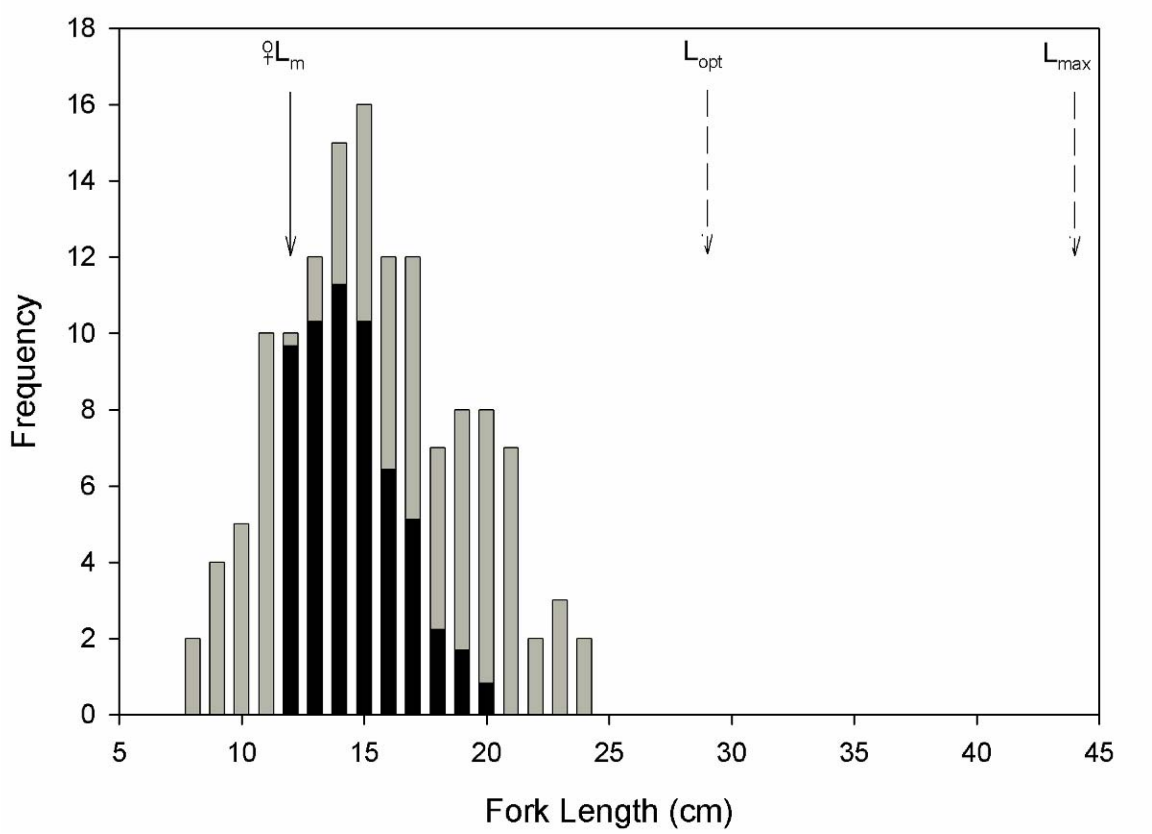


**Figure 77. Size structure of *Parupeneus barberinus*. The dark portion of bars represent estimated number of mature females, light portion represents all other individuals.**

***Parupeneus cyclostomus* (Lacepède, 1801)** or ***iwaŋgale bokole***. Figure 78.

**Figure 78. *Iwaŋgale bokole* (*Parupeneus cyclostomus*).**

An additional seven (7) specimens were added to our data set in 2012, yielding a combined total 20 individuals captured on video suitable for length estimation. However, the additional data did not shift our 2011 mean fork length estimate of 18 cm. Mean size is 41% of the maximum reported length of 44 cm, and 62% of estimates of optimum length and female $L_m$, both 29 cm (Figure 79).

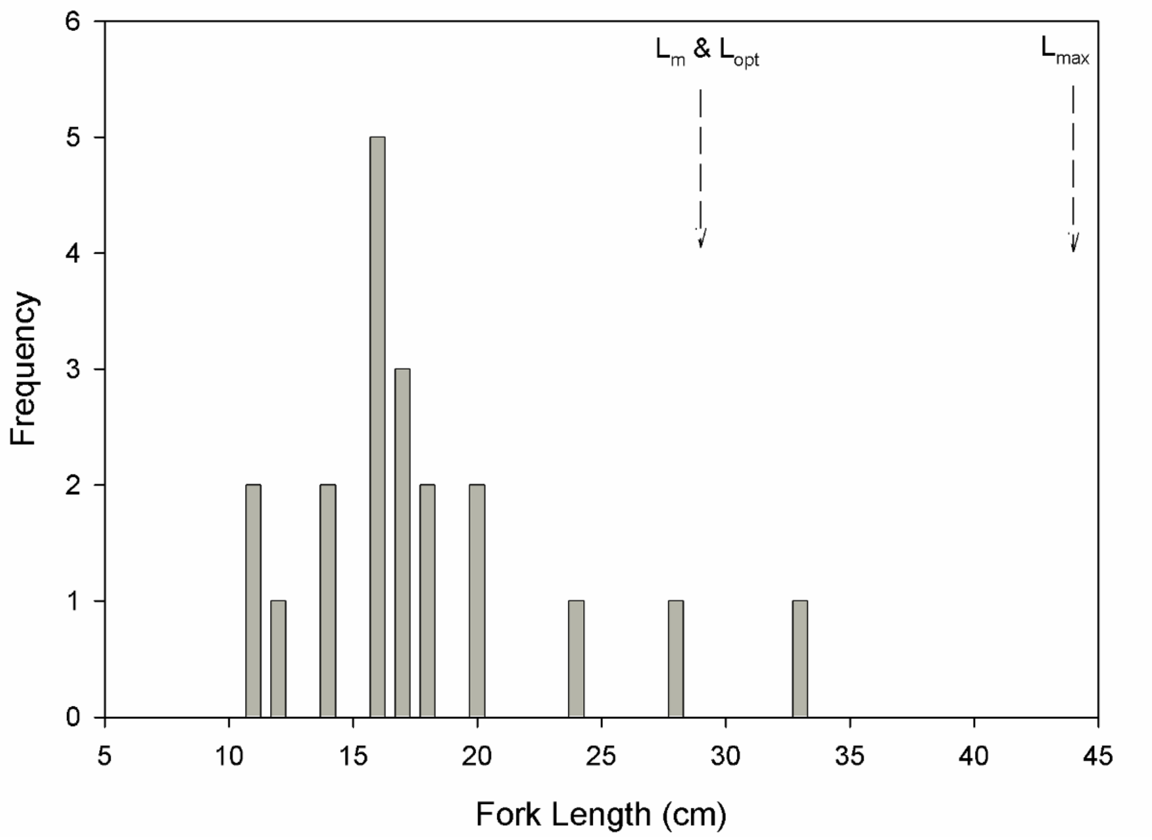


**Figure 79. Size structure of *Parupeneus cyclostomus*.**

***Parupeneus multifasciatus* (Quoy & Gaimard, 1825)** or ***iwaŋgale bote***. Figure 80.

**Figure 80.** ***Iwaŋgale bote*** **(*Parupeneus multifasciatus*).**

An additional 30 specimens were added to our data set in 2012, yielding a combined total 99 individuals captured on video suitable for length estimation. The additional data did not change the mean fork length estimate of 14 cm, which is 54% of the maximum reported length of 26 cm, 82% of the estimated optimum length of 17 cm and 93% of the published female $L_{50}$ of 15 cm (Figure 81). Size-at-maturity, size-specific sex ratio, and maximum-female-size information suggest that 14% of the population captured on video is composed of mature females.

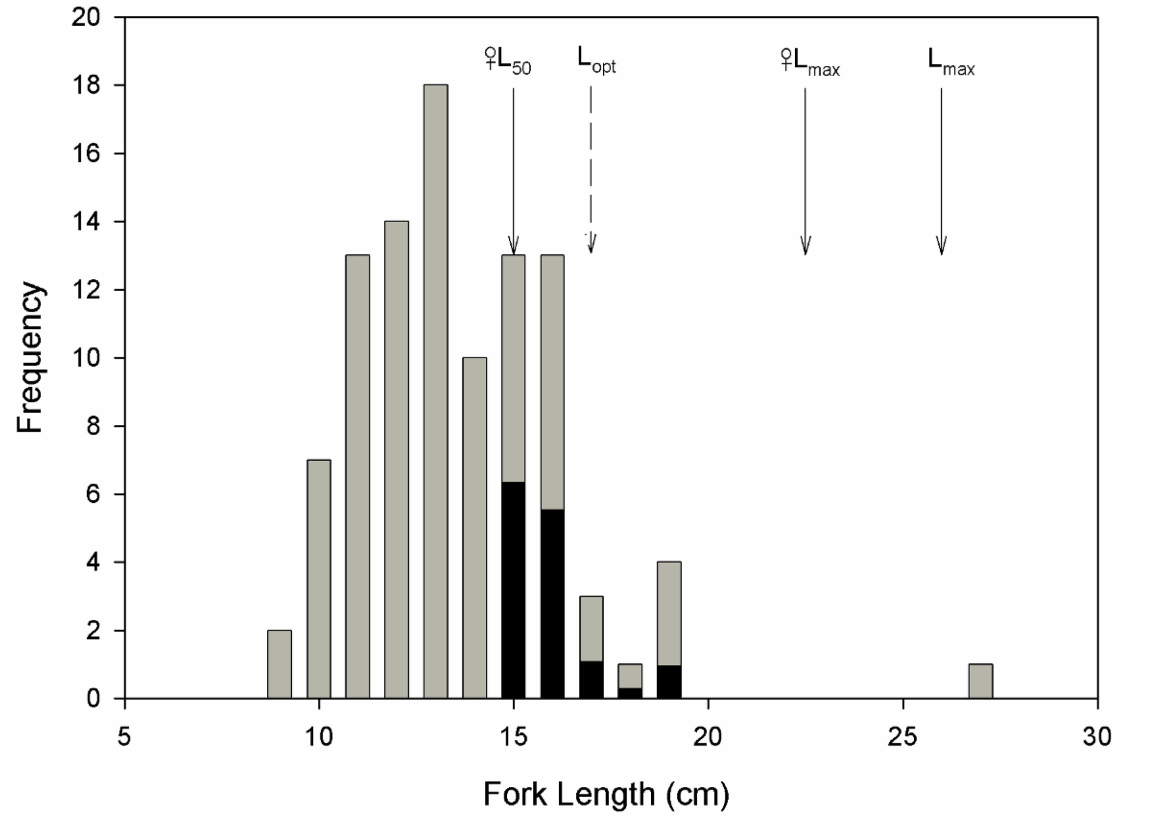


**Figure 81. Size structure of *Parupeneus multifasciatus*. The dark portion of bars represent estimated number of mature females, light portion represents all other individuals.**

***Parupeneus trifasciatus*** **(Lacepède, 1801)** or ***walia***. Figure 82.

**Figure 82. *Walia* (*Parupeneus trifasciatus*). Laser dots are separated by 39 mm.**

An additional seven (7) specimens were added to our data set in 2012, yielding a total 35 individuals captured on video suitable for length estimation. The additional data shifted our mean fork length estimate to 19 cm from our 2011 mean of 20 cm. The updated mean size is 61% of the estimated maximum length of 31 cm and 95% of the estimated optimum length of 20 cm (Figure 83). Mean length is 173% of the published female $L_m$ of 11 cm, and 100% of individuals had attained this size. Size-at-maturity and sex-ratio information suggest that 63% of the population captured on video is composed of mature females.

