Population Size Structure and Rapid Reproductive Analysis of Exploited Reef-fish Populations at Kamiali Wildlife Management Area, Papua New Guinea

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Honolulu, Hawaii
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COVER

Kamiali resident, Utula Kondio, assists Bishop Museum's Ross Langston and Holly Bolick process specimens for rapid, on-site reproductive analysis.

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Contents

List of Tables

List of Figures

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. This area – which includes approximately 120,000 acres of terrestrial and marine habitat – is larger than most of the state parks of California and is globally significant, with numerous endemic plants and animals. The success of the Kamiali Initiative is contingent upon Kamiali villagers preserving the natural environment such that biological field researchers are motivated to work in the area. This project is arguably the most successful large-scale terrestrial/marine biodiversity conservation project implemented in Papua New Guinea and it is the only such project that is fully sustainable.

The most challenging conservation issues at Kamiali relate to coral reef fishes. Fish comprise the overwhelming majority of dietary protein for this coastal village, and coral-reef habitats are preferred fishing sites. Thus, fishing practices must balance the conflicting needs of conserving fish populations to attract research against the subsistence needs of Kamiali residents.

Here we describe the status of Kamiali's exploited reef-fish populations to help guide and evaluate conservation efforts. We describe a method to rapidly estimate the reproductive parameters necessary for life-history-based management of fisheries, use a combination of advanced diving technology and laser videogrammetry to augment our 2009 descriptions of the size structure of exploited species, expand a literature review of reproductive parameters, estimate (when sufficient information exists) the percentage of reproductive individuals in each population, and estimate the percentage of mature females in populations for which sufficient information exists.

We described the reproductive biology of the small snapper, *Lutjanus biguttatus*, using methods suitable for expeditionary work (*i.e*, where laboratory equipment is limited and electrical service is lacking). Fifty percent of 16 cm (fork length) females are mature, and 50% of 12 cm (fork length) males are mature. Sex ratio was not significantly different from 1:1. There was no evidence for hermaphroditism in this species.

We also described the relationship between total length (TL) and fork length (FL) for three species: for *Myripristis adusta*, FL = -1.598 + 0.942(TL); for *Myripristis vittata*, FL = 1.420 + 0.825(TL); and for *Lutjanus biguttatus*, FL = -0.276 + 0.971(TL).

The above reproductive information and length relationships were generated during a three-week period when we spent the majority of our available time preparing for and conducting fish surveys. Our analyses were limited by the availability of specimens (not processing time), therefore the methods we describe can help fill an information void that prevents life-history-based management of coral-reef fishes.

A total of 926 individuals were captured on video during 2010, yielding a combined total 1709 individuals representing 41 reef-fish species from 13 families (inclusive of 2009 data). The mean length of all individuals was 19 cm, about 52% of the average maximum length of all 33 species. That is, an exploited reef fish swimming in Kamiali Wildlife Management Area is likely to be about ½ its potential maximum length. Size at maturity is known for only 41% of the species studied. Of these, mean individual length was at least 104% of female reproductive size. Sex-ratios are known for only seven species. Considering only these species, an average 20% of individuals are mature females.

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 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 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

Background

The Kamiali Initiative is a project to develop a self-sustaining cycle of environmental conservation, economic development, and scientific research in the coastal community of Kamiali, Papua New Guinea. The foundation of this project is 32,000 ha of terrestrial habitat and 15,000 ha of adjacent marine habitat which the village established in 1996 as the Kamiali Wildlife Management Area.

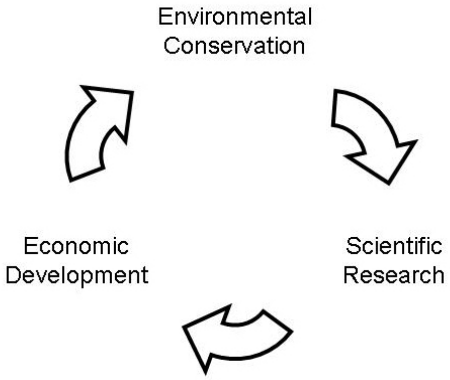

Figure 1. Conceptual illustration of Bishop Museum's conservation initiative at Kamiali Wildlife Management Area.

Although gardening and subsistence fishing form the basis of the Kamiali economy and the focus of village life, residents need money for basic supplies and services (*e.g.*, medicine and education). In August 2007, Bishop Museum and Kamiali leaders signed a Memorandum of Understanding outlining the development of a world-class remote scientific research station. Visiting researchers will pay fees for research permits, lodging, and meals. These fees will cover operating costs at the research station and fund a trust to pay for education and community development. The Kamiali Initiative thus establishes 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, Kamiali villagers must conserve their natural environment such that it continues to attract biological field researchers. As such, village exploitation of coral reef fishes may represent the biggest challenge to this project; fishes comprise the overwhelming majority of dietary protein for this coastal village, and coral-reef habitats are preferred fishing sites. Thus, the village must balance the conflicting needs of conservation to attract research against exploitation for subsistence diets.

Fishery Surveys

The most productive starting point to help the village balance fish conservation and exploitation is a baseline description of the size structure of exploited fish populations. This information has intuitive appeal; Kamiali residents understand that shrinking average fish size may be indicative of unsustainable fishing practices. Length-frequency information is also the basis for science-based fishery management and conservation. When combined with life history parameters, an understanding of population size structure enables predictions about the outcome of various management and conservation actions. Finally, baseline demographic information permits evaluation of the effectiveness of management and conservation efforts.

Rapid Reproductive Analysis

Although detailed descriptions of size structure is the foundation of fishery management and conservation, one of the biggest challenges to converting those data into action is a lack of basic life history information about the majority of exploited fish species. Results from a literature review indicate that remarkably little is known about reproductive parameters for Kamiali's exploited reef fishes. Size at maturity is known for only 27% of 33 species examined (Longenecker *et al*. 2009). This problem is not restricted to Papua New Guinea; many efforts to evaluate the status of exploited coral reef fishes are conducted without basic information such as size at maturity. Longenecker et al. (2008b) 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 when this information is missing.

The sheer diversity of coral-reef fishes, and the purported cost associated with the reproductive analysis of each species are often cited as obstacles 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. However, sound conservation decisions simply cannot be made without estimates of reproductive parameters. We further argue that these estimates should be based on detailed, histological examination of the species of interest; while conducting the present study, we evaluated our accuracy in determining the sex and reproductive status of individual fish based on gross (macroscopic) and fine (histological) examination of gonads. Our gross evaluation misclassified reproductive status and/or sex in 47% of specimens examined.

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. With this method, reproductive parameters can be estimated relatively quickly, and its low cost eliminates one of the arguments against broad-scale reproductive analysis. Because the method can be done rapidly and in the field, it has two additional advantages: 1) it allows reproductive information to be generated when bureaucracy makes exporting biological specimens difficult, and 2) it allows fine-tuning collecting efforts such that important size classes can be obtained while researchers are in the field (*i.e.*, still have the opportunity to collect specimens). Further, providing reproductive information will allow resource owners in developing countries (*i.e.*, villagers) to answer their own questions about how fishing practices may be impacting the marine environment. For instance, "Have fish on the dinner table had the chance to reproduce?" Or, "Are there enough reproductively active fish to insure food for future generations?"

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 in 2009. Length-frequency information will be examined in light of life-history parameters such as maximum length, reproductive size, and sex-ratios. Given the lack of reproductive information (above) for fishes found at Kamiali (and other Indo-Pacific coral reefs) we will present a method for rapidly generating these much-needed parameters. Size-structure surveys will provide important baseline information to allow Kamiali residents to detect changes in fish populations and, when necessary, take action to improve their fish stocks. Providing this information in the context of life history 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 control the distribution and use of land, adjacent marine areas, and the resources contained therein. The northern boundary of the Kamiali Wildlife Management Area is the mouth of the Bitoi River, whereas the Sela River is the southern limit. A third major river, the Alealer, also drains into the management area. 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 Kamiali Wildlife Management Area is remarkably undeveloped and characterized by lush vegetation. Kamiali Village is concentrated along the northern portion, where the shoreline is exclusively sandy beach. The southern shoreline is dominated by fringing reefs on Capes Dinga and Roon. Fringing reefs also surround the islands of Lababia and Jawani. These reefs may abut rocky shoreline or sandy coves. The intertidal zone is dominated by mangroves, mud flats, or seagrass beds. Seaward, the reef flats typically feature carbonate bench or coral beds with occasional patches of sand or rubble. The reef crest features a high abundance and diversity of corals, although occasional beds of rubble composed of coral fragments also occur. The reef face is steep, typically descending 20 to 30 meters, and features corals, consolidated carbonate substrate, and rubble. At the base, fringing 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. These latter features are most frequently targeted by local fishers.

Rapid Reproductive Analysis

We captured specimens with a pole spear, measured fork length (FL) to the nearest mm, and estimated whole body weight with a hanging spring scale. We made a mid-ventral incision from the vent toward the head (through the pelvic girdle) to expose the gonads. We noted sex, based on gross examination, then removed and fixed gonads in a modified Dietrich's solution (30% ethanol,10% formalin, and 2% acetic acid) for 24 h. We cut an approximate 2 mm^3 section from each sample, placed the sections in a 24-well tissue culture plate, and dehydrated them in a graded alcohol series (30 min in each of 50%, 75%, and 95%% ethanol). We placed tissues in Beem capsules (size 00), then infiltrated and embedded them in plastic (JB4- Electron Microscopy Sciences) per kit instructions. Because of the high-humidity in our open-air laboratory often prevented tissue blocks from hardening completely, we removed the cured tissue blocks from the capsules and dehydrated them for 12 h in a desiccating chamber (an airtight container containing silica gel packets).

We distributed 10 drops of water on pre-labeled slides using a 1 cc insulin syringe and attached needle, then obtained 10 tissue sections (approximately 7 µm thick), distributed evenly throughout each tissue block, with an MT1 Porter-Blum microtome outfitted with a glass knife. We floated a tissue section on each of the pre-distributed water drops, and dried the slides on a "warmer" (a glass sheet elevated approximately 2 cm above a dark surface -in our case – sand exposed to direct sunlight). We stained tissue sections (now affixed to slides) in a 0.5% solution Toluidine Blue in water (w/w) for 15 sec. Excess stain was removed with a gentle stream of water and slides were once again dried on the "warmer". Tissue sections were examined at 40X on a dissecting microscope for evidence of reproductive maturity. We classified ovaries according to Wallace & Sellman (1981) and testes according to Nagahama (1983). We considered female fish 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 10 mm size class versus fork length (the average length of individuals within a size class) indicates 50% of individuals are mature.

Fishery Surveys

We conducted 14 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 80 m. Due to the lengthy decompression obligations incurred while working at these depths (*e.g.*, 3 hours for a 20-minute dive to 80 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 (Figure 2, Table 1).

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 (Figure 3). We then reviewed the video with Sony Picture Motion Browser® and captured 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. These size estimates were calculated using

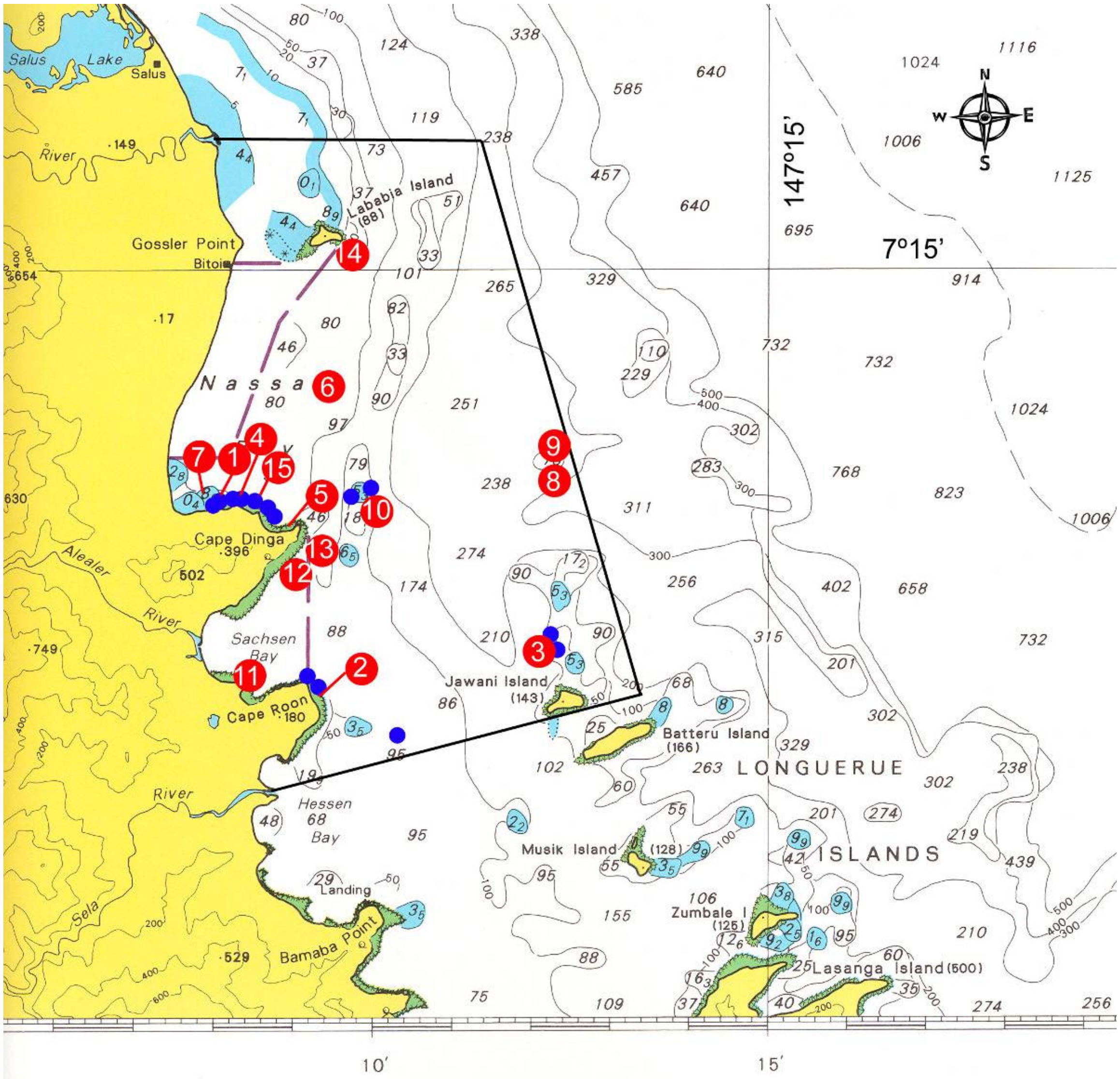

Figure 2. The marine portion of Kamiali Wildlife Management Area (circumscribed in black). Red circles indicate locations of 2010 survey sites (coordinates are given in Table 1). Smaller blue circles indicate 2009 survey sites (coordinates in Longenecker *et al*. 2009). Adapted from chart Aus 523, published by the Australian Hydrographic Service. Depths are in meters.

Table 1. List of marine sites surveyed at Kamiali Wildlife Management Area during 2010. Latitude and longitude were estimated by GPS using the WGS84 datum. FR = Fringing Reef, OP = Offshore Pinnacle.

Survey	Date	Latitude (°S)	Longitude (°E)	Habitat	Max Depth (m)
1	22-May-10	7.30047589	147.13442657	FR	19
2	24-May-10	7.34244375	147.15992055	FR	41
3	25-May-10	7.31865557	147.20658286	OP	61
4	26-May-10	7.30047589	147.13442657	OP	23
5	27-May-10	7.30343722	147.14919423	OP	80
6	28-May-10	7.28663452	147.16413111	OP	30
7	30-May-10	7.30034471	147.13268867	FR	30
8	31-May-10	7.29024687	147.20831296	OP	42
9	1-Jun-10	7.29067376	147.20836024	OP	36
10	2-Jun-10	7.30781249	147.16619248	OP	41
11	3-Jun-10	7.33468973	147.13824260	FR	26
12	3-Jun-10	7.32164866	147.14474872	FR	27
13	4-Jun-10	7.31234408	147.14888267	FR	34
14	5-Jun-10	7.24586545	147.16154781	FR	35
15	6-Jun-10	7.30054362	147.13443931	FR	21

ImageJ software (National Institutes of Health). 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 (Figure 4).

The fishes included in this study 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 41 species representing 13 families (Acanthuridae, Balistidae, Caesionidae, Carangidae, Ephippidae, Haemulidae, Holocentridae, Kyphosidae, Lethrinidae, Lutjanidae, Mullidae, Serranidae, and Siganidae) met these criteria.

The length information presented below is the distance between the front of the head and the end of the middle caudal ray. These lengths correspond to fork length (FL) for acanthurids, balistids, caesionids, carangids, ephippids, holocentrids, kyphosids, lethrinids, lutjanids and mullids; and total length (TL) for haemulids and serranids. This length slightly underestimates total length for siganids, which have an emarginate caudal fin, and is called "fork" length in this report.

A systematic literature review was conducted using the methods of Longenecker *et al*. 2008b 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

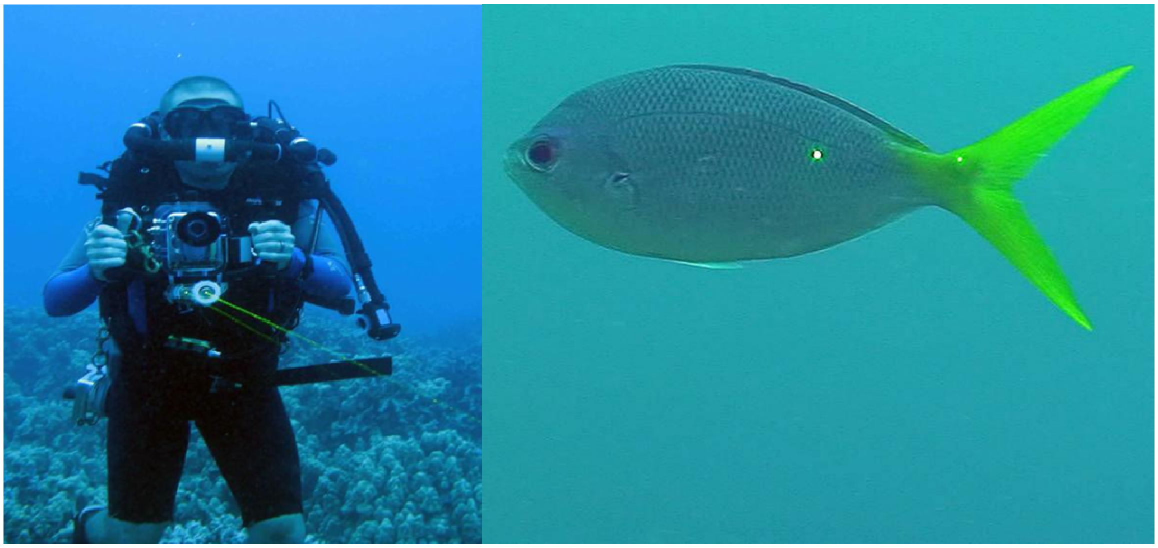

Figure 3. Laser videogrammetry, a non-destructive technique to estimate fish length. A diver operates a video camera fitted with parallel lasers (left); the lasers superimpose a measurement scale on the side of *Caesio cuning* (right).

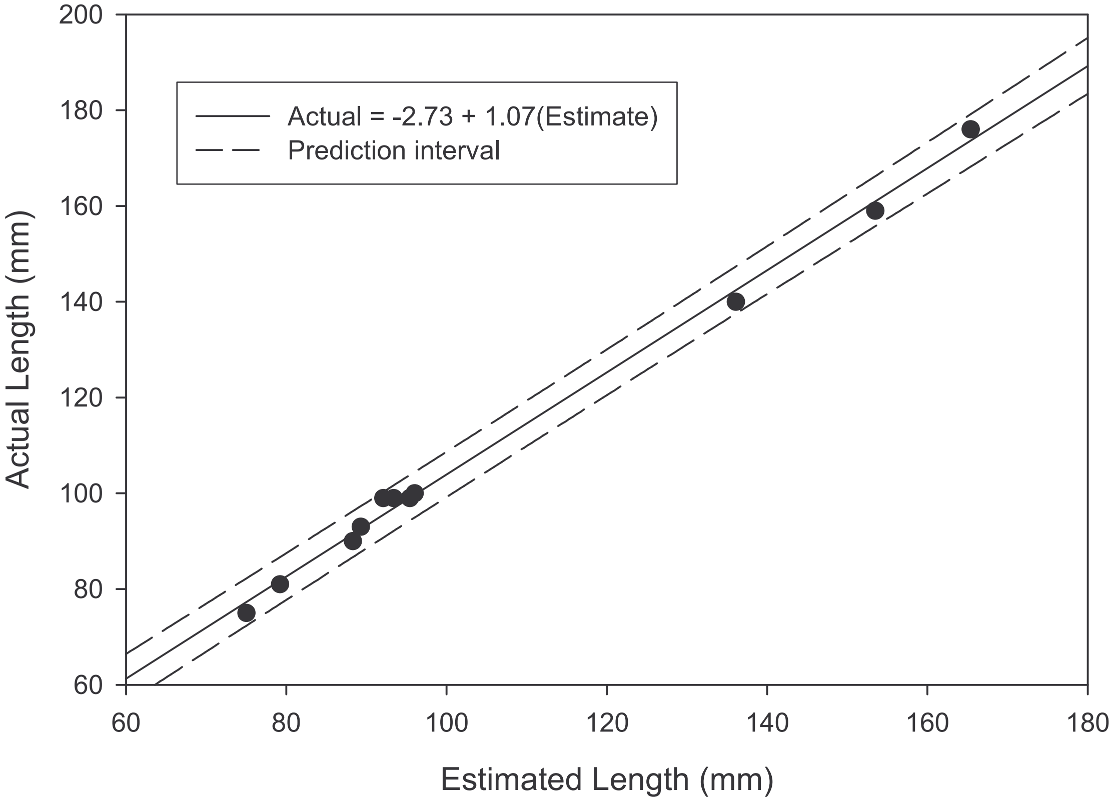

Figure 4. The relationship between estimated and actual lengths of specimens "captured" on videotape for laser videogrammetry and subsequently speared. The prediction interval suggests that 95% of length estimates will be within 0.5 cm of actual fish length (from Longenecker & Langston 2008).

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}), the size class in which 50% of individuals are mature, over other estimates of size at maturity (*e.g.*, minimum size at maturity). Results from studies outside the southern hemisphere were included only when data for southern populations were not available (*e.g.*, reproductive size for *Caranx melampygus*). Conversely, information on spawning seasonality was included only for southern hemisphere populations.

RESULTS

Reproductive Analysis

We histologically examined gonads 16 male and 20 female *Lutjanus biguttatus*. Figures 5 and 6 show examples of immature and mature gonads of males and females, respectively, and serve as examples of the quality of histological preparations we were able to produce in the field.

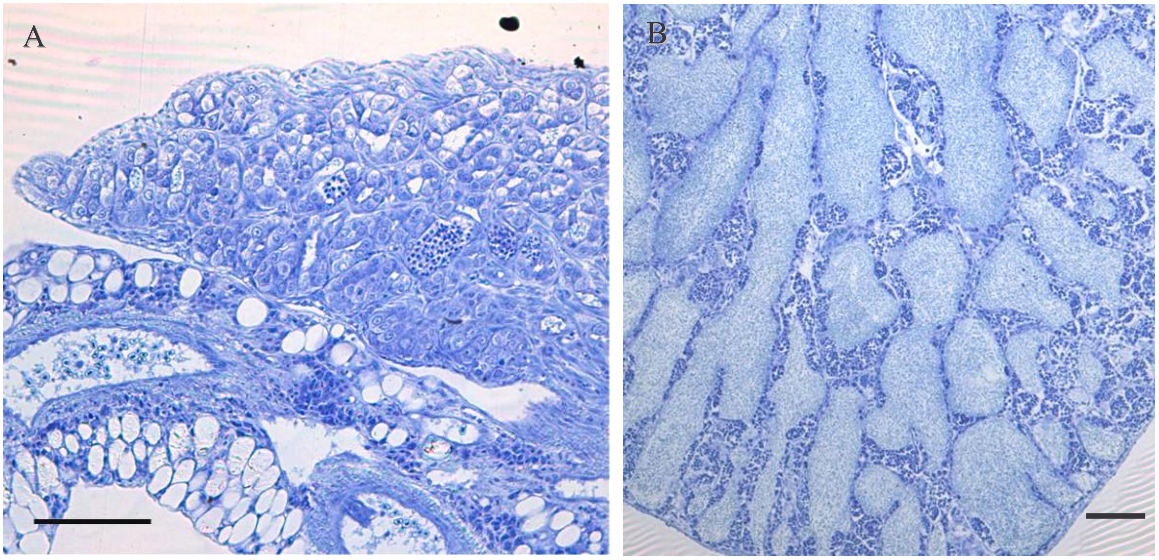

Figure 5. Histological preparations of testes. (A) immature male, 115 mm FL, (B) mature male, 140 mm FL. Scale bars = 100 µm.

The smallest male with spermiated testes was 126 mm FL. This individual was also in the size class containing male L_{50} (125 mm FL, Figure 7). All males ≥ 140 mm were mature. Ovaries contained stage III (vitellogenic) oocytes in females as small as 162 mm FL. Female L_{50} is estimated as 167 mm FL (Figure 7). All females ≥ 186 mm were mature.

Sex ratio in this population, from the size class at male maturity (12 cm) through maximum observed size (19 cm), is 1:1.2 ♂:♀. However, a X^2 analysis indicates the observed ratio is not significantly different from 1:1. Further, regression analysis indicates sex ratio does not vary with size.

We found no evidence for sequential hermaphroditism in *L. biguttatus*. A t-test for a sex-based bimodal size distribution was not significant. Nor did we see classic histological signs of sex change (see Sadovy & Shapiro 1987): testes lacked a lumen or brown bodies, and ovaries did not contain spermatogenic tissue. *Lutjanus biguttatus* is apparently a gonochore.

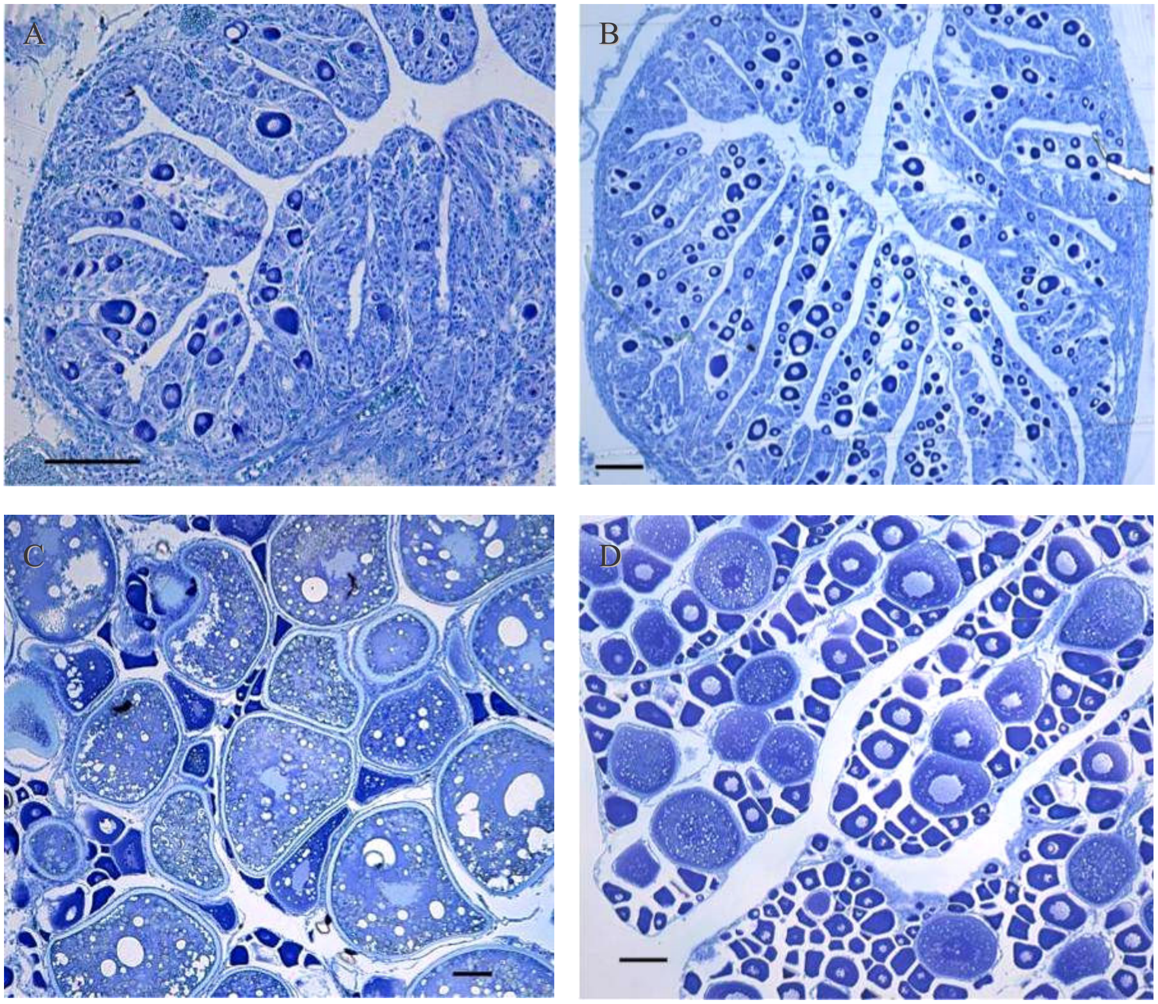

Figure 6. Histological preparations of ovaries. (A) immature female, 93 mm FL, (B) immature female, 117 mm FL, (C) mature female, 162 mm FL, (D) mature female, 164 mm FL. Scale bars = 100 µm.