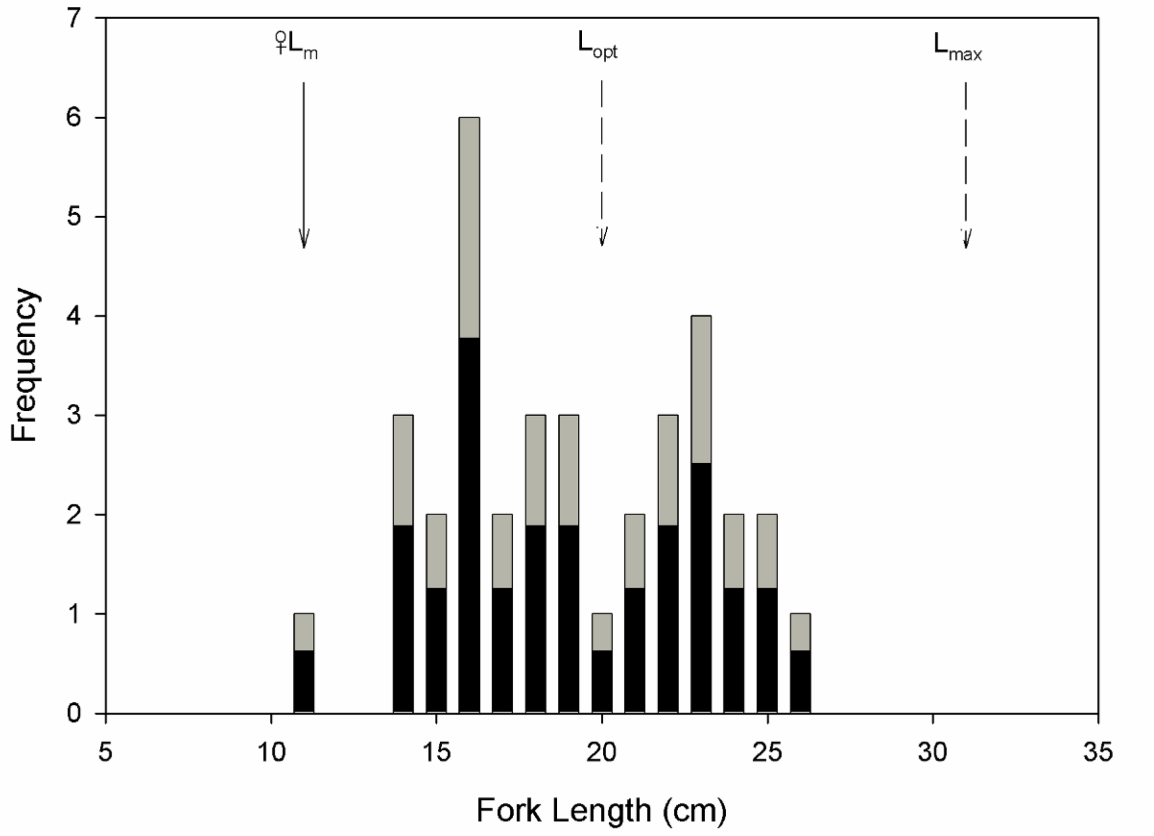


**Figure 83. Size structure of *Parupeneus trifasciatus*. The dark portion of bars represent estimated number of mature females, light portion represents all other individuals.**

## Nemipteridae

***Scolopsis bilineata* (Bloch, 1793)**; Kala name not yet recorded. Figure 84.

**Figure 84. *Scolopsis bilineata*. Laser dots are separated by 39 mm.**

A total eight (8) specimens were captured on video from 2009 to 2012. Due to low sample size, a size distribution is not presented. However, the mean fork length of 13 cm is 57% of max length of 23 cm, 87% of the estimated optimum total length of 15 cm, and 81% of estimated female $L_m$ 16 cm (TL). The above estimates are presented as total length because no relationship between total and fork lengths is available. Therefore the above percentages are likely underestimates.

## Priacanthidae

***Priacanthus hamrur* (Forsskål, 1775)**; Kala name not yet recorded. Figure 85.

**Figure 85. *Priacanthus hamrur*. Laser dots are separated by 39 mm.**

A total three (3) specimens were captured on video from 2009 to 2012. Due to low sample size, a size distribution is not presented. However, the mean fork length of 23 cm is 58% of maximum published total length of 40 cm, 88% of estimated of optimum total length of 26 cm, and 115% of published female $L_{50}$ of 20 cm (assumed FL). Size-at-maturity and sex-ratio information suggest that 43% of the population captured on video is composed of mature females. The above total and optimum length estimates are presented as total length because no relationship between total and fork lengths is available; therefore the corresponding percentages are likely underestimates.

### Scaridae

***Chlorurus bleekeri* (de Beaufort, 1940)**; Kala name not yet recorded.  Figure 86.

**Figure 86.  *Chlorurus bleekeri* initial phase (left) and terminal male (right).  Laser dots are separated by 31.5 mm.**

A total five (5) specimens were captured on video from 2009 to 2012.  Due to low sample size, a size distribution is not presented.  However, the mean total length of 18 cm is 60% of maximum published length of 30 cm, 95% of estimated optimum length of 19 cm, and 90% of estimated female $L_m$ of 20 cm.

***Chlorurus bowersi* (Snyder, 1909)**; Kala name not yet recorded.  Figure 87.

**Figure 87.  *Chlorurus bowersi*.  Laser dots are separated by 31 mm.**

A total three (3) specimens were captured on video from 2009 to 2012.  Due to low sample size, a size distribution is not presented.  However, the mean fork length of 22 cm is 71% of maximum published length of 31 cm, 110% of estimated optimum length of 20 cm, and 105% of estimated female $L_m$ of 21 cm.

***Scarus flavipectoralis*** **Schultz, 1958** or ***iŋga talaŋ*** (initial phase) and ***iŋga tali lau*** (terminal male). Figure 88.

**Figure 88. *Iŋga talaŋ* (left) and *iŋga tali lau* (right) or *Scarus flavipectoralis* initial phase (left) and terminal male (right). Laser dots are separated by 36 and 39 mm, respectively.**

A total 14 individuals were added to our data set in 2012, yielding a combined total 27 specimens captured on video suitable for length estimation. The additional data shifted mean total length to 19 cm from our 2011 estimate of 20 cm. The updated mean length is 66% of the maximum reported length of 29 cm, and 100% of estimates of optimum length and female $L_m$, both 19 cm (Figure 89).

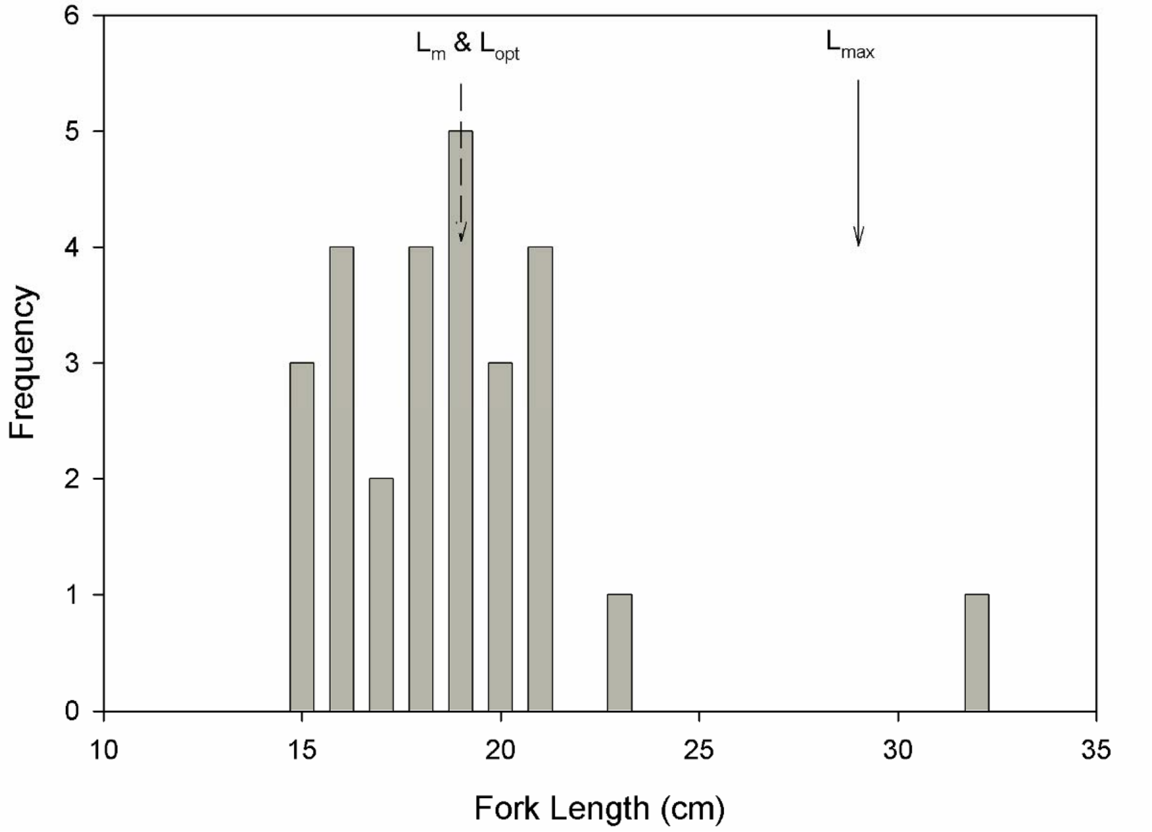


**Figure 89. Size structure of *Scarus flavipectoralis*.**

Scombridae

***Gymnosarda unicolor* (Rüppell, 1836)** or ***itaŋgi talaloŋa***. Figure 90.

**Figure 90. *Itaŋgi talaloŋa* (*Gymnosarda unicolor*). Laser dots are separated by 31.5 mm.**

One (1) specimen was added to our data set in 2012, yielding a combined total 18 specimens captured on video suitable for length estimation. The additional datum did not shift our 2011 mean fork length estimate of 59 cm, which is 43% of the estimated maximum length of 137 cm, 64% of the estimated optimum length of 92 cm, and 85% of the published female $L_m$ of 70 cm (Figure 91).