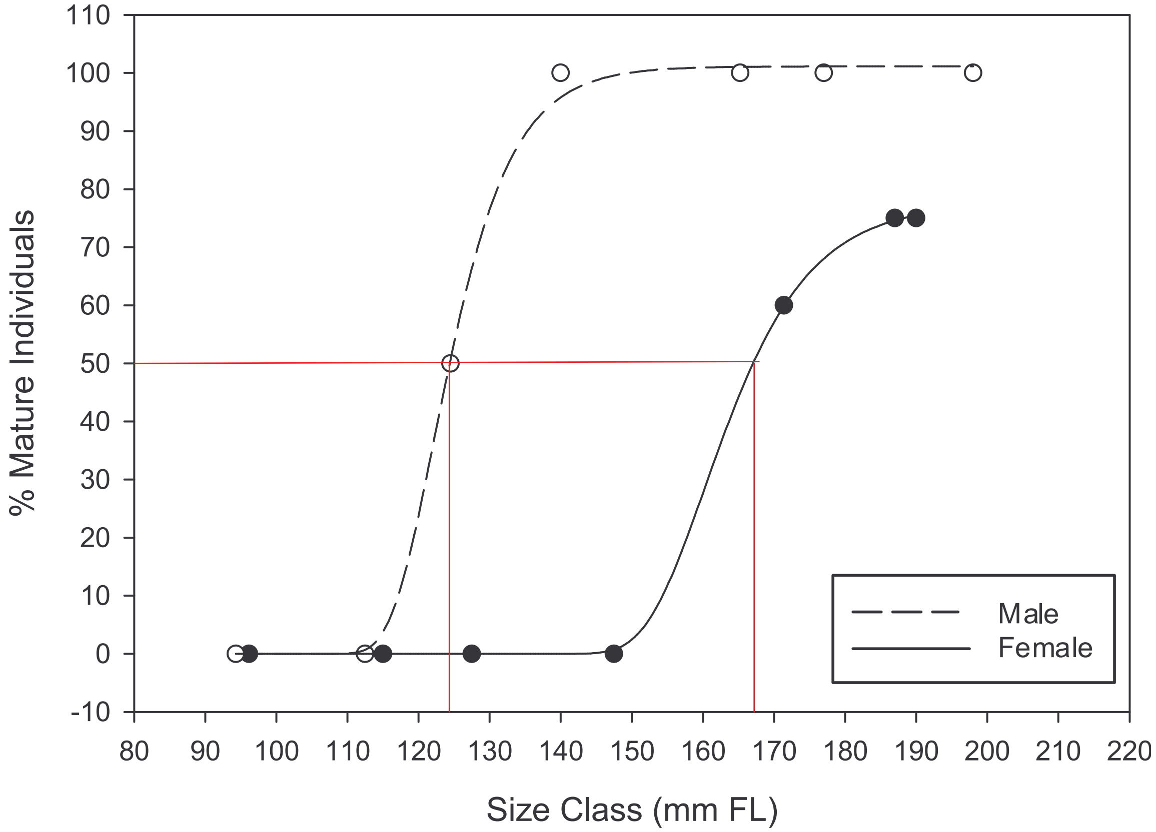

Figure 7. L$_{50}$ for *Lutjanus biguttatus*. 50% of males are mature at 125 mm FL, 50% of females are mature at 167 mm.

Fishery Surveys

In 2010, we captured an additional 926 specimens on video suitable for length estimation, yielding a combined total 1709 individuals analyzed in 2009 and 2010. These specimens include eight (8) species not analyzed in the 2009 survey (Longenecker *et al*., 2009). 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 41 species in Table 2. The mean length of all individuals was 19 cm, representing 52% of the weighted mean maximum length of all 41 species, combined. That is, an exploited reef fish swimming in Kamiali Wildlife Management Area is likely to be about ½ its potential maximum length.

Information about reproduction in these species is remarkably scant. Size at maturity is known for only 41% of the species studied. Of this subset, an individual *Neoniphon samara*, *Lutjanus carponotatu*s, *Lutjanus gibbus, Parupeneus barberinus, Parupeneus trifasciatus, Cephalopholis boenak*, or *C. cyanostigma* in Kamiali Wildlife Management Area was more likely than not to be reproductively mature. However, no individual of the larger *Plectropomus areolatus* had reached maturity. For all species combined, mean individual length was approximately 104% of female reproductive size.

For four of the seven species for which sex ratios have been published (*Lutjanus gibbus, Lutjanus vitta, Parupeneus multifasciatus*, *Plectropomus leopardus)*, larger size classes are increasingly male dominated. For a fifth species, *Lutjanus carponotatus*, the possibility of size-specific sex ratios was not examined (Kritzer 2004). However, sex-specific growth curves indicate males attain a larger size than females, thus sex ratios would become increasingly male biased as length approaches maximum size. Although sex ratios were not examined in the majority of serranid studies, they are all 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 *Plectropomus leopardus*). Applying known size-specific sex ratios to the size structure information generated from laser-videogrammetry surveys study suggests, on average, 16% of the exploited reef fish population is composed of mature females. This estimate is dominated by *Lutjanus biguttatus* (51% of specimens), for which we were unable to examine size-specific sex ratios due to a low sample size. If this species is omitted from the analysis, 21% individuals are mature females.

Demographic information for each of 41 species is presented below. Each species account, with the exception of *Cephalopholis boenak*, includes an *in situ* image from Kamiali Wildlife Management Area. When at least 15 individuals were captured on video suitable for length estimates, these accounts also include size-frequency histograms.

Table 2. Size and reproductive information for common, exploited fishes in Kamiali Wildlife Management Area (updated from Longenecker *et al*. 2009). Values bridging female and male L_{50} columns (*Naso hexacanthus, Cephalopholis cyanostigma* and *Siganus lineatus*) indicate no sex-specific size-at-maturity values were provided.

Taxon	N	Mean length (cm)	L_{max} (cm)	Female L_{50} (cm)	Male L_{50} (cm)	Sex ratio	Spawning season	Reproductive mode
ACANTHURIDAE								
Naso hexacanthus	60	43	71[a,b]	50[b,c]				Gonochore[d]
Naso vlamingii	9	35	51[a,b]					Gonochore[d]
BALISTIDAE								
Canthidermis maculata	13	33	35[a]					Gonochore[d]
CAESIONIDAE								
Caesio cuning	425	16	42[a,b]					Gonochore[e]
CARANGIDAE								
Carangoides bajad	34	26	51[a,b]					
Carangoides plagiotaenia	15	25	38[a,b]					

Caranx melampygus	28	26	72[a,b]	31[f]				Gonochore[f]
Caranx papuensis	6	47	66[b,g]					
EPHIPPIDAE								
Platax pinnatus	5	24	30[a]					
HAEMULIDAE								
Plectorhinchus lineatus	15	36	50[a]					
HOLOCENTRIDAE								
Myripristis adusta	13	18	28[a,h]					Gonochore[d]
Myripristis kuntee	44	12	19[a,i] (TL)					Gonochore[d]
Myripristis violacea	40	13	20[a,i] (TL)					Gonochore[d]
Myripristis vittata	19	11	17[a,j]					Gonochore[d]
Neoniphon sammara	10	14	32[a,i] (TL)	~8[k]			Nov – May[k]	Gonochore[d]

KYPHOSIDAE								
Kyphosus cinerascens	54	30	41[b,g]					
LETHRINIDAE								
Monotaxis grandoculis	43	24	60[a,i] (TL)					
LUTJANIDAE								
Lutjanus argentimaculatus	3	50	118[a,b]	53[l]	47[l]	1♂:1.18♀[l]	Oct – Nov[m], Dec[l]	Gonochore[n]
Lutjanus biguttatus	183	14	19[a,o]	17[p]	13[p]	1:1[p]		Gonochore[p]
Lutjanus boutton	141	14	28[a,b]					Gonochore[n]
Lutjanus carponotatus	15	23	38[a,b]	19[q]		~1:1[q]	Oct – Dec[q]	
Lutjanus fulvus	33	18	39[a,b]					Gonochore[n]
Lutjanus gibbus	19	19	42[a,b]	~16[k]-23[r]		Increasingly male-biased with length[s]	Jan – Apr[k]	Gonochore[n]
Lutjanus russellii	73	22	43[a,b]	22[t]			Aug – Feb[u]	Gonochore[n]

Lutjanus semicinctus	23	19	34[a,b]					
Lutjanus vitta	18	15	37[a,b]	15[v]		Increasingly male-biased > 29 cm[w]	Sep – Apr[w,x]	Gonochore[n]
Macolor macularis	13	30	55[a,b]					
MULLIDAE								
Parupeneus barberinus	85	15	50[a,i] (TL)	~12[k]			Oct – May[k]	
Parupeneus cyclostomus	10	19	50[a,i] (TL)					
Parupeneus multifasciatus	50	14	26[a,y]	15[z]	15[z]	Increasingly male-biased with length[z]		Gonochore[z]
Parupeneus trifasciatus	12	20	35[a,i] (TL)	~10[k]			Sep – Apr[k]	
SERRANIDAE								
Anyperodon leucogrammicus	8	25	52[a]					Protogynous[aa]
Cephalopholis boenak	10	17	24[a]	15[bb]	16[bb]		Apr – Oct[bb]	Protogynous[bb]
Cephalopholis cyanostigma	46	19	35[a]	<14[cc]				Protogynous[aa]

Cephalopholis micropríon	13	13	23[a]					Protogynous[aa]
Cephalopholis urodeta	4	17	27[a]					Protogynous[aa]
Plectropomus areolatus	5	15	70[a]	40[dd]	48[dd]		Jan – May[dd]	Protogynous[aa]
Plectropomus leopardus	3	30	68[a,b]	32[ee]	37[bb]	Increasingly male-biased > 44 cm[ee]	Sep – Dec[ff]	Protogynous[ff]
Plectropomus oligacanthus	37	31	65[a]					Protogynous[aa]
SIGANIDAE								
Siganus javus	33	25	53[g,i] (TL)					
Siganus lineatus	39	26	41[a,b]	>23[gg]			Year round[hh]	Gonochore[bb]

(a) Allen & Swainston 1993; (b) using length-length relationship from Froese & Pauly 2009; (c) Choat & Robertson 2002 (authors do not describe how estimate was obtained); (d) Thresher 1984; (e) Carpenter 1998; (f) Sudekum *et al*. 1991; (g) Randall *et al*. 1990; (h) Present study: FL = 1.420 + 0.825(TL), r^2 = 0.970, n = 6; (i) no length-length relationship available; (j) Present study: FL = -1.598 + 0.942(TL), r^2 = 0.989, n = 8; (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) Russell & McDougall 2008; (m) Pakoa 1998; (n) Allen 1985; (o) Present study: FL = -0.276 + 0.971(TL), r^2 = 0.998, n = 33; (p) Present Study; (q) Kritzer 2004; (r) Heupel *et al*. 2009 (all females > 23 cm FL were mature); (s) results from Heupel *et al*. 2009 suggest the proportion of females is inversely related to size; (t) Kritzer in Williams *et al*. 2002; (u) authors' interpretation of GSI and developmental stages in Sheaves 1995; (v) Davis & West 1993; (w) authors' interpretation of data in Davis & West 1992: sex ratio is 1:1 to 29 cm, then %♀ = 1.986 – 0.00534(FL); (x) Loubens 1980; (y) Longenecker & Langston unpublished data: FL = 0.2121 + 0.8736(TL), r^2 = 0.993, n = 67; (z) Longenecker & Langston 2008, %♀ = 141.3 – 0.6167(FL in mm) with all individuals male above 225 mm; (aa) Heemstra & Randall 1993; (bb) Chan & Sadovy 2002; (cc) Moss *et al*. in Williams *et al*. 2002, no fish smaller than 14 cm were collected for this study and all were mature, maximum female size is 26 cm; (dd) Rhodes & Tupper 2007; (ee) 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; (ff) Ferreira 1995; (gg) Woodland 1990 reports the smallest individual to spawn was 23 cm; (hh) Hamilton *et al*. 2004 report year-round spawning aggregations during the first quarter of the moon phase.

Species Accounts

Acanthuridae

Naso hexacanthus (Bleeker, 1855). Figure 8.

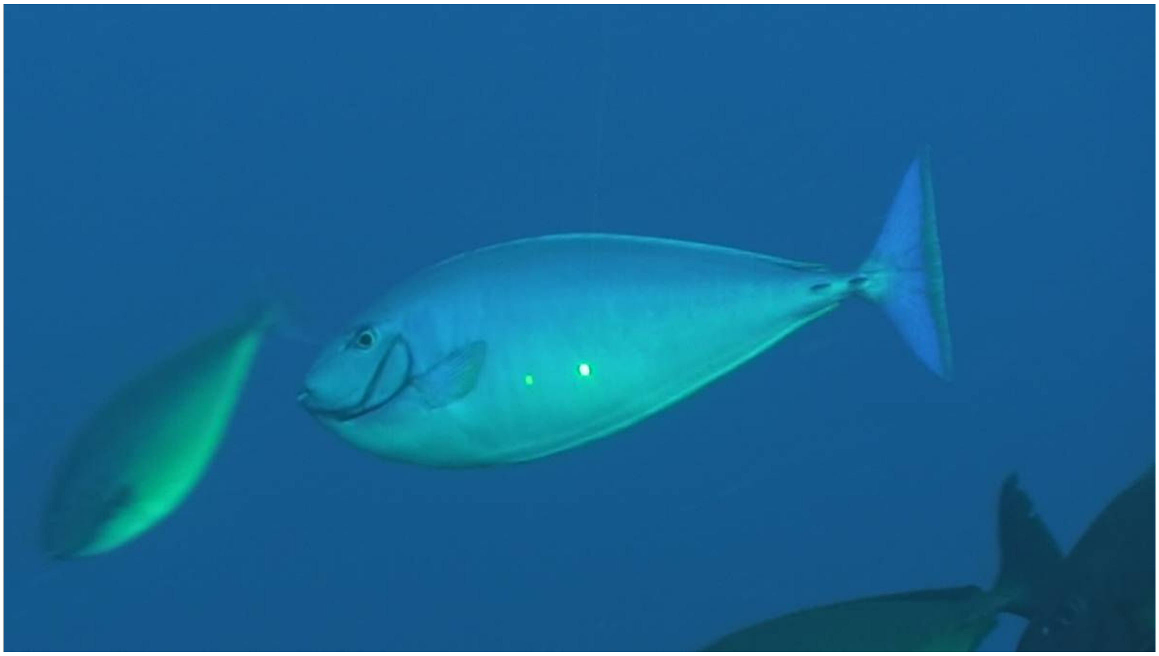

Figure 8. *Naso hexacanthus*. Laser dots are separated by 36 mm.

A total 60 individuals were captured on video suitable for length estimation. Mean total length was 43 cm, which is 61% of the maximum reported length of 71 cm and 86% of the female L_{50} of 50 cm (Figure 9). Results suggest only one (1) of the individuals had attained female reproductive size, however we were not able to evaluate the reliability of the size-at-maturity estimate.

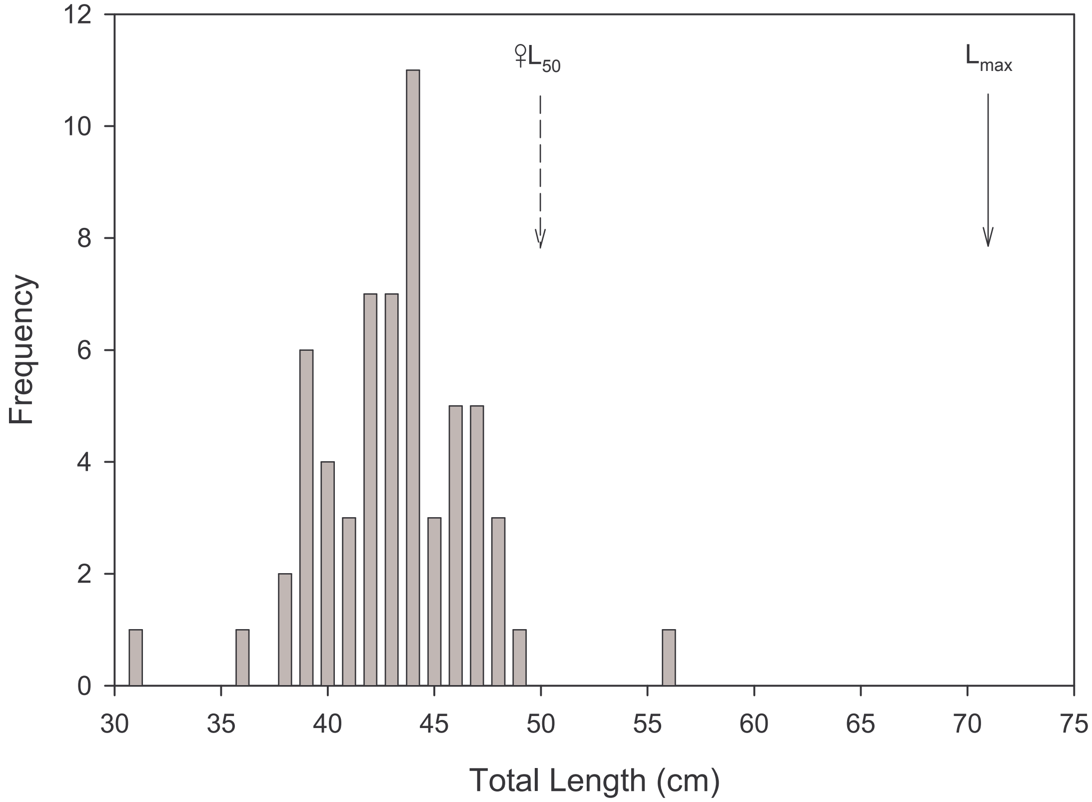

Figure 9. Size structure of *Naso hexacanthus*.

Naso vlamingii (Valenciennes, 1835). Figure 10.

Figure 10. ***Naso vlamingii*****.**

A total nine (9) 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 35 cm, which is 69% of the maximum reported length of 51 cm.

Balistidae

Canthidermis maculata (Bloch, 1786). Figure 11.

Figure 11. *Canthidermis maculata*. Laser dots are separated by 36 mm.

A total 13 individuals were 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 95% of the maximum reported length of 35.

<u>Caesionidae</u>

Caesio cuning (Bloch, 1791). Figure 12.

Figure 12. *Caesio cuning*.

An additional 261 specimens were added to our data set in 2010, yielding a combined total 425 individuals captured on video suitable for length estimation. The additional data did not change the mean fork length estimate of 16 cm, which is 39% of the maximum reported length of 42 cm (Figure 13).

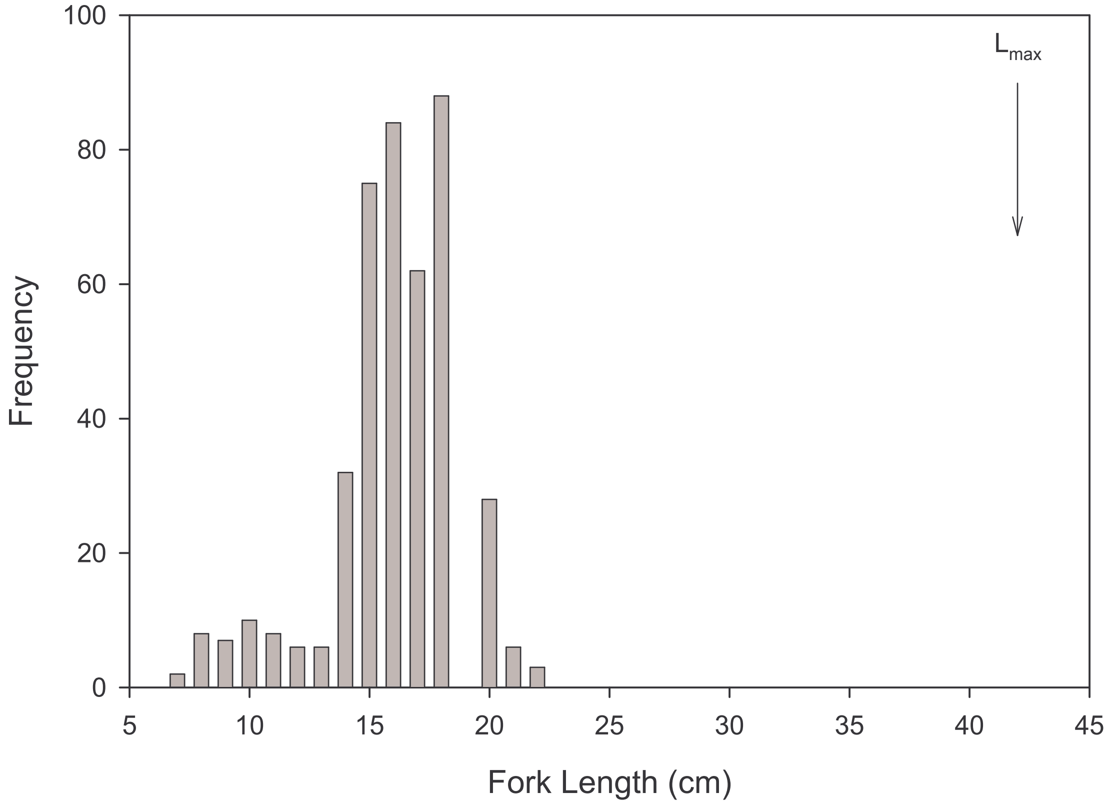

Figure 13. Size structure of *Caesio cuning*.

Carangidae

Carangoides bajad (Forsskål, 1775). Figure 14.

Figure 14. *Carangoides bajad*. Laser dots are separated by 39 mm.

An additional 11 specimens were added to our data set in 2010, yielding a combined total 34 individuals captured on video suitable for length estimation. The additional data did not change the mean fork length estimate of 26 cm, which is 52% of the maximum reported length of 51 cm (Figure 15).

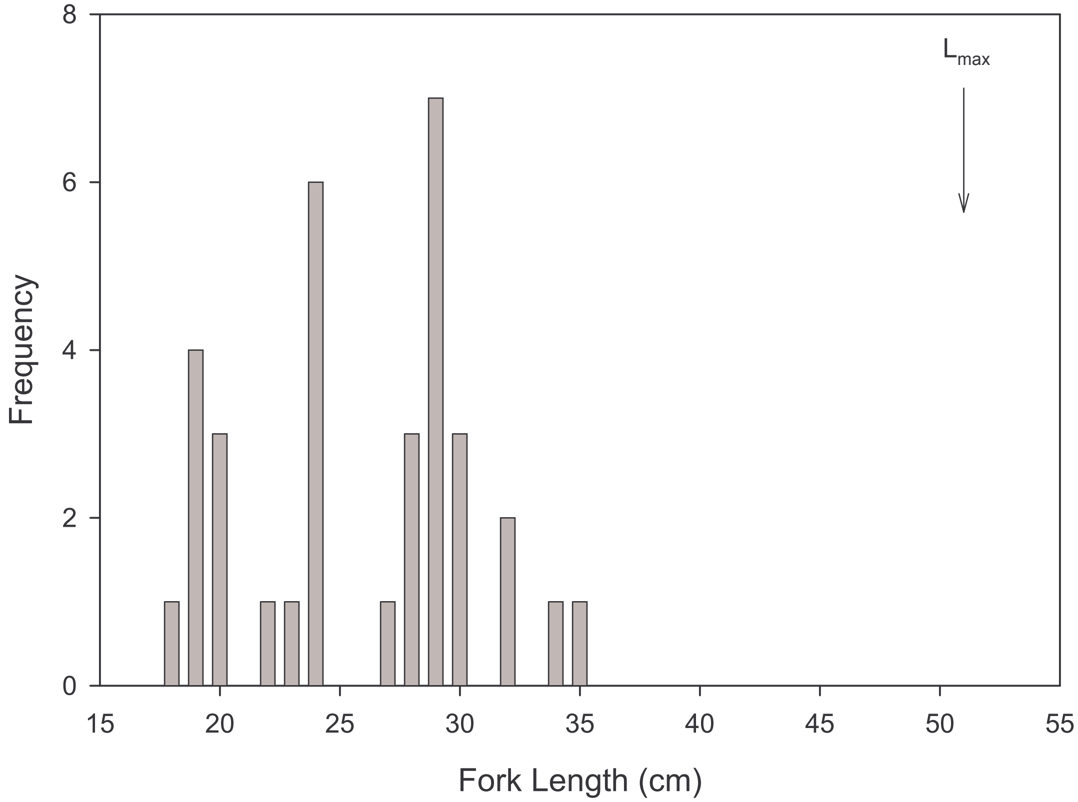

Figure 15. Size structure of *Carangoides bajad*.

Carangoides plagiotaenia Bleeker, 1857. Figure 16.

Figure 16. *Carangoides plagiotaenia*. Laser dots are separated by 36 mm.

A total 15 individuals were captured on video suitable for length estimation. The mean fork length was 25 cm, which is 66% of the maximum reported length of 38 cm (Figure 17).

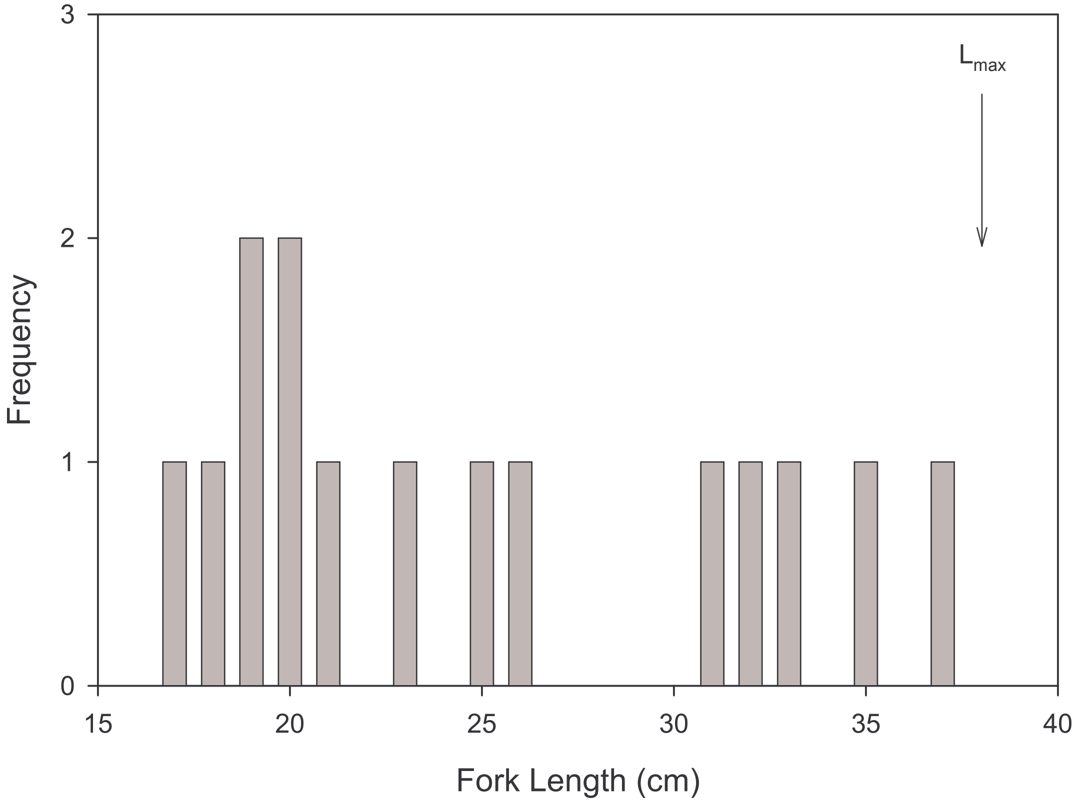

Figure 17. Size structure of *Carangoides plagiotaenia*.

Caranx melampygus Cuvier, 1833. Figure 18.

Figure 18. *Caranx melampygus*.

An additional 12 specimens were added to our data set in 2010, yielding a combined total 28 individuals captured on video suitable for length estimation. The additional data included larger size classes than seen in 2009, and shifted mean fork length from 23 to 26 cm, which is 36% of the maximum reported length of 72 cm and 84% of the female L_{50} of 35 cm (Figure 19). Three (or 11%) of these individuals had attained the reported female reproductive size (however, size-specific sex ratios are not known).