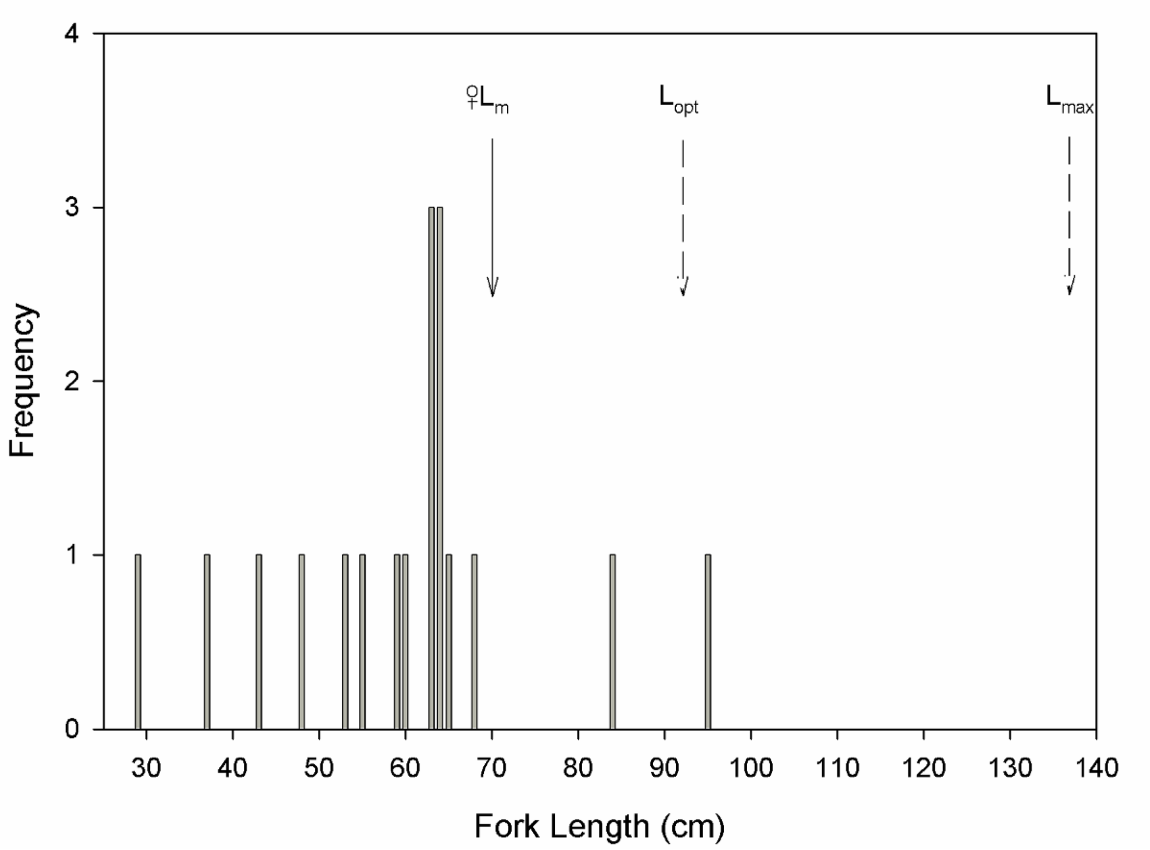


**Figure 91. Size structure of *Gymnosarda unicolor*.**

***Rastrelliger kanagurta*** **(Cuvier, 1816)**; Kala name not yet recorded.  Figure 92.

**Figure 92.  *Rastrelliger kanagurta*.  Laser dots are separated by 31.5 mm.**

A total four (4) individuals were captured on video suitable for length estimation.  Due to low sample size, a size distribution is not presented.  However, mean fork length was 23 cm, which is 70% of the maximum reported length of 33 cm, 110% of the estimated optimum length of 21 cm, and 121% of the published female $L_{50}$ of 19 cm.

***Scomberomorus commerson*** **(Lacepède, 1800)** or ***itaŋgi***.  Figure 93.

**Figure 93.  *Itaŋgi* (*Scomberomorus commerson*).  Laser dots are separated by 31 mm.**

One (1) specimen was added to our data set in 2012, yielding a combined total five (5) individuals captured on video suitable for length estimation.  Due to low sample size, a size distribution is not presented.  The additional datum did not change our mean total length estimate of 95 cm, which is 44% of the maximum reported length of 218 cm, 64% of the estimated optimum length of 148 cm, and 146% of the published female $L_m$ of 65 cm.  Size-at-maturity and size-specific sex ratio information suggest that 82% of the population captured on video is composed of mature females.

Serranidae

***Anyperodon leucogrammicus*** **(Valenciennes, 1828)** or ***ikula damasã***.  Figure 94.

**Figure 94.  *Ikula damasã* (*Anyperodon leucogrammicus*).  Laser dots are separated by 39 mm.**

An additional four (4) specimens were added to our data set in 2012, yielding a combined total 15 individuals captured on video suitable for length estimation.  The additional data shifted mean length to 25 cm from our 2011 estimate of 26 cm.  The updated mean size is 48% of the maximum reported length of 52 cm, 74% of the estimated optimum length of 34 cm and 76% of the estimated female $L_m$ of 33 cm (Figure 95).

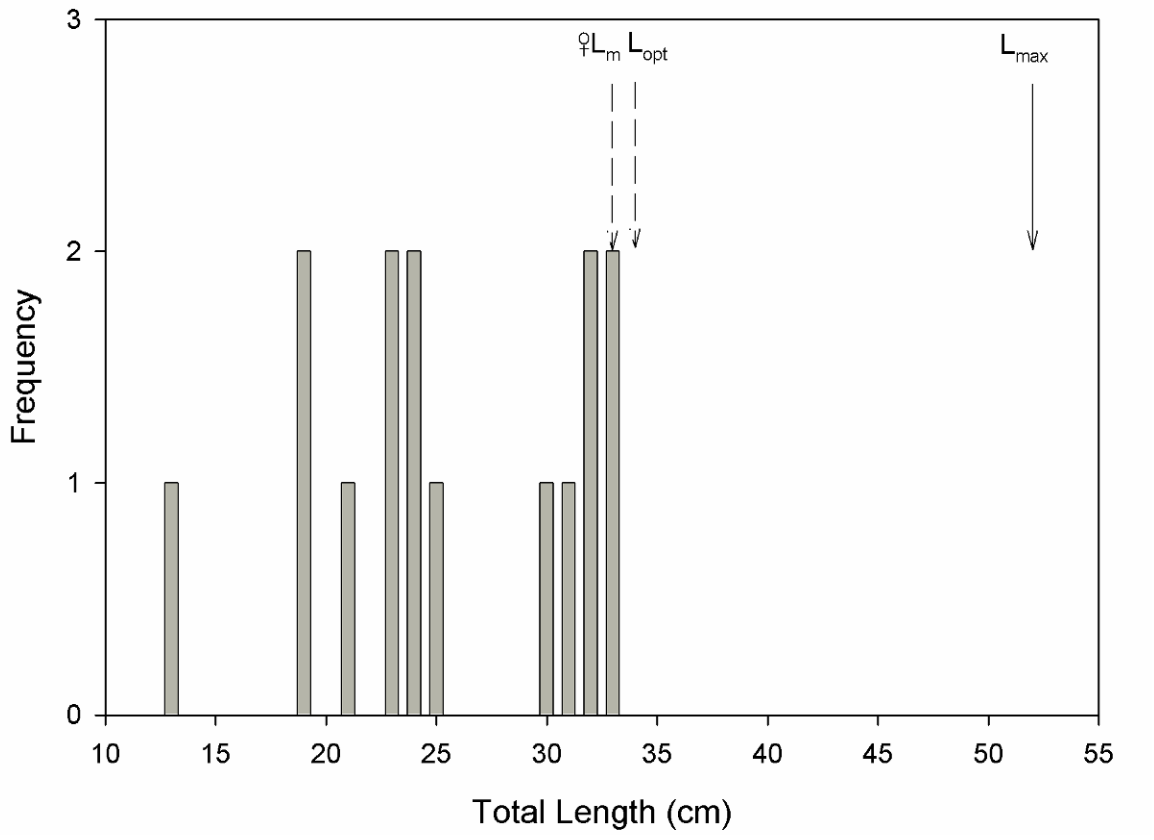


**Figure 95. Size structure of *Anyperodon leucogrammicus*.**

***Cephalopholis boenak*** **(Bloch, 1790)** or ***ikula bobo***. Figure 96.

**Figure 96. *Ikula bobo* (*Cephalopholis boenak*).**

No new specimens were added to our data set in 2012, leaving a total 10 individuals captured on video suitable for length estimation. Due to low sample size, a size distribution is not presented. However, mean total length is 16 cm, which is 67% of the maximum reported length of 24 cm and 107% of the estimated optimum length and the published female $L_{50}$, both 15 cm. Size-at-maturity and sex-ratio information suggest that 63% of the population captured on video is composed of mature females.

***Cephalopholis cyanostigma* (Valenciennes, 1828)** or ***ikula sa***. Figure 97.

**Figure 97. *Ikula sa* (*Cephalopholis cyanostigma*).**

An additional 13 specimens were added to our data set in 2012, yielding a combined total 76 individuals captured on video suitable for length estimation. The additional data did not change the mean total length estimate of 19 cm, which is 54% of the maximum reported length of 35 cm and 83% of estimated optimum length and published female $L_{50}$, both 23 cm. Given $L_{50}$, size-specific sex ratios and the maximum female size of 26 cm, 0.9% of the population captured on video is composed of mature females. However, if minimum size at female maturity is considered, up to 39% of individuals captured on video may be mature females (Figure 98).