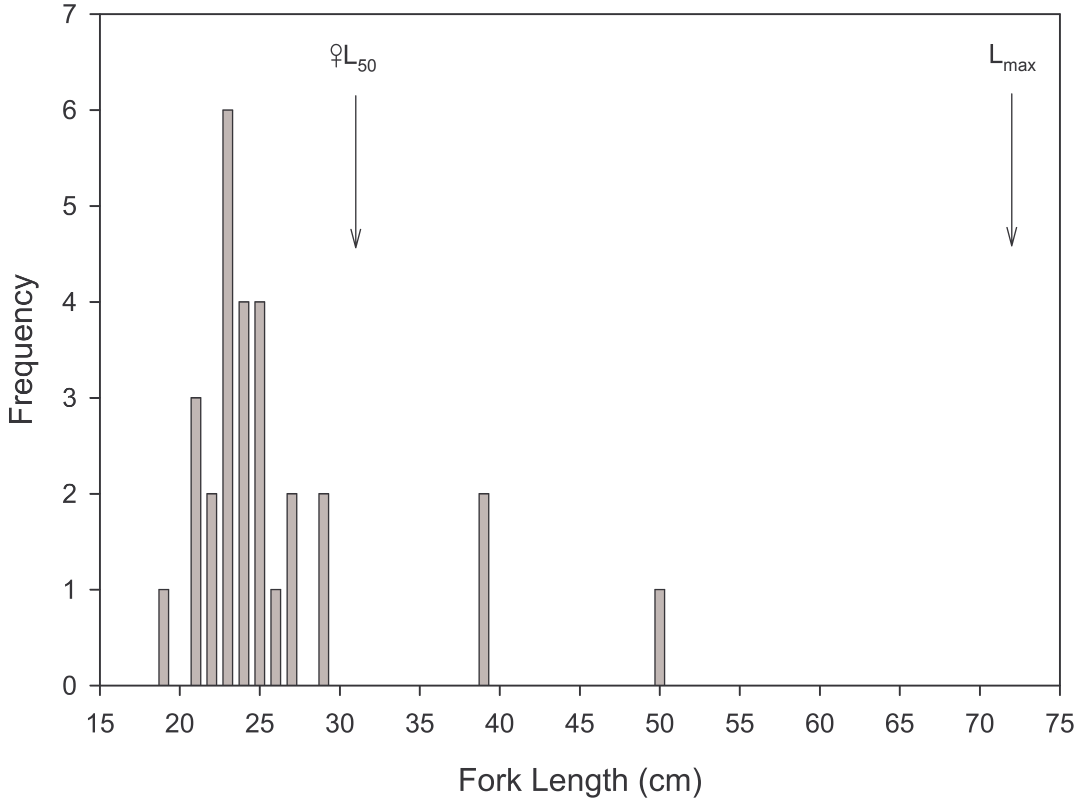

Figure 19. Size structure of *Caranx melampygus*.

Caranx papuensis Alleyne & MacLeay, 1877. Figure 20.

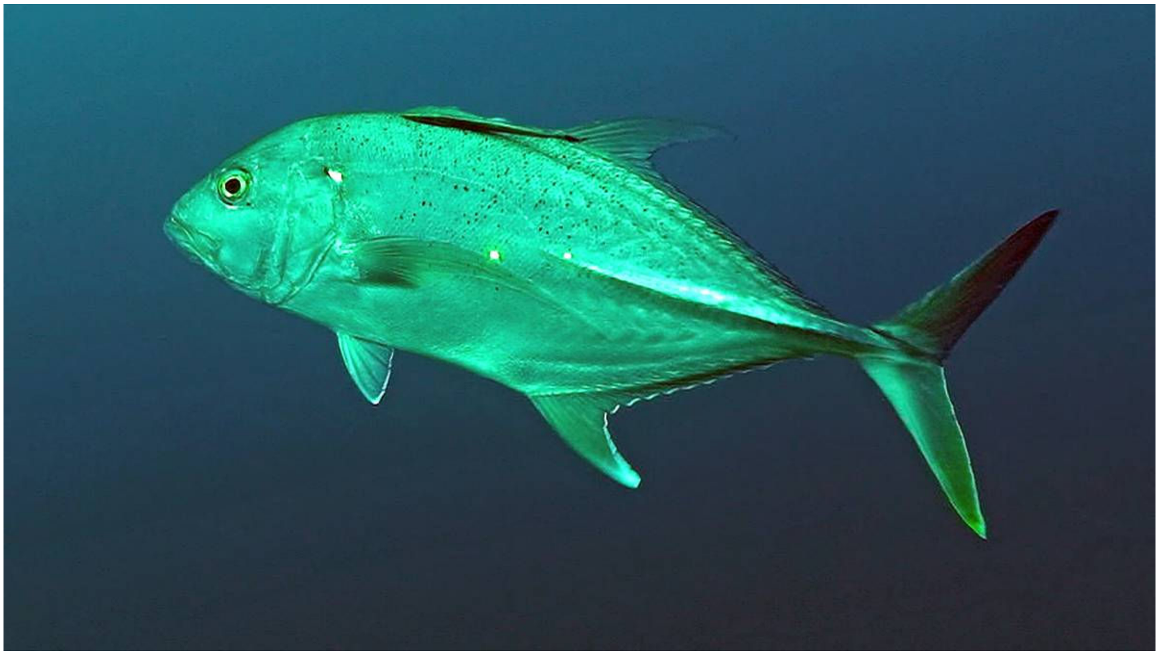

Figure 20. *Caranx papuensis* (with a remora attached near the origin of the first dorsal fin). Laser dots are separated by 39 mm.

No new specimens were added to our data set in 2010, leaving a 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 fork length was 47 cm, which is 70% of the maximum reported length of 66 cm.

Ephippidae

Platax pinnatus (Linneaus, 1758). Figure 21.

Figure 21. *Platax pinnatus*. Laser dots are separated by 36 mm.

A total five (5) individuals were captured on video suitable for length estimation. Due to low sample size, a size distribution is not presented. However, the mean total length was 24 cm, which is 80% of the maximum reported length of 30 cm.

Haemulidae

Plectorhinchus lineatus (Linnaeus, 1758). Figure 22.

Figure 5. *Plectorhinchus lineatus*. Laser dots are separated by 39 mm.

An additional five (5) specimens were added to out data set in 2010, yielding a combined total 15 individuals captured on video suitable for length estimation. The additional data shifted mean total length from 35 to 36 cm. The updated mean size is 72% of the maximum reported length of 50 cm (Figure 23).

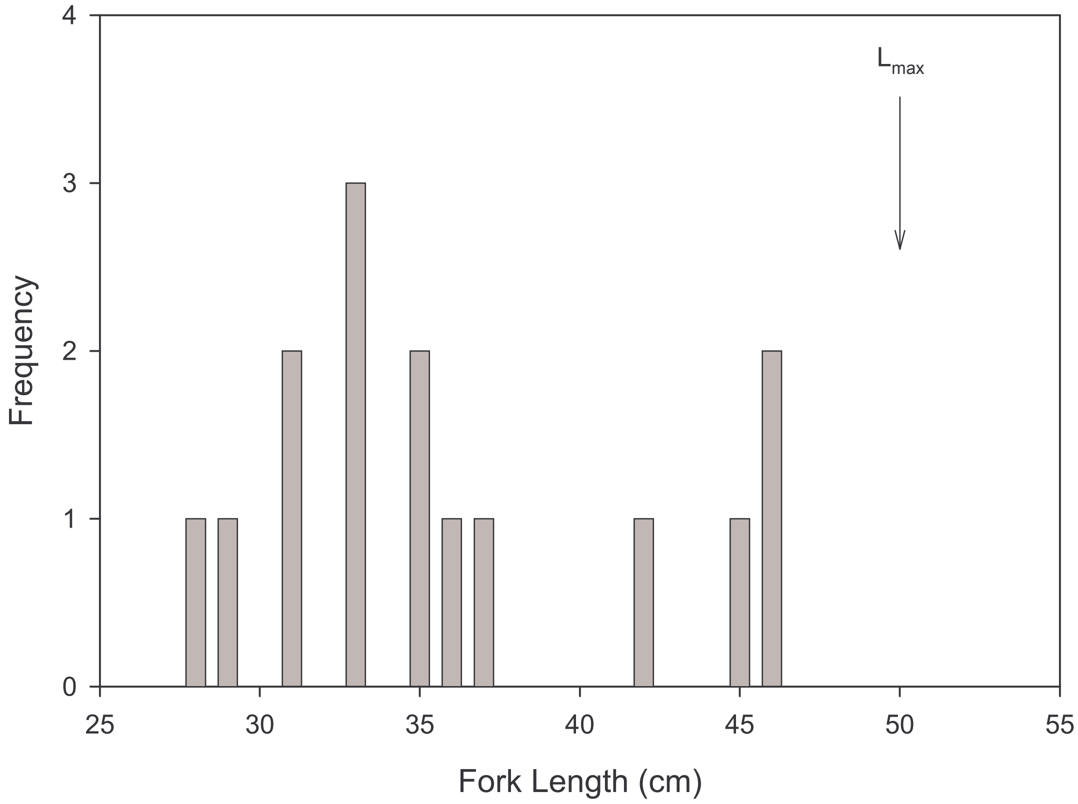

Figure 23. Size structure of *Plectorhinchus lineatus*.

Holocentridae

Myripristis adusta Bleeker, 1853. Figure 24.

Figure 6. ***Myripristis adusta*.**

No new specimens were added to our data set in 2010, leaving a total 13 individuals captured on video suitable for length estimation. Due to low sample size, a size distribution is not presented. However, mean fork length was 18 cm, which is 66% of the maximum reported length of 28 cm.

Myripristis kuntee Valenciennes, 1831. Figure 25.

Figure 25. ***Myripristis kuntee*****. Laser dots are separated by 39 mm.**

An additional three (3) specimens were added to our data set in 2010, yielding a combined total 44 individuals captured on video suitable for length estimation. The additional data did not change the mean fork length estimate of 12 cm. Because the relationship between total and fork lengths has not been published for this species, we described the relationship between maximum length and fork length of individuals captured on video. We applied this relationship (FL = 1.7790 + 0.7242(TL); $r^2 = 0.856$; n = 15) to published maximum length, yielding a maximum fork length of 16 cm. Because this is likely an overestimate (total length was probably underestimated because the longest caudal rays typically were not completely extended), results suggest the mean size of this population is at least 75% of the maximum length (Figure 26).

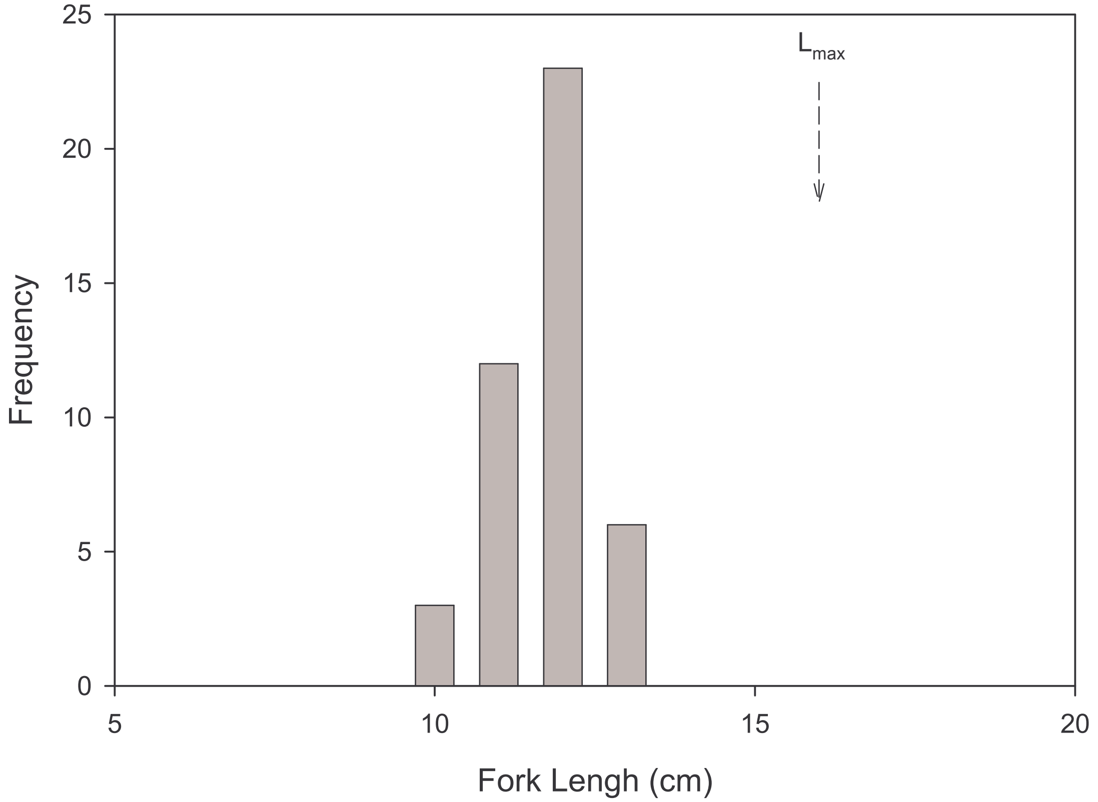

Figure 26. Size structure of *Myripristis kuntee*.

Myripristis violacea Bleeker, 1851. Figure 27.

Figure 27. *Myripristis violacea*.

An additional six (6) specimens were added to our data set in 2010, yielding a combined total 40 individuals captured on video suitable for length estimation. The additional data did not change the mean fork length estimate of 13 cm. Because the relationship between total and fork lengths has not been published for this species, we described the relationship between maximum length and fork length of individuals captured on video. We applied this relationship (FL = 1.3429 + 0.7832(TL); $r^2 = 0.913$; n = 15) to published maximum length, yielding a maximum fork length of 17 cm. Because this is likely an overestimate (total length was probably underestimated because the longest caudal rays typically were not completely extended), results suggest the mean size of this population is at least 76% of the maximum length (Figure 28).

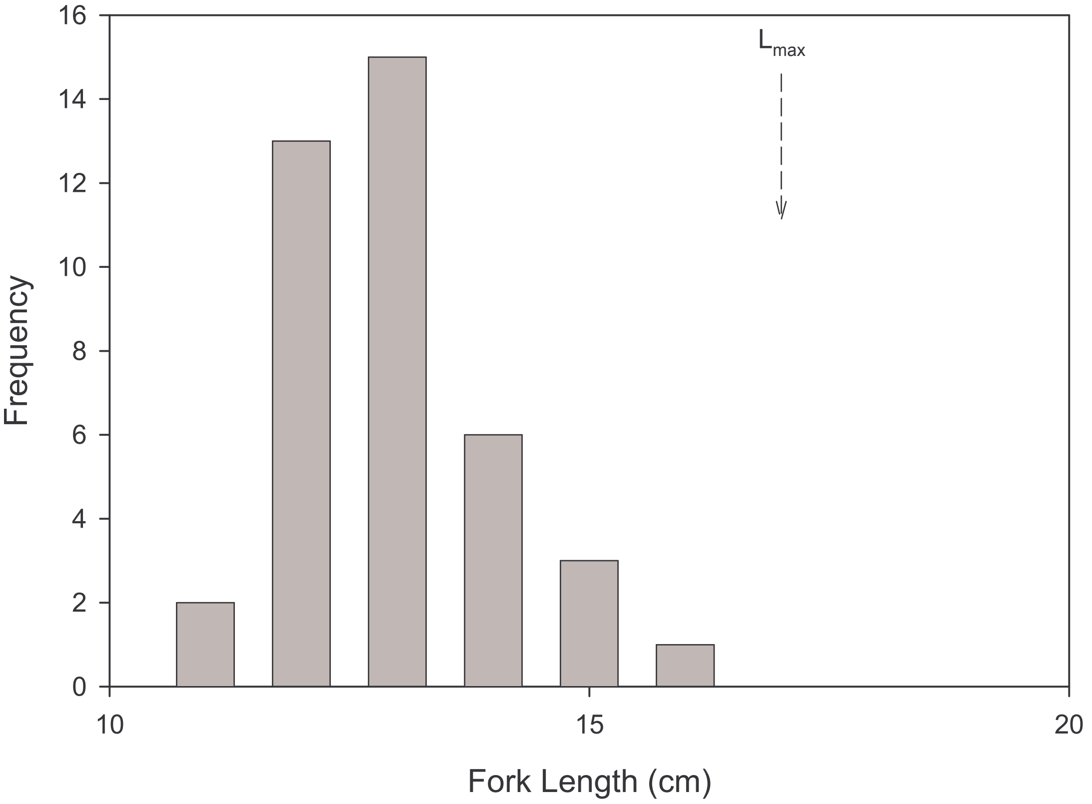

Figure 28. Size structure of *Myripristis violacea*.

Myripristis vittata (Valenciennes, 1831). Figure 29.

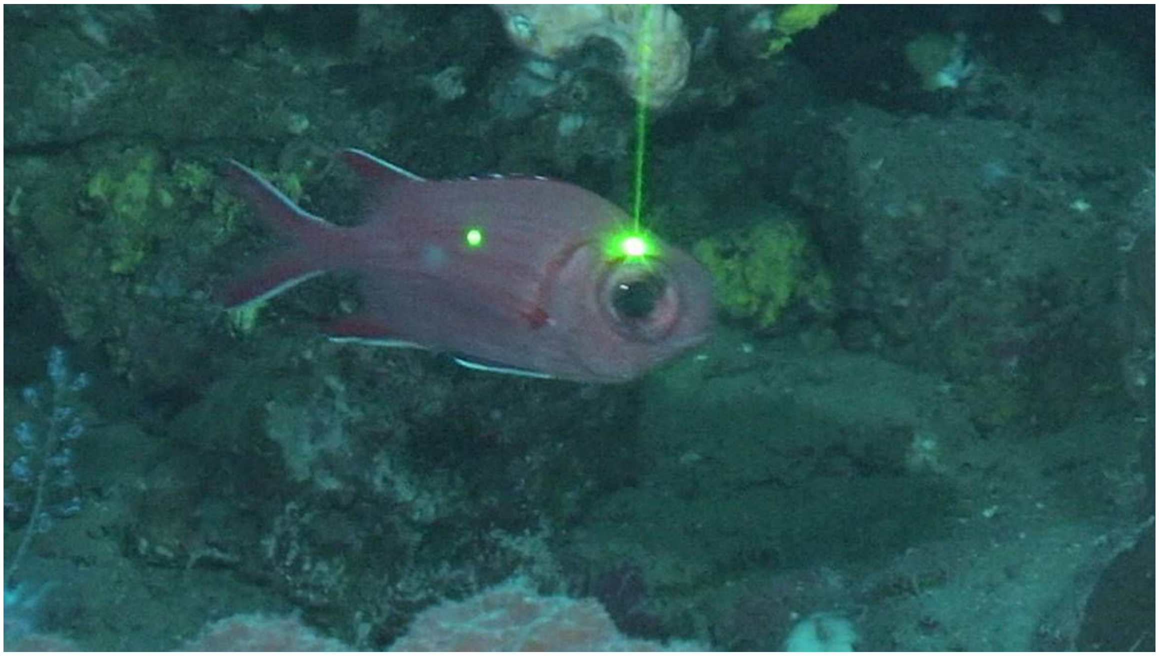

Figure 29. *Myripristis vittata*. Laser dots are separated by 36 mm.

A total 19 individuals were captured on video suitable for length estimation. The mean fork length was 11 cm, which is 65% of the maximum reported length of 17cm (Figure 30).

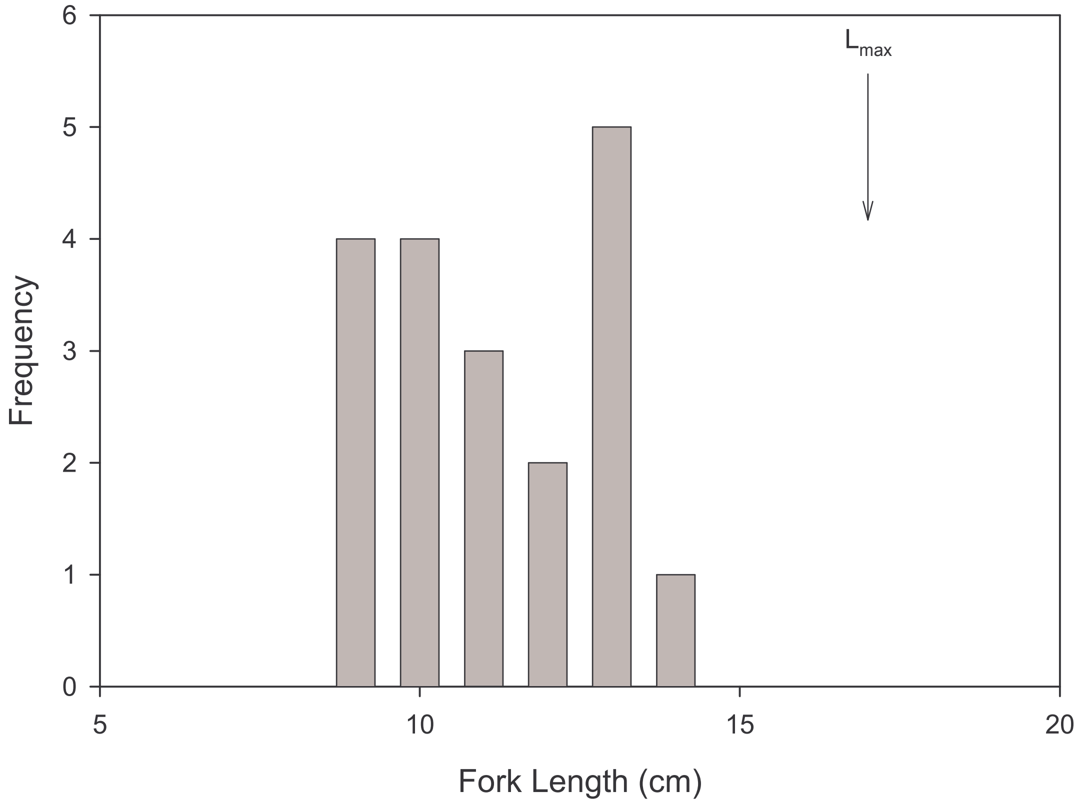

Figure 30. Size structure of *Myripristis vittata*.

Neoniphon sammara (Forsskål, 1775). Figure 31.

Figure 31. *Neoniphon sammara*. Laser dots are separated by 39 mm.

An additional three (3) specimens were added to our data set in 2010, 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 did not change the mean fork length estimate of 14 cm. Because the relationship between total and fork lengths has not been published for this species, we described the relationship between maximum length and fork length of individuals captured on video. We applied this relationship ($FL = 1.0867 + 0.8068(TL)$; $r^2 = 0.889$; $n = 7$) to published maximum length, yielding a maximum fork length of 27 cm. Because this is likely an overestimate (total length was probably underestimated because the longest caudal rays typically were not completely extended), results suggest the mean size of this population is at least 50% of the maximum length. Mean length is 174% of minimum female size at maturity of eight (8) cm, and 100% of individuals had attained this size. Sex ratios have not been examined in this species, so the proportion of mature females cannot be estimated.

Kyphosidae

Kyphosus cinerascens (Forsskål, 1775). Figure 32.

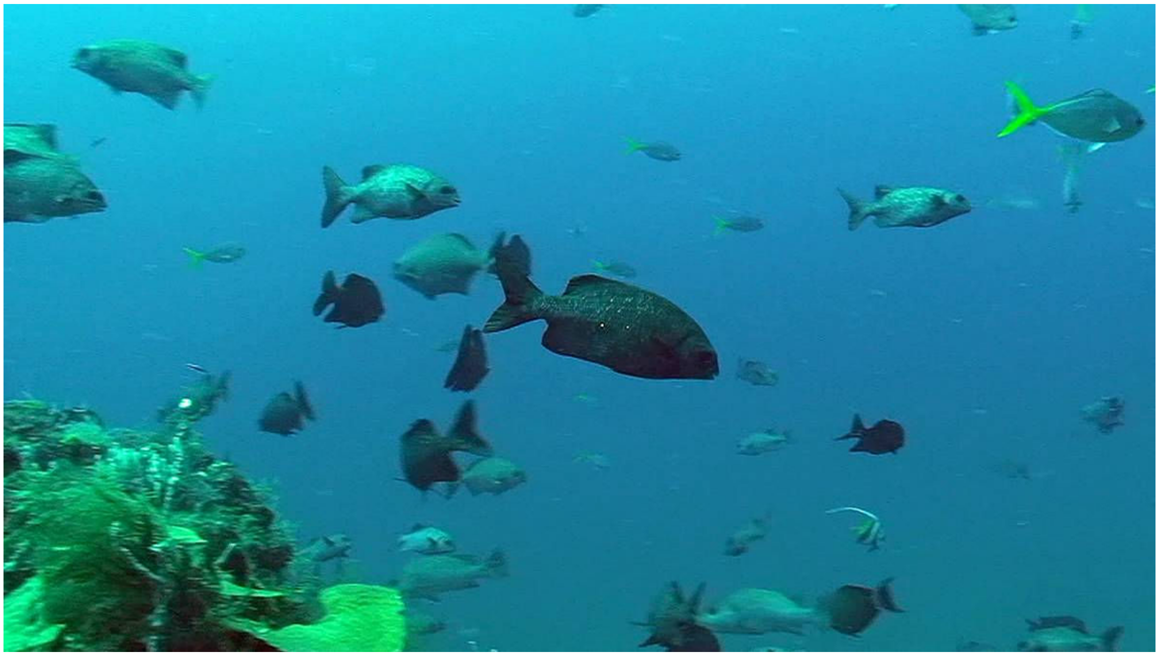

Figure 32. *Kyphosus cinerascens*. Laser dots are separated by 39 mm.

An additional five (5) specimens were added to our data set in 2010, yielding a combined total 54 individuals captured on video suitable for length estimation. The additional data did not change the mean fork length estimate of 30 cm, which is 72% of the maximum reported length of 41 cm (Figure 33).

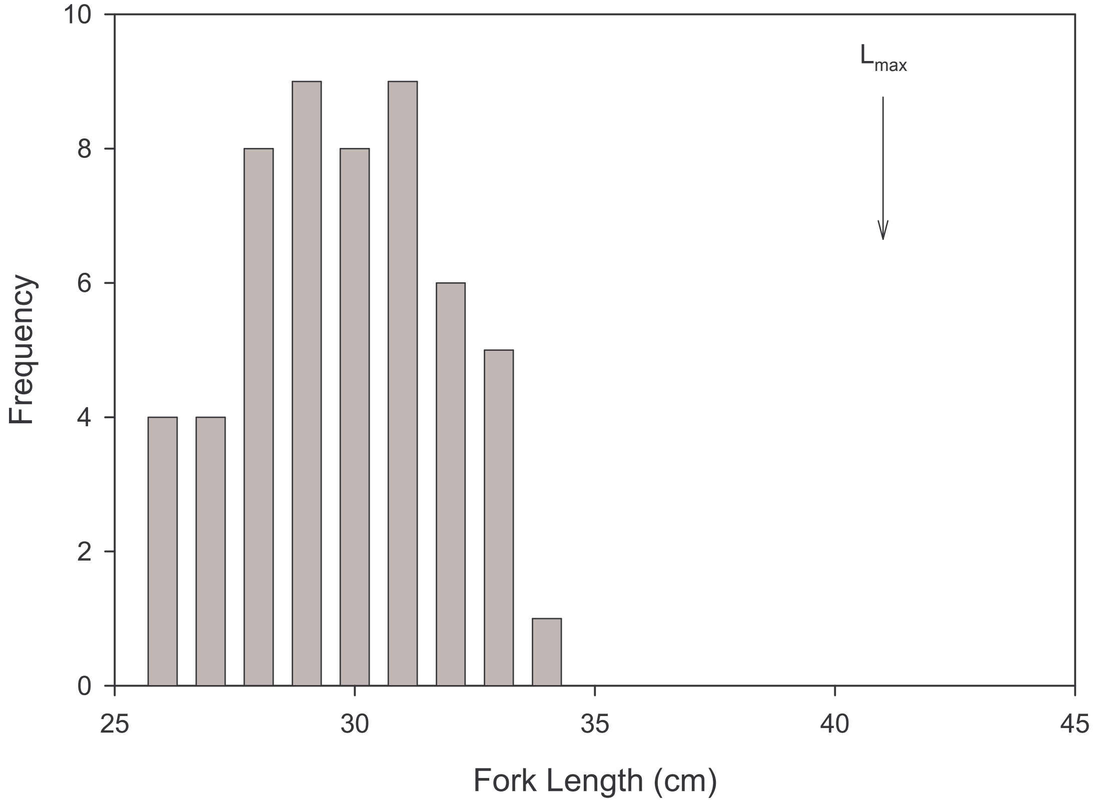

Figure 33. Size structure of *Kyphosus cinerascens*.

Lethrinidae

Monotaxis grandoculis (Forsskål, 1775). Figure 34.

Figure 34. *Monotaxis grandoculis* juvenile (left) and adult (right).

An additional 24 specimens were added to our data set in 2010, yielding a combined total 43 individuals captured on video suitable for length estimation. The additional data shifted mean fork length from 20 to 24 cm. Because the relationship between total and fork lengths has not been published for this species, we described the relationship between maximum length and fork length of individuals captured on video. We applied this relationship (FL = -1.2794 + 0.9586(TL); $r^2 = 0.997$; n = 15) to published maximum length, yielding a maximum fork length of 56 cm. Because this is likely an overestimate (total length was probably underestimated because the longest caudal rays typically were not completely extended), results suggest the mean size of this population is at least 43% of the maximum length (Figure 35).