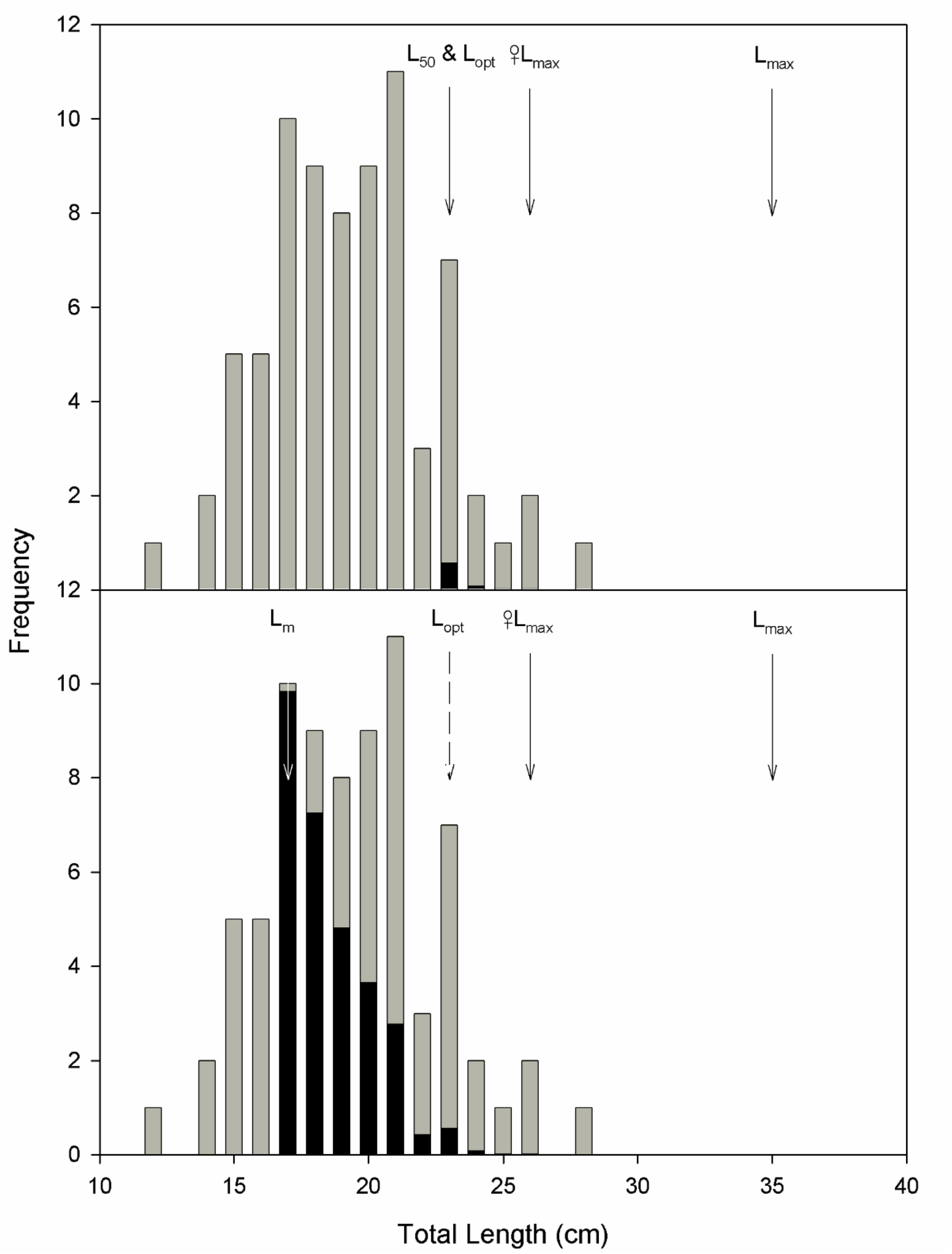


**Figure 98. Size structure of *Cephalopholis cyanostigma*. The dark portion of bars represent estimated number of mature females if $L_{50}$ is considered (top) or if $L_m$ is considered (bottom), light portion represents all other individuals.**

***Cephalopholis microprion*** **(Bleeker, 1852)** or ***ikula yuyeŋ***. Figure 99.

**Figure 99.** ***Ikula yuyeŋ*** **(*Cephalopholis microprion*). Laser dots are separated by 39 mm.**

An additional two (2) specimens were added to our data set in 2012, yielding a combined total 22 individuals captured on video suitable for length estimation. The additional data did not shift our 2011 total length estimate of 13 cm. Mean size is 57% of the maximum reported length of 23 cm, 87% of the estimated optimum length of 15 cm and 81% of the estimated female $L_m$ of 16 cm (Figure 100).

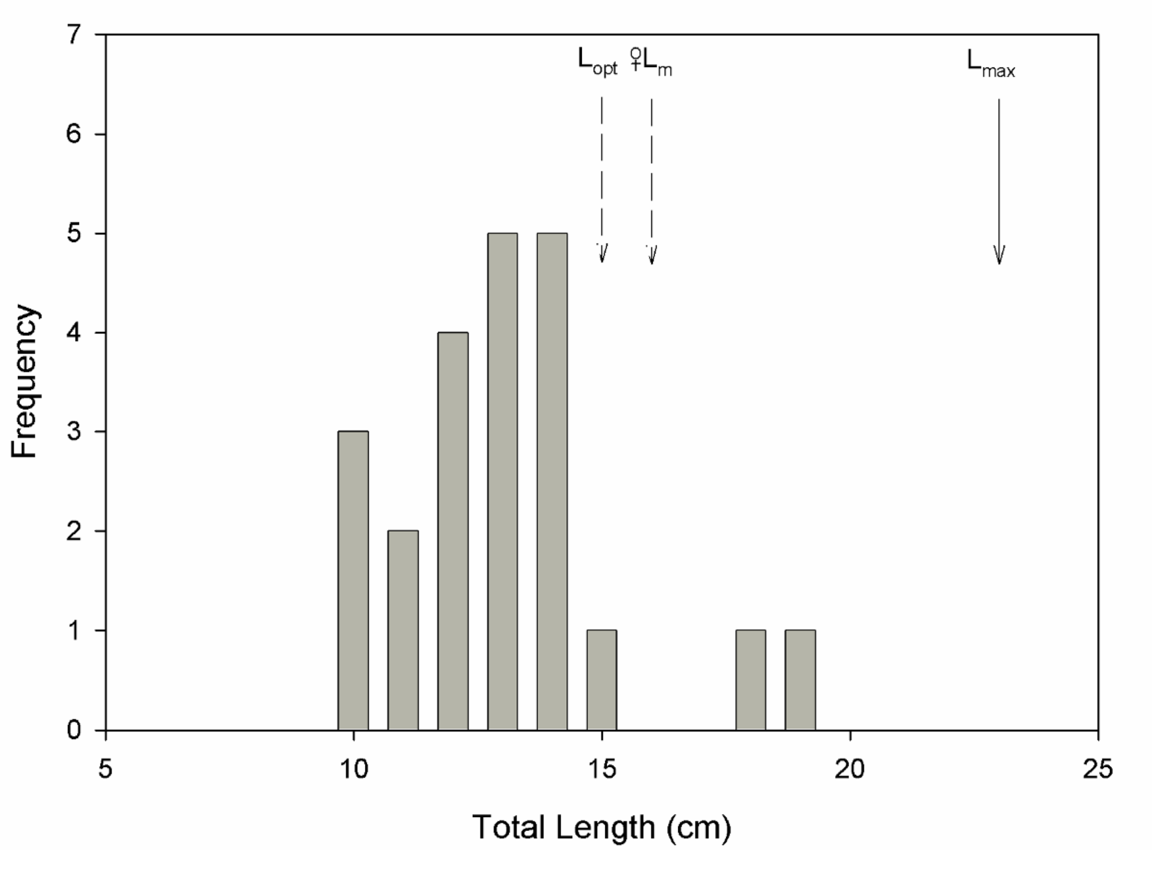


**Figure 100. Size structure of *Cephalopholis microprion*.**

***Cephalopholis sexmaculata* (Rüppell, 1830)** or ***ikula tumi***. Figure 101.

**Figure 101. *Ikula tumi* (*Cephalopholis sexmaculata*). Laser dots are separated by 36 mm.**

One (1) specimen was added to our data set in 2012, yielding a combined total four (4) individuals captured on video suitable for length estimation. Due to low sample size, a size distribution is not presented. The additional datum shifted our mean total length estimate to 24 cm from our 2011 mean of 21 cm. The updated mean length is 51% of the published maximum length of 47 cm, 77 % of the estimated optimum length of 31 cm and 100% of the published female $L_m$ of 24 cm.

***Cephalopholis urodeta* (Forster, 1801)** or ***ikula karu guŋ-guŋ***. Figure 102.

**Figure 102. *Ikula karu guŋ-guŋ* (*Cephalopholis urodeta*). Laser dots are separated by 39 mm.**

No new specimens were added to our data set in 2012, leaving a combined total six (6) individuals captured on video suitable for length estimation. Due to low sample size, a size distribution is not presented. However, the mean total length estimate of 18 cm is 67% of the maximum reported length of 27 cm, 106% of estimated optimum length of 17 cm, and 100% of estimated female $L_m$ of 18 cm. Size-at-maturity and sex-ratio information suggest that 49% of the population captured on video is composed of mature females.

***Plectropomus areolatus* (Rüppell, 1830)** or ***ikula su mani balã***. Figure 103.

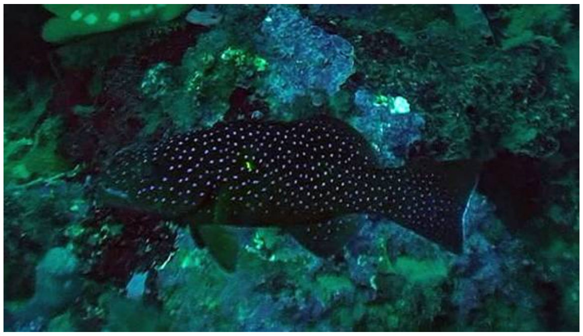


**Figure 103. *Ikula su mani balã* (*Plectropomus areolatus*). Laser dots are separated by 39 mm.**

No additional specimens were added to our data set in 2012, leaving a total 15 individuals captured on video suitable for length estimation. Mean length is 18 cm, which is 26% of the maximum reported length of 70 cm, 39% of the estimated optimum length of 46 cm, and 45% of the published female $L_{50}$ of 40 cm (Figure 104). Apparently, none of the individuals captured on video had attained reproductive size.

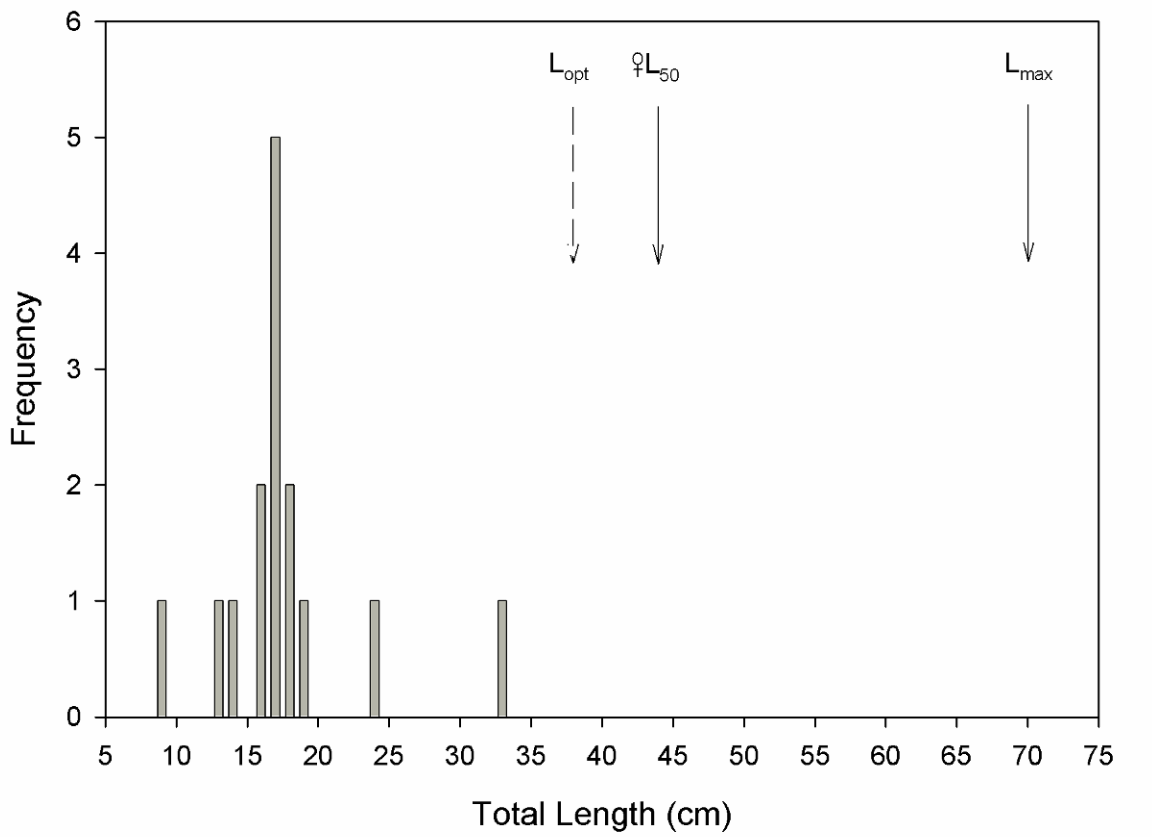


**Figure 104. Size structure of *Plectropomus areolatus*.**

***Plectropomus leopardus* (Lacepède, 1802)** or ***yula***. Figure 105.

**Figure 105. *Yula* (*Plectropomus leopardus*). Laser dots are separated by 36 mm.**

An additional four (4) individuals were added to our data set in 2012, yielding a total 10 individuals captured on video suitable for length estimation. Due to low sample size, a size distribution is not presented. However, the additional data shifted mean total length to 32 cm from our 2011 estimate of 34 cm. The updated mean size is 47% of the estimated maximum length of 68 cm, 71% of the estimated optimum length of 45 cm, and 100% of the published female $L_{50}$ of 32 cm. Size-at-maturity and size-specific sex ratio information suggest that 56% of the population captured on video is composed of mature females.

***Plectropomus oligacanthus* (Bleeker, 1855)** or ***ikula su tatalõ***. Figure 106.

**Figure 106. *Ikula su tatalõ* (*Plectropomus oligacanthus*).**

An additional 13 specimens were added to our data set in 2011, yielding a combined total 54 individuals captured on video suitable for length estimation. The additional data shifted mean fork length to 33 cm from our 2011 estimate of 32 cm. The updated mean size is 51% of the maximum reported length of 65 cm, 77% of the estimated optimum length of 43 cm, and 79% of the estimated $L_m$ of 42 cm (Figure 107).

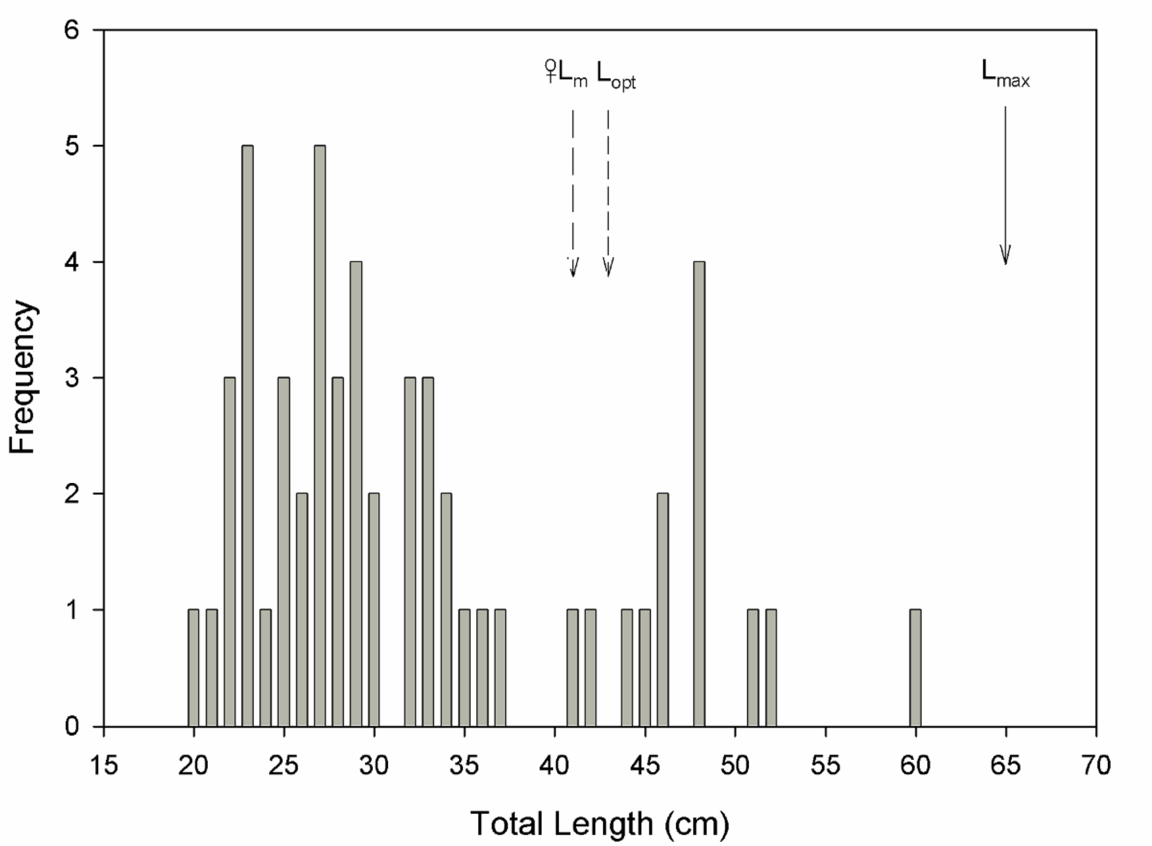


**Figure 107. Size structure of *Plectropomus oligacanthus*.**

## Siganidae

### *Siganus javus* (Linnaeus, 1766) or *yulawe kokoranawa*. Figure 108.

**Figure 108. *Yulawe kokoranawa* (*Siganus javus*). Laser dots are separated by 39 mm.**

No new specimens were added to our data set in 2012, leaving a total 33 individuals captured on video suitable for length estimation. Mean "fork" length was 25 cm, which is 47% of the maximum reported total length of 53 cm, 71% of the estimated optimum length of 35 cm, and 74% of the estimated female $L_m$ of 34 cm (Figure 109). The percentages presented here are slight underestimates because the caudal fin of this species is emarginate, thus total length is longer than "fork" length (distance to the end of the middle caudal ray used throughout this study).

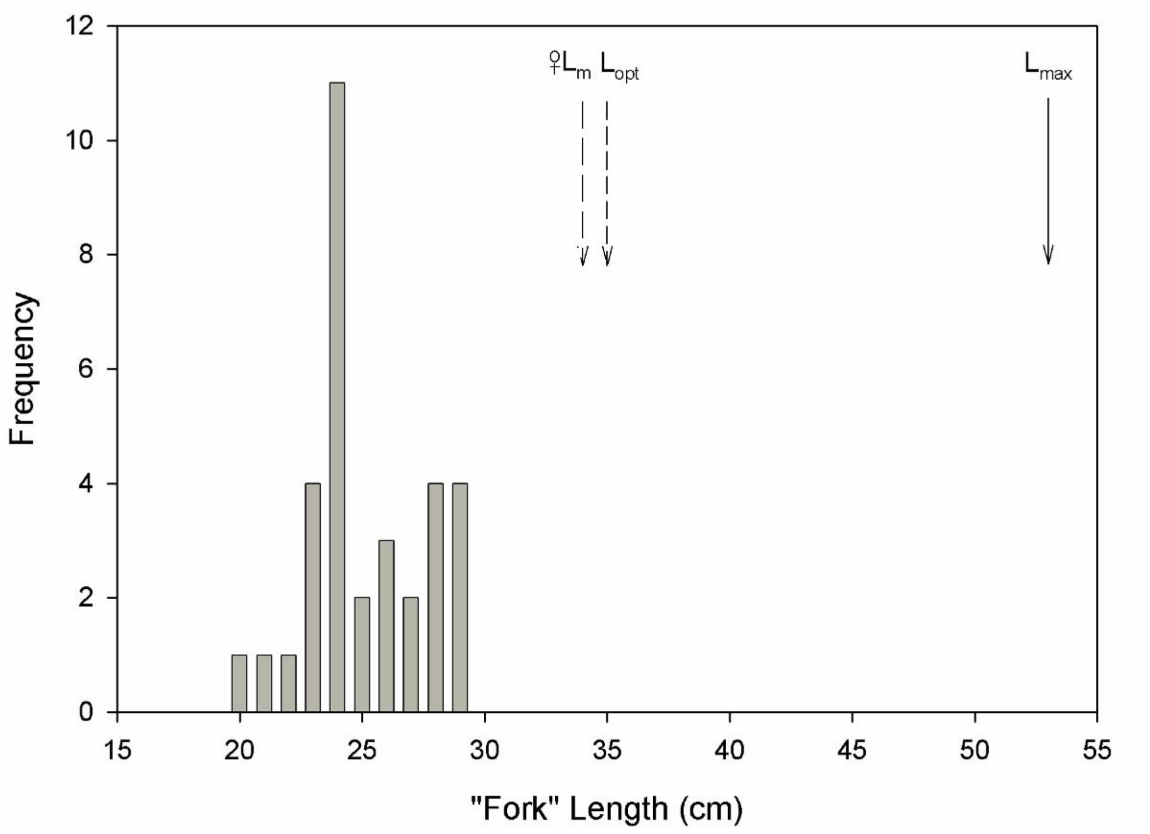


**Figure 109. Size structure of *Siganus javus*.**

***Siganus lineatus* (Valenciennes, 1835)** or ***yulawe***. Figure 110.

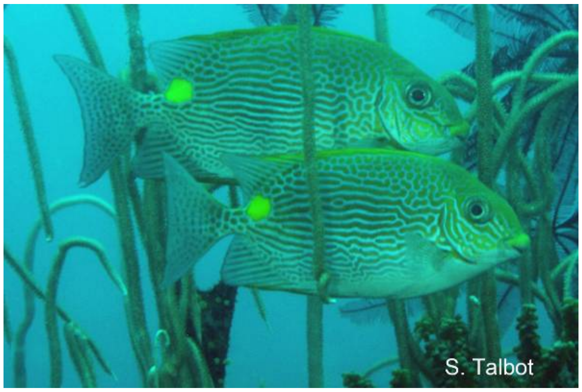


**Figure 110. *Yulawe* (*Siganus lineatus*).**

An additional six (6) specimens were added to our data set in 2012, yielding a combined total 71 individuals captured on video suitable for length estimation. The additional data did not change our 2010 mean "fork" length estimate of 26 cm. Mean size estimate is 63% of the estimated maximum "fork" length of 41 cm, 96% of the estimated optimum length of 27 cm, and 108% of published female $L_{50}$ of 24 cm. The above information, when considered in light of size-specific sex ratios and maximum published female length, suggests 32% of the individuals captured on video are mature females (Figure 111).