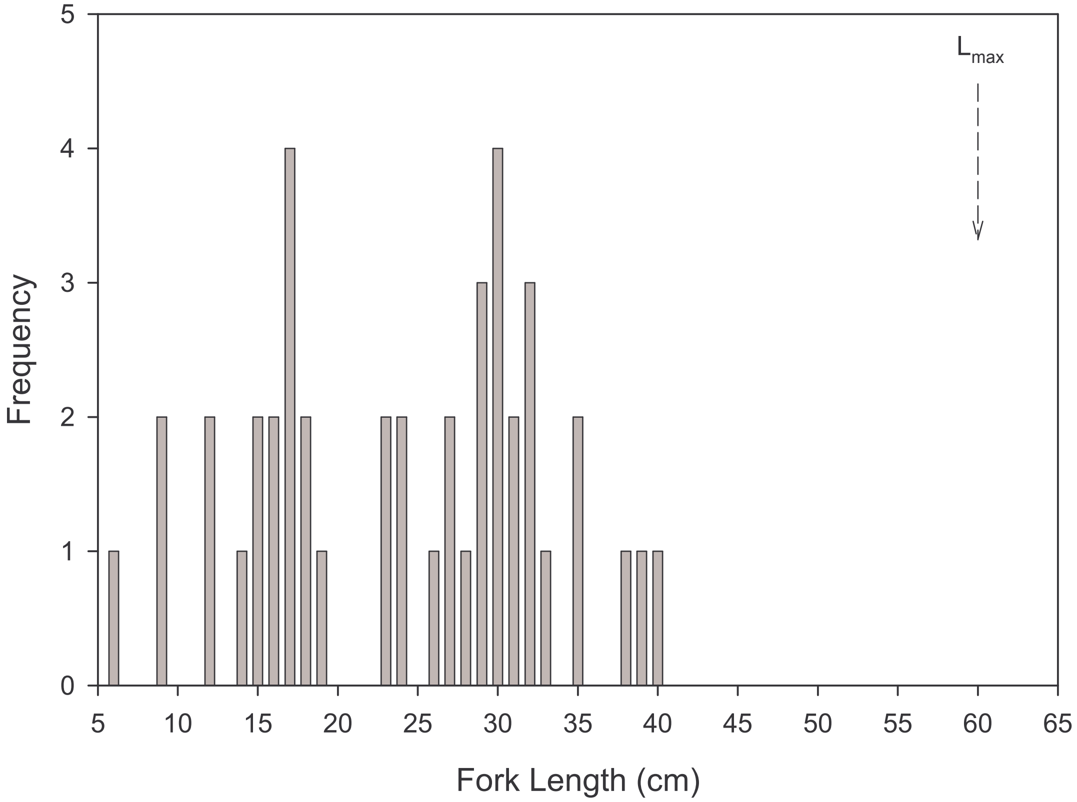

Figure 35. Size structure of *Monotaxis grandoculis*.

Lutjanidae

Lutjanus argentimaculatus (Forsskål, 1775). Figure 36.

Figure 36. *Lutjanus argentimaculatus*. Laser dots are separated by 36 mm.

A total three (3) 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 50 cm, which is 42% of the maximum reported length of 118 cm and 94% of the female L_{50} of 53 cm. The above information, when considered in light of the approximately 1:1 (♂:♀) sex-ratio, suggests that about 36% of the population is mature females.

Lutjanus biguttatus (Valenciennes, 1830). Figure 37.

Figure 37. *Lutjanus biguttatus*. Laser dots are separated by 39 mm.

An additional 125 specimens were added to our data set in 2010, yielding a combined total 183 individuals captured on video suitable for length estimation. The additional data included smaller size classes than seen in 2009, and shifted mean fork length from 15 to 14 cm. The updated mean size estimate is 71% of the maximum reported length of 19 cm and 88% of the female L_{50} of 17 cm (Figure 38). Given that sex ratios are not significantly different from 1:1, about 11% of the population is mature females.

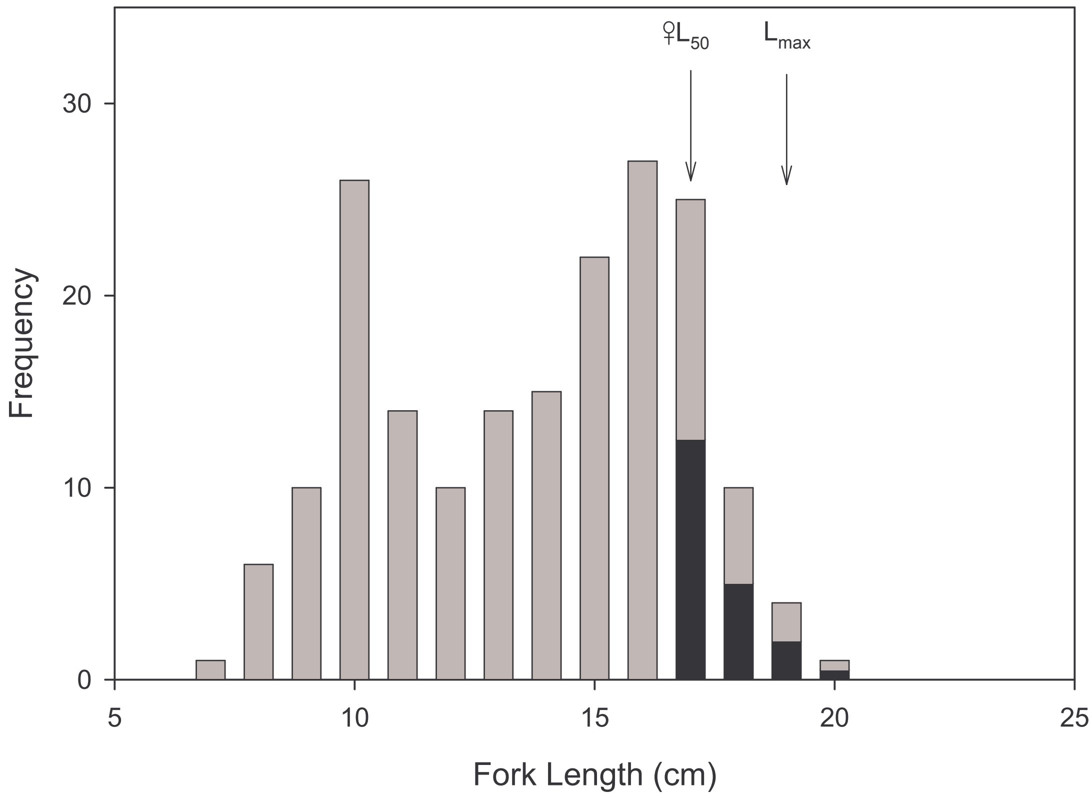

Figure 38. Size structure of *Lutjanus biguttatus*. The dark portion of bars represent estimated number of mature females, light portion represents all other individuals.

Lutjanus boutton (Lacepède, 1802). Figure 39.

Figure 39. *Lutjanus boutton*. Laser dots are separated by 39 mm.

An additional 75 specimens were added to our data set in 2010, yielding a combined total 141 individuals captured on video suitable for length estimation. The additional data did not change the mean fork length estimate of 14 cm, which is 48% of the maximum reported length of 28 cm (Figure 40).

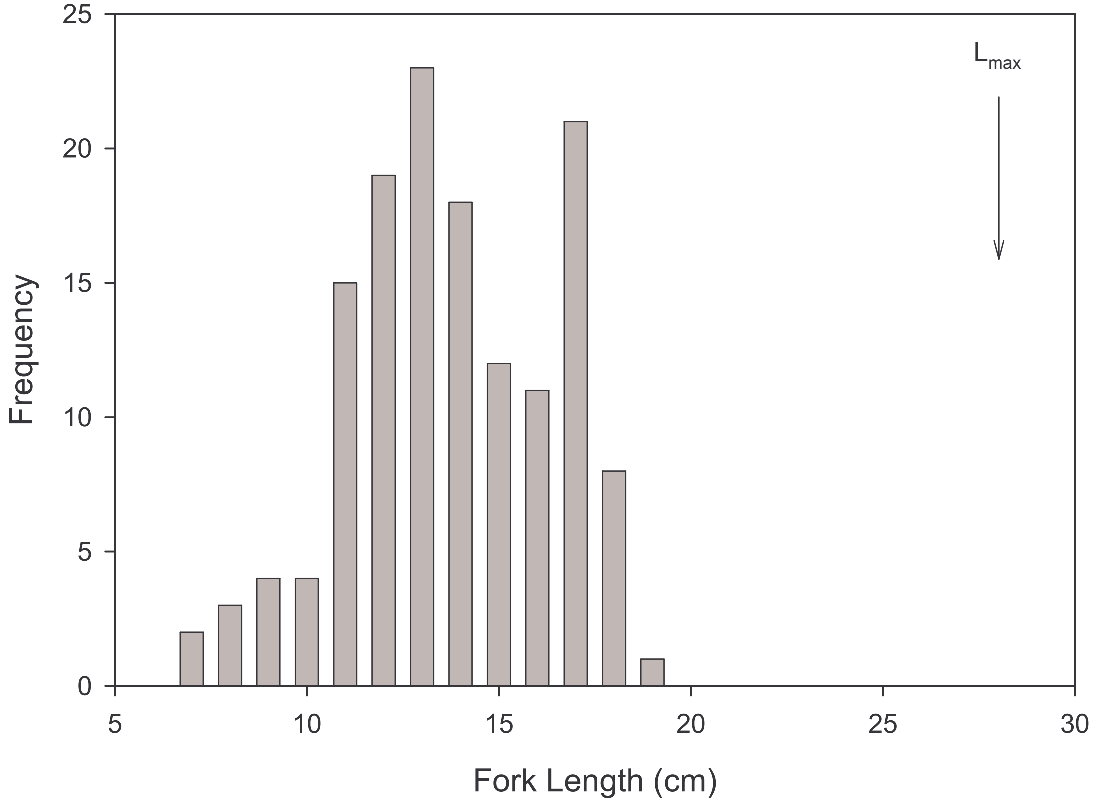

Figure 40. Size structure of *Lutjanus boutton*.

Lutjanus carponotatus (Richardson, 1842). Figure 41.

Figure 41. *Lutjanus carponotatus*.

An additional seven (7) specimens were added to our data set in 2010, yielding a combined total 15 individuals captured on video suitable for length estimation. The additional data shifted mean fork length from 22 to 23 cm, which is 59% of the maximum reported length of 38 cm and 119% of the female L_{50} of 19 cm (Figure 42). The above information, when considered in light of the approximately 1:1 sex-ratio, suggests that about 37% of the population is mature females.

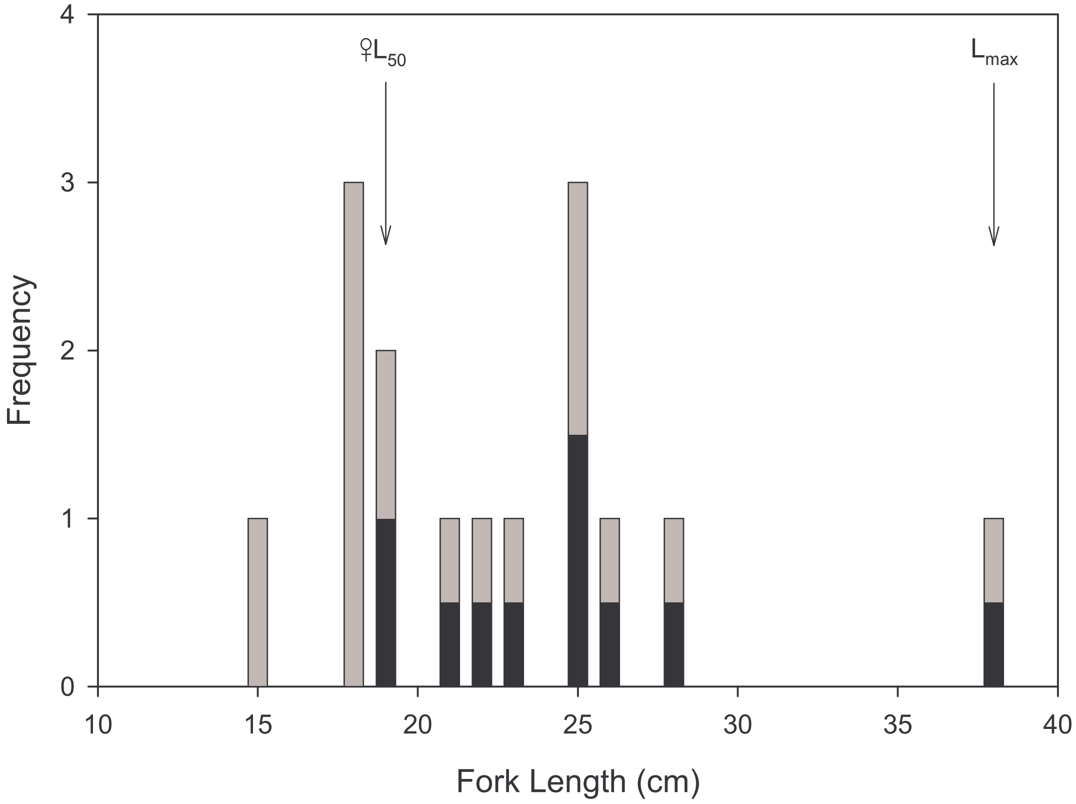

Figure 42. Size structure of *Lutjanus carponotatus*. The dark portion of bars represent estimated number of mature females, light portion represents all other individuals.

Lutjanus fulvus (Forster, 1801). Figure 43.

Figure 43. *Lutjanus fulvus*.

An additional 15 specimens were added to our data set in 2010, yielding a combined total 33 individuals captured on video suitable for length estimation. The additional data did not change the mean fork length estimate of 18 cm, which is 47% of the maximum reported length of 39 cm (Figure 44).