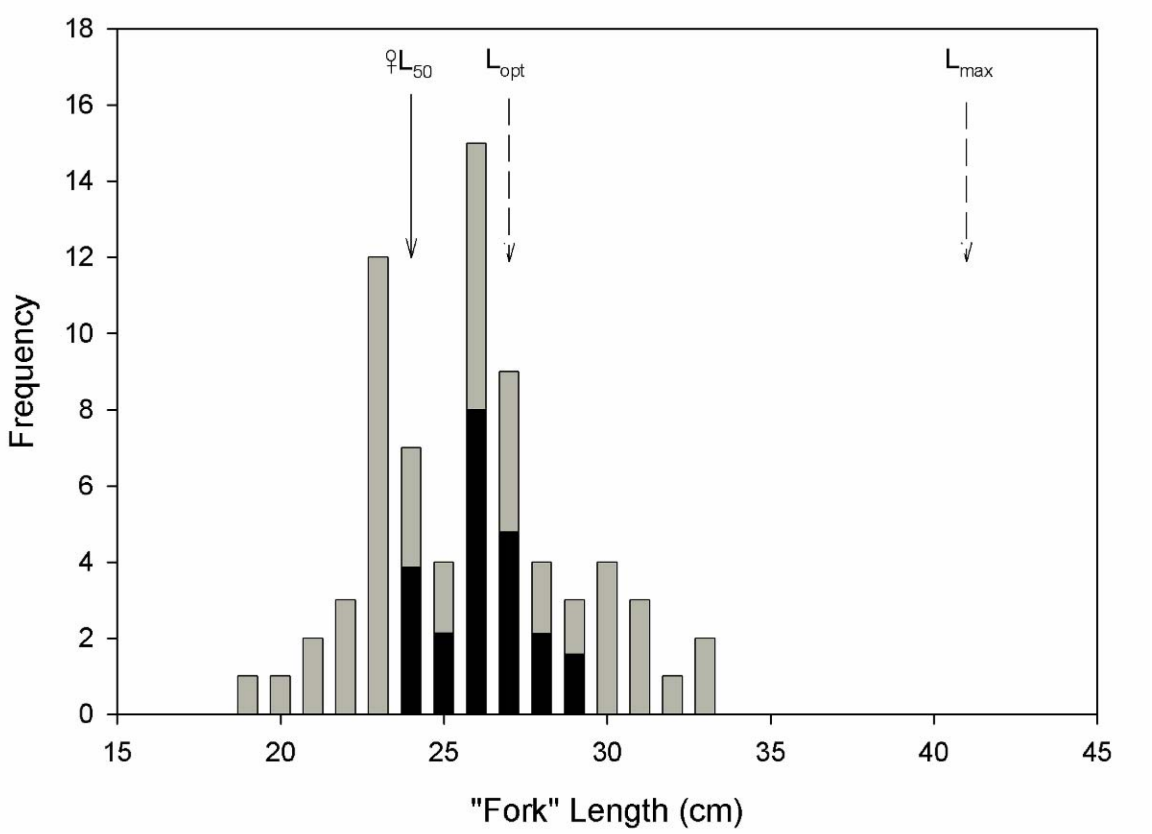


**Figure 111. Size structure of *Siganus lineatus*. The dark portion of bars represent estimated number of mature females, light portion represents all other individuals**.

***Siganus puellus* (Schlegel, 1852)** or ***indaŋa***. Figure 112.

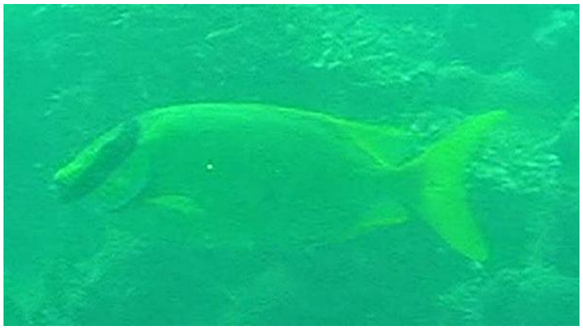


**Figure 112. *Indaŋa* (*Siganus puellus*). Laser dots are separated by 39 mm.**

No new specimens were added to our data set in 2012, leaving a total three (3) individuals captured on video suitable for length estimation. Due to low sample size, a size distribution is not presented. However, mean fork length is 22 cm, which is 58% of the estimated maximum length of 38 cm, and 88% of estimates of optimum length and female $L_m$, both 25 cm.

***Siganus vulpinus* (Schlegel & Müller, 1845)**; Kala name not yet recorded. Figure 113.

**Figure 113. *Siganus vulpinus*. Laser dots are separated by 31.5 mm.**

A total four (4) specimens were captured on video from 2009 to 2012. Due to low sample size, a size distribution is not presented. However, mean total length is 16 cm, which is 53% of the estimated maximum length of 30 cm, and 80% of estimates of optimum length and female $L_m$, both 20 cm.

### *Catch Characteristics and Fishery Selectivity*

A size-frequency histogram of *iyayaŋ kurĩ naba* (*Lutjanus fulvus*) caught by village residents participating in our fishing program from February through June 2012 is presented in Figure 114. We assume the catch is representative of normal village fishing practices. A t-test indicated average length (16.4 cm FL) was significantly lower than the at-large population mean of 18.2 cm. Harvest of *Lutjanus fulvus* at KWMA appears to select smaller individuals. Average fork length is 34% lower than the estimated optimum length ($L_{opt}$) of 25 cm and 13% lower than the observed female $L_{50}$, of 19 cm. A one-sample t-test indicates average size is significantly lower than $L_{opt}$ and female $L_{50}$. Only 1.6% of individuals were within 10% of $L_{opt}$.

When size-specific sex ratios and sex-specific maturity parameters are considered, 58% of the catch was mature individuals. However, males mature at a smaller size than females (13.5 and 18.8 cm FL, respectively; Longenecker *et al*. in review). Thus 44.7 percent of the catch was mature males, whereas 13.4 % of the catch was mature females. So, although the majority of the catch is composed of mature individuals, current fishing practices are biased toward mature males.

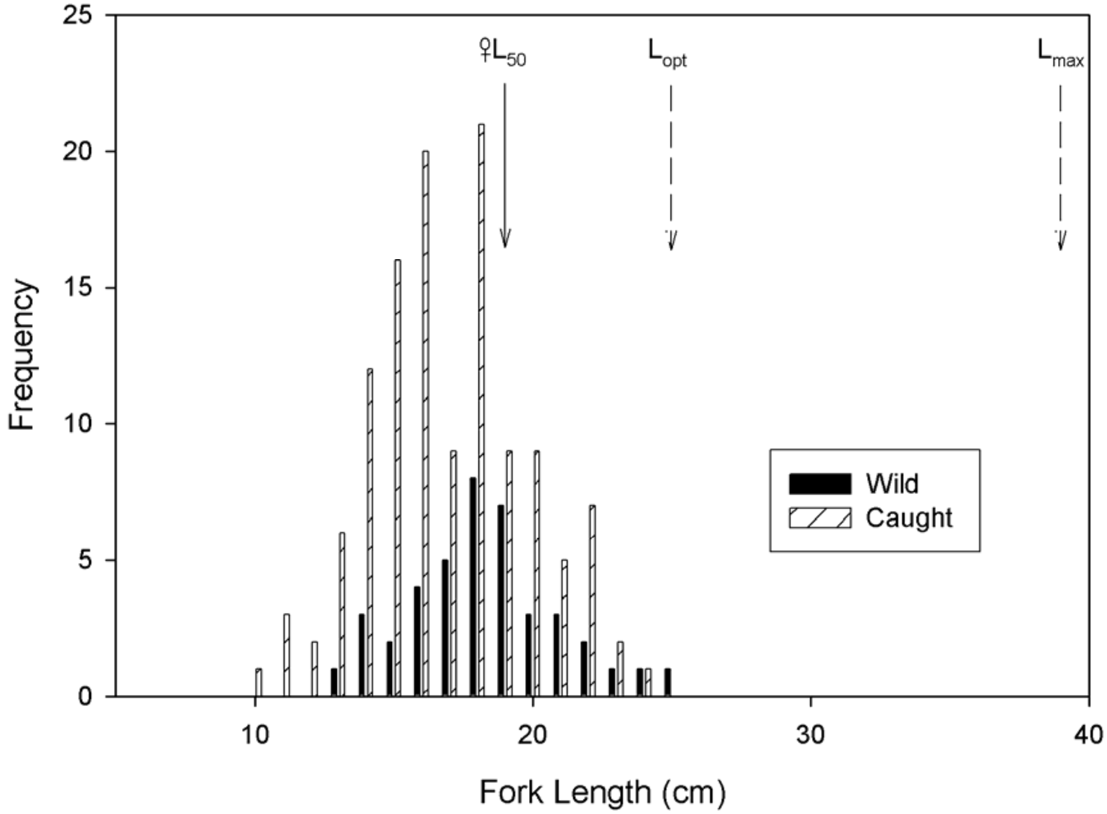


**Figure 114. Size structure of fish catch (dark bars) and at-large population (hashed bars) for *iyayaŋ kurĩ naba* (*Lutjanus fulvus*) at Kamiali Wildlife Management Area.**

***Time Series***

Plots of annual average length estimates are presented in Figure 115 for *luduŋ ŋai* or *mai* (*Caesio cuning*), *ikula sa* (*Cephalopholis cyanostigma*), *itale* (*Lutjanus biguttatus*), *iwaŋgale* (*Parupeneus barberinus*), and *iwaŋgale bote* (*Parupeneus multifasciatus*). Three-year moving averages suggest that the size of four species is relatively stable. Only *iwaŋgale bote* (*Parupeneus multifasciatus*) appears to be decreasing in size. However, we only have two points for the 3-year moving averages.

Mean lengths for all but *iwaŋgale* (*Parupeneus barberinus*) are less than size at female maturity. For three of these species [*ikula sa* (*Cephalopholis cyanostigma*), *itale* (*Lutjanus biguttatus*), and *iwaŋgale bote* (*Parupeneus multifasciatus*)] mean length is within a few centimeters of female reproductive size. The greatest difference is seen for *luduŋ ŋai* or *mai* (*Caesio cuning*). However, this difference is based on an estimated size-at-maturity (rather than values obtained by reproductive analysis as for the other species).

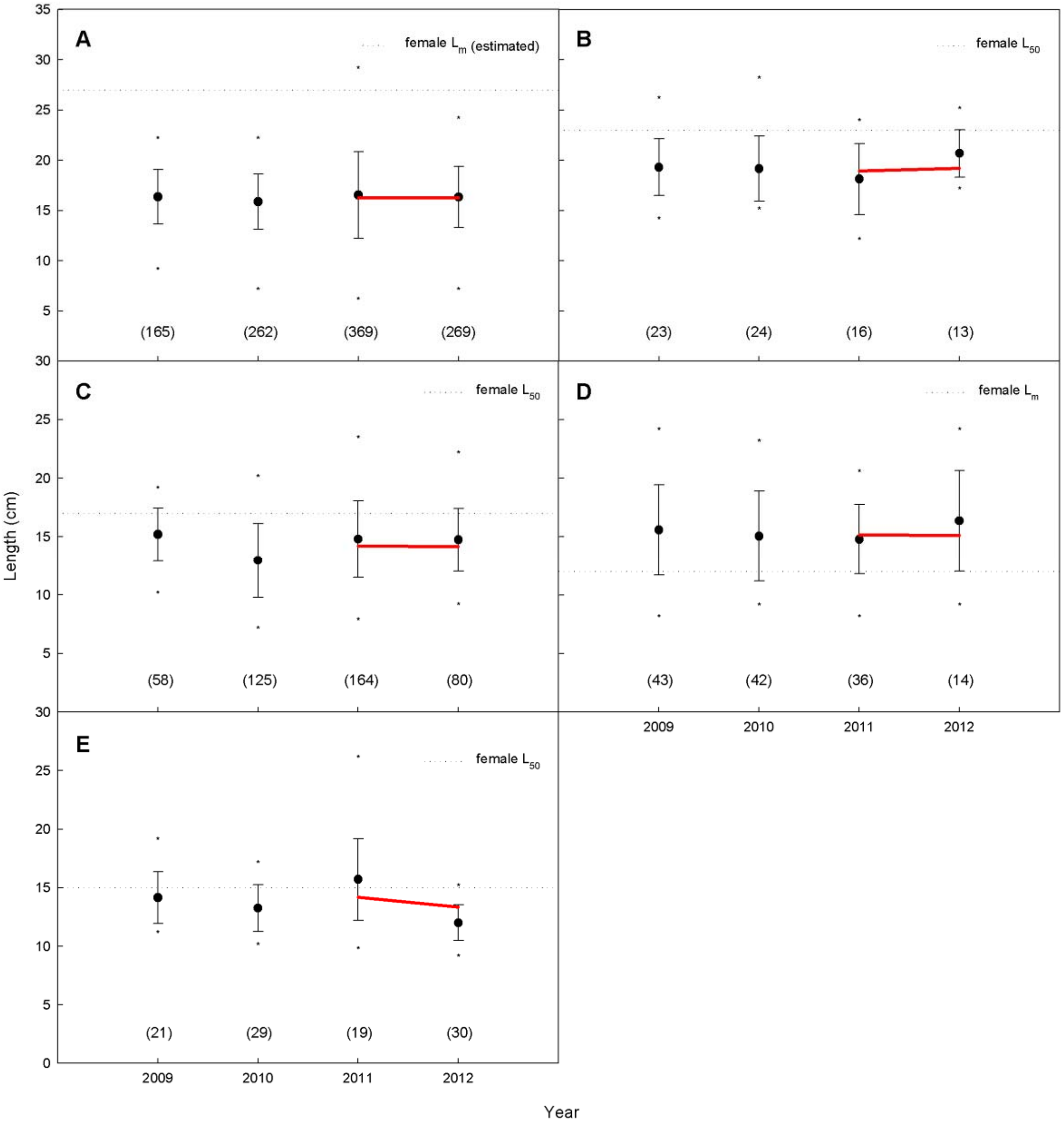


**Figure 115. Time-series plots of average length. Red lines = 3-year moving average; solid circles = annual means; vertical bars = standard deviation; asterisks = minima and maxima. A) *luduŋ ŋai* or *mai* (*Caesio cuning*), B) *ikula sa* (*Cephalopholis cyanostigma*), C) *itale* (*Lutjanus biguttatus*), D) *iwaŋgale* (*Parupeneus barberinus*), E) *iwaŋgale bote* (*Parupeneus multifasciatus*).**

## DISCUSSION

### *Reproductive Analysis*

We generated histology-based reproductive information for four exploited fishes at Kamiali Wildlife Management Area (KWMA). Three of these species have broad geographic ranges [*imbilĩ tombo gabo* (*Myripristis adusta*), *italawe* (*Kyphosus cinerascens*), and *iyayaŋ kurĩ naba* (*Lutjanus fulvus*)]. Thus, the results of our reproductive analyses provide crucial information for the conservation and management of reef fishes throughout the Indo-Pacific region. The fourth species, *ikula su tatalõ* (*Plectropomus oligacanthus*), is known only from the Western Pacific (*i.e.*, the Coral Triangle). However, it is considered Near Threatened because it is overexploited for subsistence fishing and exported for the live-reef-fish trade (Cabanban *et al.* 2012). Given that very little has been published on the biology of this rare species (Heemstra & Randall 1993, 1999), any information should be useful for its recovery.

A thorough analysis of reproduction in *iyayaŋ kurĩ naba* (*Lutjanus fulvus*) is presented in Longenecker *et al.* (in review). Unfortunately, village fishing efforts within KWMA in 2012 resulted in too few specimens for detailed reproductive analyses for the remaining three species [*italawe* (*Kyphosus cinerascens*), *imbilĩ tombo gabo* (*Myripristis adusta*), and *ikula su tatalõ* (*Plectropomus oligacanthus*)]. However, the specimens we did obtain provide preliminary estimates of minimum size-at-maturity ($L_m$) and fecundity for two species.

All eight (8) *ikula su tatalõ* (*Plectropomus oligacanthus*) specimens we examined were females, all were smaller than estimated $L_m$ (based on Froese & Binohlan 2000), and none of them were mature. It is possible that none of these specimens showed evidence of reproductive activity because collections were not made during spawning season or lunar phase; however, until more-detailed reproductive analysis is completed, it seems most-prudent to use the estimated $L_m$ of 42 cm FL derived from the equation of Froese and Binohlan (2000).

For *imbilĩ tombo gabo* (*Myripristis adusta*) and *italawe* (*Kyphosus cinerascens*), observed minimum female size-at-maturity ($L_m$) was 2-cm smaller than estimates derived from the predictive equation of Froese and Binohlan (2000). Our $L_m$ estimates may be revised lower as more specimens are obtained. Longenecker *et al.* (in review) report that for *iyayaŋ kurĩ naba* (*Lutjanus fulvus*), the more-conservative size-at-50%-maturity ($L_{50}$) for females is 7-cm shorter than $L_m$ predicted by the equation of Froese and Binohlan (2000). These results are consistent with earlier observations that the predictions based on Froese and Binohlan (2000) systematically overestimate female size-at-maturity for exploited fishes at KWMA (Longenecker *et al.* 2011). On the basis of results to date, the equation overestimates female $L_m$ of 12 species for which $L_m$ is known. Further, the degree of overestimation increases as maximum size increases. Given that $L_{50} \geq L_m$, we find it even more remarkable that $L_m$ estimated from the predictive equation is higher than 13 of 15 observed values of female $L_{50}$. As above, the degree of overestimation increases as maximum size increases. These comparisons highlight the need for continued life-history work, particularly where conservation efforts must be balanced with against subsistence-fishing needs. If reproductive size is the basis of conservation and management decisions (*e.g.*, minimum catch size = reproductive size), using estimates of size-at-maturity may be counterproductive at KWMA. The estimates would unnecessarily raise minimum catch size, perhaps making it more difficult to catch food (in a manner consistent with conservation guidelines) and ultimately leading to lower compliance. On the other hand, decisions based on more-accurate species-specific life-history analysis should be more-readily accepted.

***Catch Characteristics***

The value of life history analysis is further demonstrated by our ability to model the outcome of fishery management/conservation proposals relative to current fishing practices. These models allow us to explore ways that subsistence fishers can maintain their current harvest levels while simultaneously promoting larger fish populations. We present information in terms of weight (important to villagers that depend on fish for their primary source of protein). More importantly, this information can be easily understood by non-specialists (*e.g.*, village residents who control marine resources at KWMA and will ultimately be responsible for any conservation/management decisions).

Below we compare current fishing practices to the hypothetical harvest under a combination of two of Froese's (2004) suggested fishing practices (all fish in the catch are mature and within 10% of estimated $L_{opt}$). With reliable estimates of size at maturity, length-weight relationships, and population size structure; we can calculate the number of fish that must be caught to obtain a yield (in weight) equal to current fishing practices.

Harvest of *iyayaŋ kurĩ naba* (*Lutjanus fulvus*) at KWMA appears to select smaller individuals; average size of a fish in the catch was significantly shorter the than the average size of free-swimming individuals captured on video. Likewise, average length of the catch was significantly shorter than $L_{opt}$ and female $L_{50}$. A total 123 fish ranging from 8.6 – 23.3 cm FL (average = 16.4 cm) yielded 10.64 kg.

Lengths within 10% of $L_{opt}$ are 23 – 28 cm FL, and all individuals within this size range would be mature. Linear regression analysis of the free-swimming population structure indicates that, at lengths > $L_{50}$, the number of individuals in each 1 cm size class is 42.3% of the number of individuals in the previous size class (*i.e.*, the number of individuals decreases 57.7% from one size class to the next). If we assume that fish catch reflects the population structure of the free-swimming population (*i.e.*, the number of each fish in each 1-cm size class is proportional to frequencies in the at-large population), residents can obtain the same 10.64 kg by harvesting only 45 fish distributed among 23 – 28 cm size classes.

The above guidelines, based on $L_{opt}$ estimated from maximum reported length, are probably unrealistic; the largest fish in the catch was 23 cm FL and the largest fish in the free-swimming population was 25 cm FL. Thus village residents are unlikely to catch fish in the larger half of the 23 – 28 cm size range. Fortunately, Froese and Binohlan (2000) offer an equation to estimate $L_{opt}$ based on size-at-maturity. This alternative estimate would be based on observed parameters observed at KWMA, rather than the maximum length of the species throughout its broad geographic range. Given the genetic distinctiveness of *Lutjanus fulvus* in the eastern part of its range (Gaither *et al*. 2010), using site-specific parameters seems appropriate. On the basis of female $L_{50}$, $L_{opt}$ is 19.3 cm. Lengths within 10% of $L_{opt}$ are 17 – 21 cm FL, but because $L_{50}$ is 19 cm, harvest consistent with Froese's (2004) guidelines would only include fish between 19 and 21 cm FL. Again, assuming fish catch reflects the population structure of the free-swimming population, residents can obtain the same 10.64 kg by harvesting only 80 fish distributed among the more realistic 19 – 21 cm size classes.

Because no immature fish are harvested under the above criteria, individuals below size at female maturity (73% of the current catch) remain in the free-swimming population. This should result in more reproductive individuals at KWMA. Thus, village residents can obtain the same amount of food and promote population growth of *iyayaŋ kurĩ naba* (*Lutjanus fulvus*) at KWMA by shifting fishing efforts to the 19 – 21 cm size classes.

***Fishery Surveys***

Most of the size-structure information presented above should be viewed as preliminary. For 69% of the species included in our laser-videogrammetry surveys, we captured too few individuals on video to describe population size structure, mean size changed with the addition of new specimens in 2012, or we did not capture additional individuals in 2012 and thus could not detect changes in mean length estimates. For these species, additional data would lead to more robust population characterizations. For 23 species, there was no change in average length estimates between 2011 and 2012. This suggests that our population characterizations are suitably robust for these species. We include *luduŋ ŋai* or *mai* (*Caesio cuning*), *imaŋalẽ babaura* (*Carangoides bajad*), *imaŋalẽ tombo gabo* (*Carangoides plagiotaenia*), *imaŋalẽ talã* (*Caranx melampygus*), *iyabua sa* (*Plectorhinchus lineatus*), *imbilĩ tombo gabo* (*Myripristis adusta*), *imbilĩ godõ nambĩ* (*Myripristis kuntee*), *imbilĩ yakẽ bumbu* (*Myripristis violacea*), *imbilĩ sa* (*Neoniphon sammara*), *italawe* (*Kyphosus cinerascens*), *labaikã taloŋ* and *labaikã* (*Monotaxis grandoculis*), *itale* (*Lutjanus biguttatus*), *iyayaŋ* (*Lutjanus boutton*), *babaura* (*Lutjanus carponotatus*), *iyayaŋ kurĩ naba* (*Lutjanus fulvus*), *imawe* (*Lutjanus semicinctus*), *iwaŋgale* (*Parupeneus barberinus*), *iwaŋgale bokole* (*Parupeneus cyclostomus*), *iwaŋgale bote* (*Parupeneus multifasciatus*), *itaŋgi talaloŋa* (*Gymnosarda unicolor*), *ikula sa* (*Cephalopholis cyanostigma*), *ikula yuyeŋ* (*Cephalopholis microprion*), and *yulawe* (*Siganus lineatus*) in this group.

Results from a literature review indicate that remarkably little is known about reproductive parameters for these coral reef fishes. In 2009, size at maturity was known for only 27% of species examined (Longenecker *et al*. 2009). In 2010, the number increased to 41% (Longenecker *et al*. 2010). In 2011, there was a slight increase to 42%. That small increase was a function of adding 16 species to our fishery surveys. In 2012, size at maturity is known for 49%. Reproductive parameters continue to be unknown for more than half of the exploited reef-associated fishes examined at Kamiali Wildlife Management Area. This lack of information is a common problem for coral-reef fisheries, even in developed countries. Longenecker *et al*. (2008a) report that size at maturity is unknown for 38% of the 13 most-heavily exploited reef fishes in Hawaii. It is impossible to evaluate the breeding status of a population or create biologically meaningful management strategies when this information is lacking.

Estimating the proportion of mature females in a population is further hindered by the scarcity of information on size-specific sex ratios. Of the 13 species at KWMA for which data on size-specific sex ratios exists, the proportion of males in a population increases with length for 62% (Davis & West 1992; Ferreira 1995; Longenecker & Langston 2008; Williams *et al*. 2008; Heupel *et al*. 2009, 2010; Longenecker *et al*. 2011). The same trend would be expected for protogynous fishes (*e.g.*, Scaridae, Serranidae, and Labridae) and is seen in many groupers (Loubens 1980). Elsewhere in the Pacific the same pattern was found in each of four of five species examined (Longenecker & Langston 2008, Longenecker *et al*. 2008b, Langston *et al*. 2009). Because females can be absent from larger size classes of these species, the reproductive status of any population would be better understood if size-specific sex ratios are known.

Given the above caveats, a typical individual in the exploited reef-fish community at Kamiali Wildlife Management Area is 52% of its maximum length (the same value reported in Longenecker *et al*. 2010, 2011) and 80% of its estimated optimum length (a decrease from the 84% reported in Longenecker *et al*. 2011). In the subset 23 species for which female $L_{50}$ is known, a typical individual is 92% of female reproductive size (an increase from the 91% reported in 2011, but lower than the 104% reported in 2010). Notably, no individual of two of the larger species considered in this subset [*godobo manibarã/tarõ* (*Diagramma pictum*) and *ikula su mani balã* (*Plectropomus areolatus*)], was of mature size. Of the remaining 51 species for which $L_m$ (either published or estimated) is our only indicator of female reproductive size, an average individual is 80% of size-at-maturity. Considering sex ratios, known for 23 species, approximately 26% of a population, on average, is composed of mature females. This is an increase from our estimate of 25% for 12 species considered in 2011 (Longenecker et al. 2011) and our 2010 estimate of 20% for 7 species (Longenecker *et al*. 2010). The inter-annual fluctuations in estimates of percent female reproductive size and percent mature females suggest more reproductive analysis is needed before robust statements about the reproductive status of exploited fish populations at KWMA can be made.

### *Time Series*

The above information (relative to maximum and optimum lengths) provides important baselines that can be used to detect future shifts in reef-fish populations. However, the static nature of the average-length information does little to identify long-term trends. To address this limitation, we plotted a time series of average-length data for the more-common exploited reef fishes. Although of limited duration, we also plotted 3-year moving averages to smooth short-term fluctuations and highlight longer-term trends (Figure 115). Average length appears stable for four of five species [*luduŋ ŋai* or *mai* (*Caesio cuning*), *ikula sa* (*Cephalopholis cyanostigma*), *itale* (*Lutjanus biguttatus*), *iwaŋgale* (*Parupeneus barberinus*)]. Our limited observations suggest a declining average length for *iwaŋgale bote* (*Parupeneus multifasciatus*). Additional monitoring is needed to fully evaluate the trends.

Mean lengths of four species are greater than [*iwaŋgale* (*Parupeneus barberinus*)] or within a few centimeters of [*ikula sa* (*Cephalopholis cyanostigma*), *itale* (*Lutjanus biguttatus*), and *iwaŋgale bote* (*Parupeneus multifasciatus*)] reproductive length. On the other hand, average length of *luduŋ ŋai* or *mai* (*Caesio cuning*) is 9 cm (or ~ 40%) shorter than estimated reproductive length. Of the five species used for time-series analysis, this is the only one whose size-at-maturity is estimated from a predictive equation (Froese & Binohlan 2000). This equation uses maximum length as the predictor variable, and the literature suggests maximum length is 42 cm FL (Allen & Swainston 1993). However, of 1,065 individuals captured on video, the maximum length we observed at KWMA is 29 cm. Thus, the $L_m$ value we used may grossly overestimate actual size-at-maturity for this species. We suggest reproductive analysis of *luduŋ ŋai* or *mai* (*Caesio cuning*) should be a priority for future work.

### *General Conclusions*

To give the above information immediate conservation relevance, it must be viewed in the context of the village's subsistence fishing practices and needs. Historically, there was no strong need to regulate marine resources use to avoid over-exploitation along the Huon Coast (Kinch 2006). Today, two canoes, on average, engage in fishing at KWMA at any one time during the day (Longenecker *et al*. 2008c). Thus, the ~600 residents of KWMA appear to obtain their primary source of dietary protein with relative ease. We present this as evidence that overfishing is not occurring on the coral reefs of Kamiali Wildlife Management Area (with the possible exception of some larger-bodied species for which we rarely observed reproductively sized individuals). If our assertion is correct, average lengths of ½ maximum size can be used as evidence of robust fish populations.

In general, people along the Huon Coast have little pragmatic concern for the environment (Kinch 2006). Despite the apparent lack of overfishing at Kamiali Wildlife Management Area, residents do not consider themselves practitioners of reef-fish conservation.

There are no gear restrictions, creel limits, minimum or maximum size limits, or seasonal closures for any species (Longenecker *et al*. 2009). Nor are Kamiali residents prohibited from fishing in any part of KWMA. Finally, because of severe barotrauma to fish caught by handline in deeper water (Longenecker *et al*. 2008c), small individuals are not returned to the water. In other words, life-history-based fishery-management methods are not currently used at KWMA.

We suggest that life-history-based methods would be appropriate for populations with few reproductive-sized individuals. However, the necessary life-history information must be generated and disseminated. KWMA is rapidly approaching the point where sufficient reproductive information is available (and, in fact, has become a major source of reproductive information for Indo-Pacific reef fishes). In 2009, size-at-maturity was known for only 27% of 33 species. Today, size-at-maturity is known for 49% of 74 species. In other words, absolute and relative numbers have increased dramatically over a four-year period. We suggest the most-effective way to disseminate reproductive information to KWMA residents (and neighboring Kala-speaking villages) is through the production and distribution of "fish-measuring tapes". These would be durable, waterproof, meter-long measuring tapes. Fish names and images would be printed on the tape at points corresponding to size-at-maturity. Thus, fishers would have a convenient means of determining whether a fish is mature. Further, a measuring tape is likely to be used for a variety of purposes. When used, these tapes would reminder KWMA residents to harvest only mature fish.

Until the time that this and other life-history-based management techniques are enacted, we think preserving aspects of village life consistent with marine conservation will be the most effective way to promote robust fish populations at KWMA. Several characteristics of the village and its fishery appear to reduce the risk of overfishing. Those are reproduced below (from Longenecker *et al*. 2011):

1) Customary tenure. Outsiders are prohibited from fishing within Kamiali Wildlife Management Area, making it a *de facto* limited-entry fishery.
2) Distance to commercial markets. Kamiali is 64 km from the city of Lae, the nearest place where fish can be sold commercially. Cinner & McClanahan (2006) suggest proximity to markets (<16 km) increases the likelihood of overfishing in Papua New Guinea. Commercial fishing in Kamiali presents an economic challenge. Because there are no roads, individuals selling fish must have a motorized vessel to transport fish to market. The cost of operating these is high; a liter of fuel can cost up to $2 (US). Based on our own travels to the village on these vessels, approximately 100 liters of fuel is used in a typical round trip, resulting in an overhead cost of about $200 (US) per commercial sale. Because there is no electrical service in Kamiali, ice must be purchased in Lae. Therefore, economic success in commercial fishing requires that a sufficient quantity of fish be caught before ice melts, and that market prices justify a costly trip to Lae. Variability in catch rate and market prices in the face of high fuel costs thus presents a significant barrier to entry in commercial fishing.
3) Subsistence economy. Because cash is limited, technologies that may lead to fishery overexploitation are cost-prohibitive. Fishing is done primarily from small, human-powered, handmade, outrigger canoes (Longenecker *et al*. 2008c). Transportation to bottom-fishing sites and propulsion while trolling requires a significant input of human energy. Hook-and-line fishing with homemade handreels and weights, or handcrafted outriggers, is the dominant fishing technique. Two spearing methods are also used. Most common is aerial hand-launching of bamboo poles fitted with metal tines (Longenecker *et al*. 2008c). Catching fish by this method appears to be infrequent. Less common are homemade

4) Plant-based diet. Although fish is the major source of dietary protein consumed by Kamiali residents, the majority of their calories are derived from fruits and vegetables grown in swidden gardens. Time spent fishing is limited by the need to conduct labor-intensive gardening.
5) Family and community obligations. As above, time spent fishing must be balanced against other time-intensive activities. These include building and repairing houses and canoes (both made from materials harvested from the surrounding forests), and attending community meetings.
6) Tidal cycles. Poison fishing is limited. The use of *Derris*, a native plant containing the non-selective ichthyocide rotenone, is limited to reef flats during lowest-low tides. This timing appears to be driven by the desire to maximize catch; extreme low tides create pools of still water where poison can be concentrated but fish cannot escape. Higher water during the majority of a lunar cycle effectively prohibits use of the method most of the time.

The factors listed above do not act in isolation. Distance to market is negatively related to the likelihood that a community will exclude outsiders from exploiting its marine environment. On the other hand, communities that subsist on marine resources may be more likely to exclude outsiders (Cinner 2005).

Ongoing and anticipated changes at Kamiali may threaten the sustainable use of its coral-reef fishes. The community is undergoing a transformation from a common-property system to a cash-based economy (Wagner 2002), and lower dependence on marine resources may reduce the likelihood that a community employs exclusionary marine tenure regimes (Cinner 2005). Cinner *et al*. (2007) indicate that customary management is at risk during economic modernization such as that underway at Kamiali Wildlife Management Area. They suggest that marine conservation initiatives based on customary tenure are more likely to succeed if organizations help reduce the impact of socioeconomic transformations. The Kamiali Initiative, by establishing a pathway to economic development that is based on effective environmental conservation, is helping to maintain a traditional lifestyle as the village economy changes.

Continued conservation success at KWMA will be sustained by information, such as that presented above, necessary to make science-based environmental-management decisions. We maintain that more life-history research is the most productive pathway to future reef-fish conservation at Kamiali Wildlife Management Area and throughout the Indo-Pacific region.

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