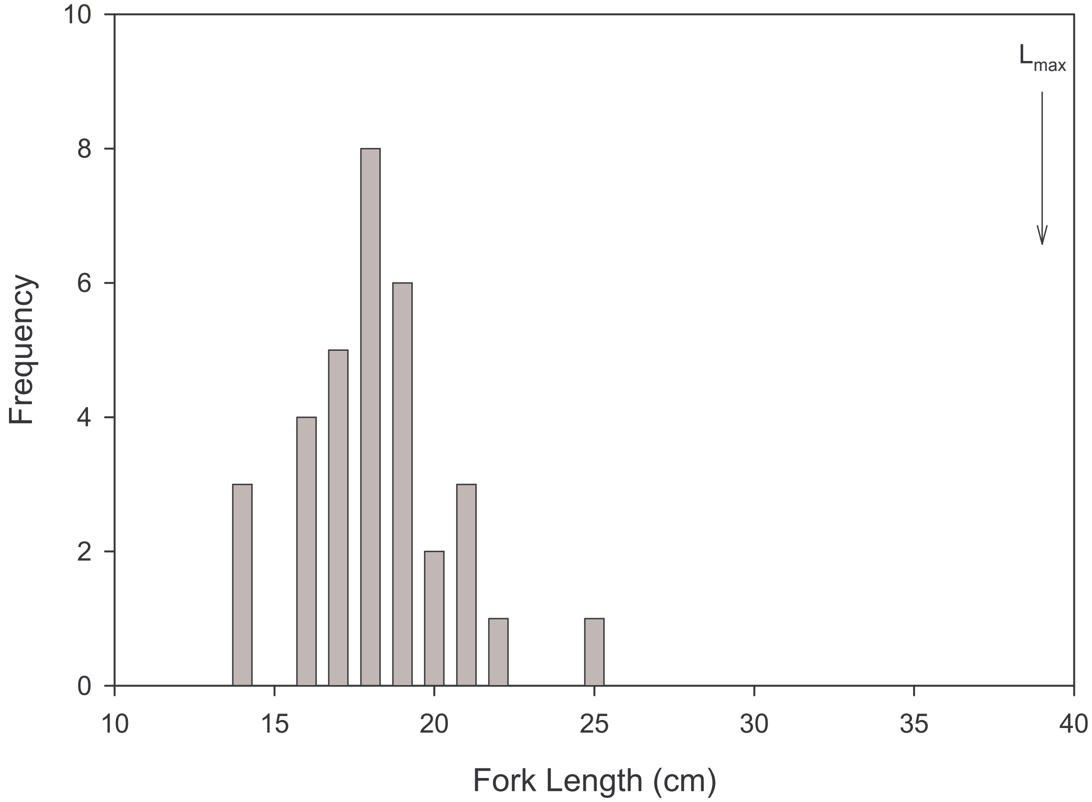

Figure 44. Size structure of *Lutjanus fulvus*.

Lutjanus gibbus (Forsskål, 1775). Figure 45.

Figure 45. *Lutjanus gibbus*. Laser dots are separated by 39 mm.

An additional nine (9) specimens were added to our data set in 2010, yielding a combined total 19 individuals captured on video suitable for length estimation. The additional data shifted mean fork length from 18 to 19 cm. The updated length estimate is 46% of the maximum reported length of 42 cm and at least 122% of the minimum female reproductive size of ~16 cm (Figure 46). Because sex ratios have not been described in detail, the percentage of mature females cannot be estimated.

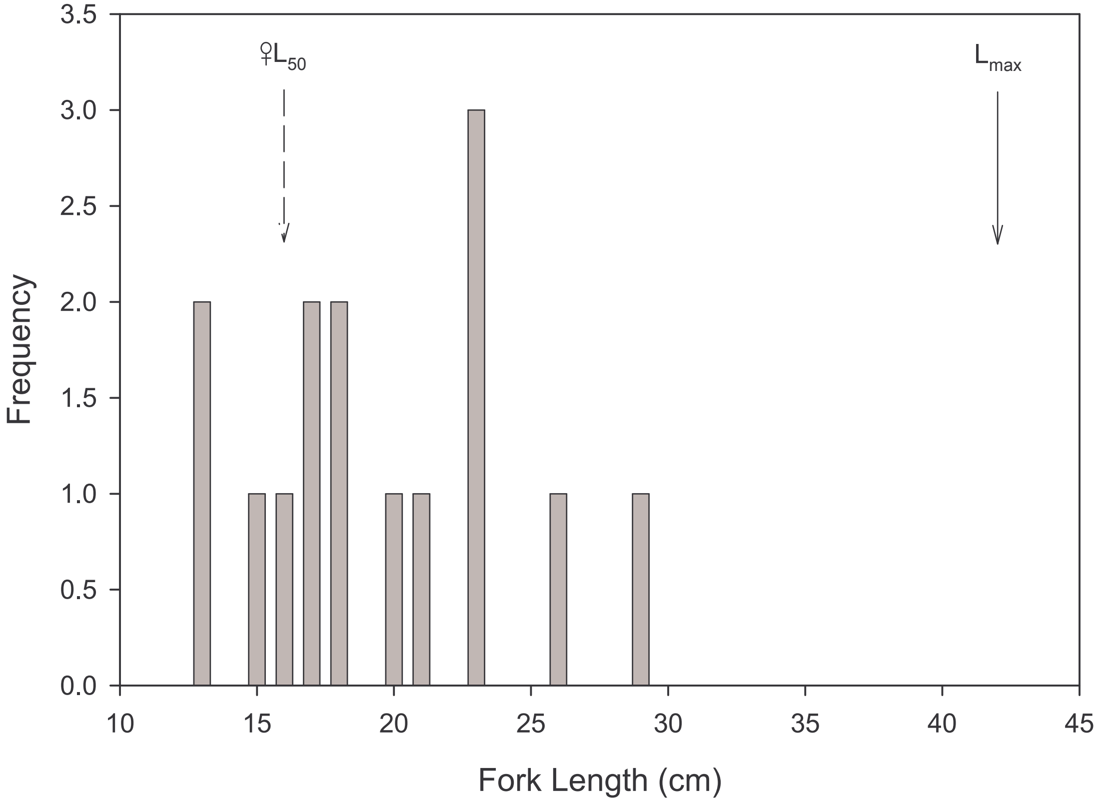

Figure 46. Size structure of *Lutjanus gibbus*.

Lutjanus russellii (Bleeker, 1849). Figure 47.

Figure 47. *Lutjanus russellii*. Laser dots on the left fish are separated by 39 mm.

An additional 34 specimens were added to our data set in 2010, yielding a combined total 73 individuals captured on video suitable for length estimation. The additional data did not change the mean fork length estimate of 22 cm, which is 50% of the maximum reported length of 43 cm and 100% of the female L_{50} of 22 cm (Figure 48). The possibility of a size-specific sex ratio has not been examined for this species. However, if a 1:1 ratio is assumed, 22% of the population is mature females.

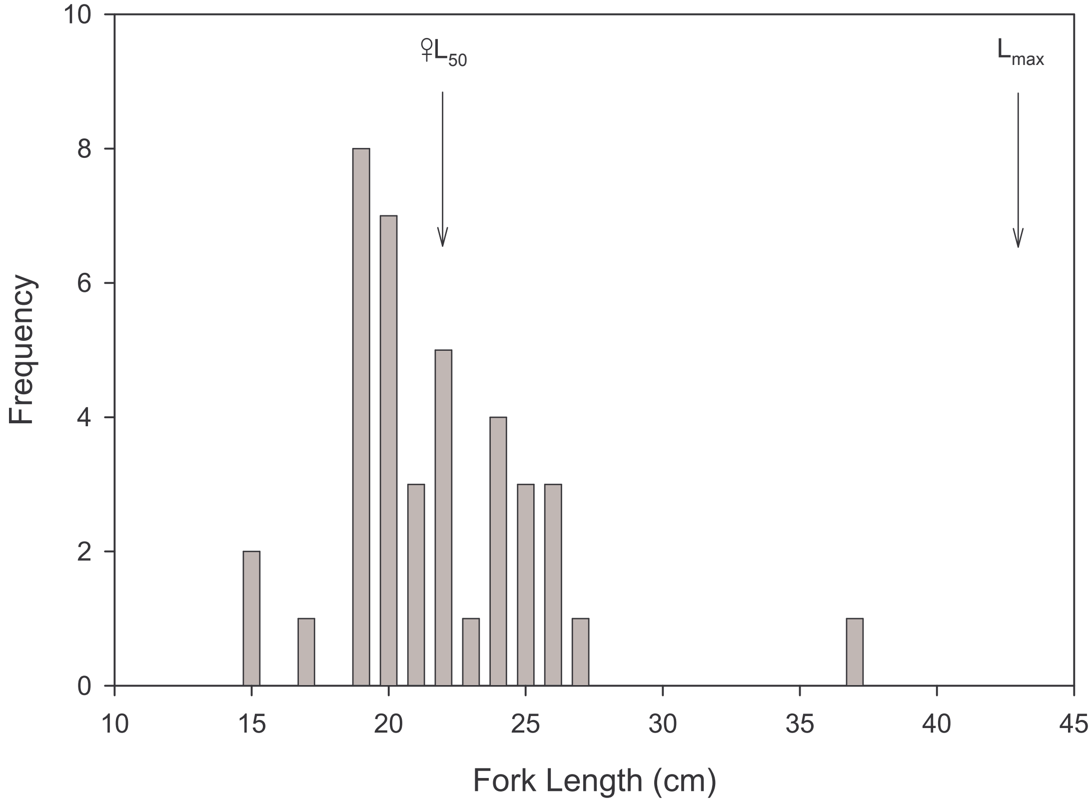

Figure 48. Size structure of *Lutjanus russellii*.

Lutjanus semicinctus Quoy & Gaimard, 1824. Figure 49.

Figure 49. *Lutjanus semicinctus*. Laser dots are separated by 39 mm.

An additional 10 specimens were added to our data set in 2010, yielding a combined total 23 individuals captured on video suitable for length estimation. The additional data shifted mean fork length from 20 to 19 cm. The updated mean size estimate is 57% of the maximum reported length of 34 cm (Figure 50).

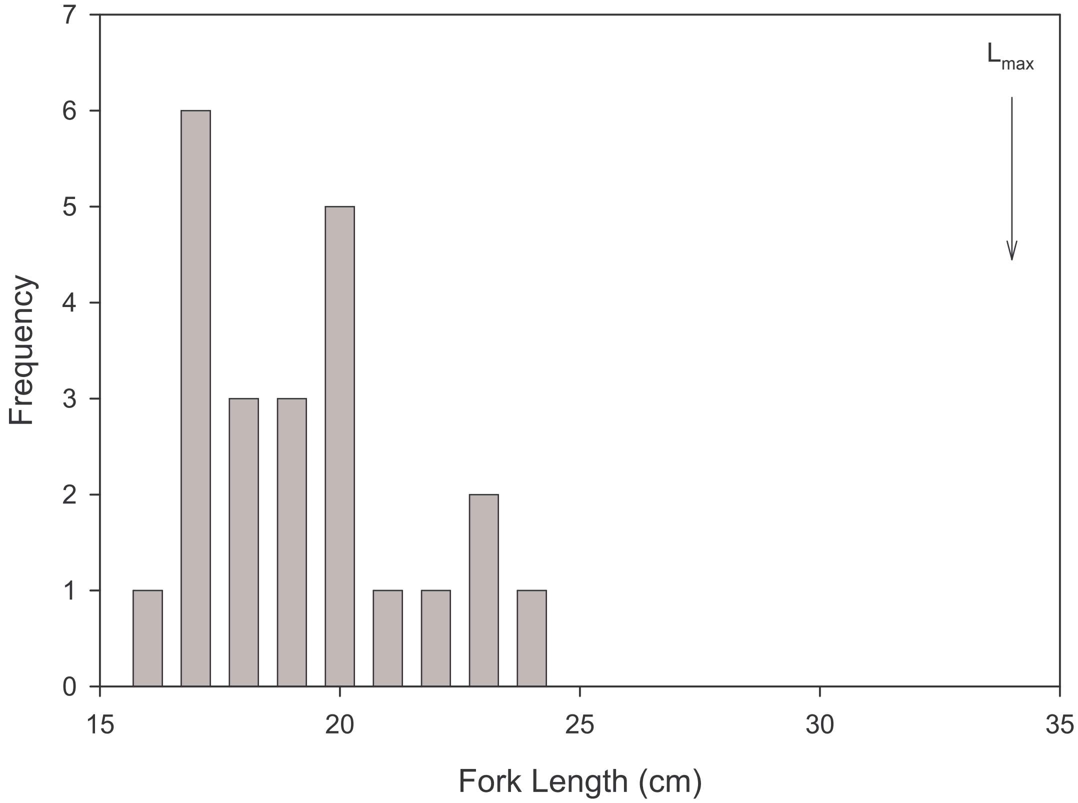

Figure 50. Size structure of *Lutjanus semicinctus*.

Lutjanus vitta (Quoy & Gaimard, 1824). Figure 51.

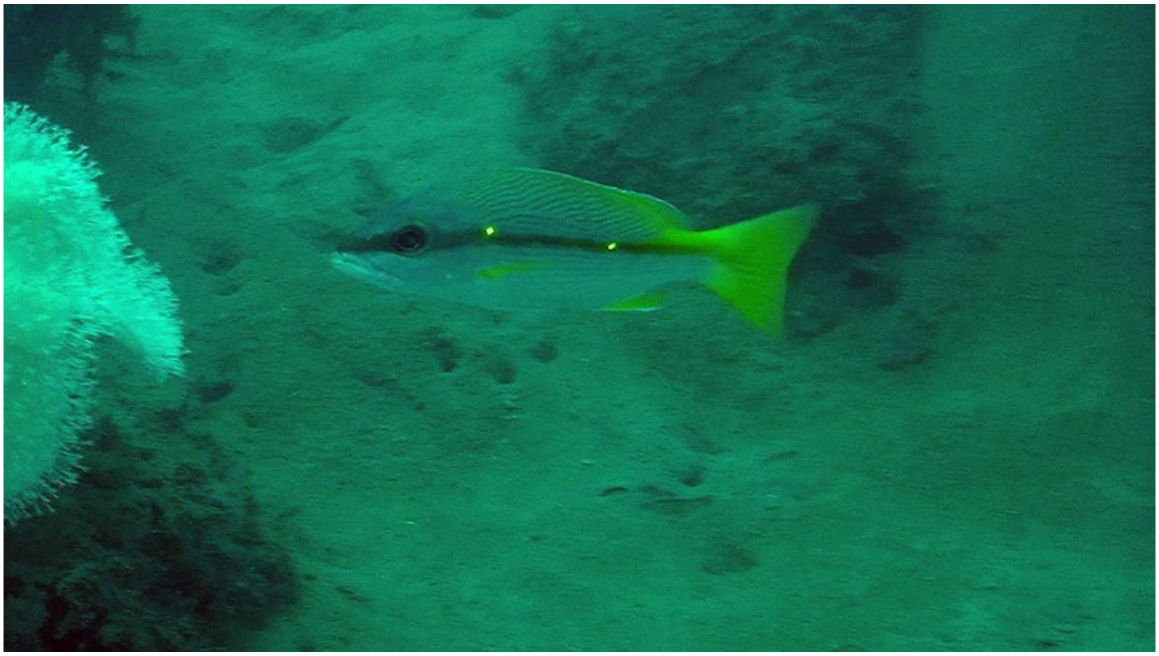

Figure 51. *Lutjanus vitta*. Laser dots are separated by 39 mm.

No new specimens were added to our data set in 2010, leaving a total 18 individuals captured on video suitable for length estimation. The mean fork length was 15 cm, which is 39% of the maximum reported length of 37 cm and 100% of the female L_{50} of 15 cm (Figure 52). The above information, when considered in light of size-specific sex ratios, suggests that about 25% of the population is mature females.

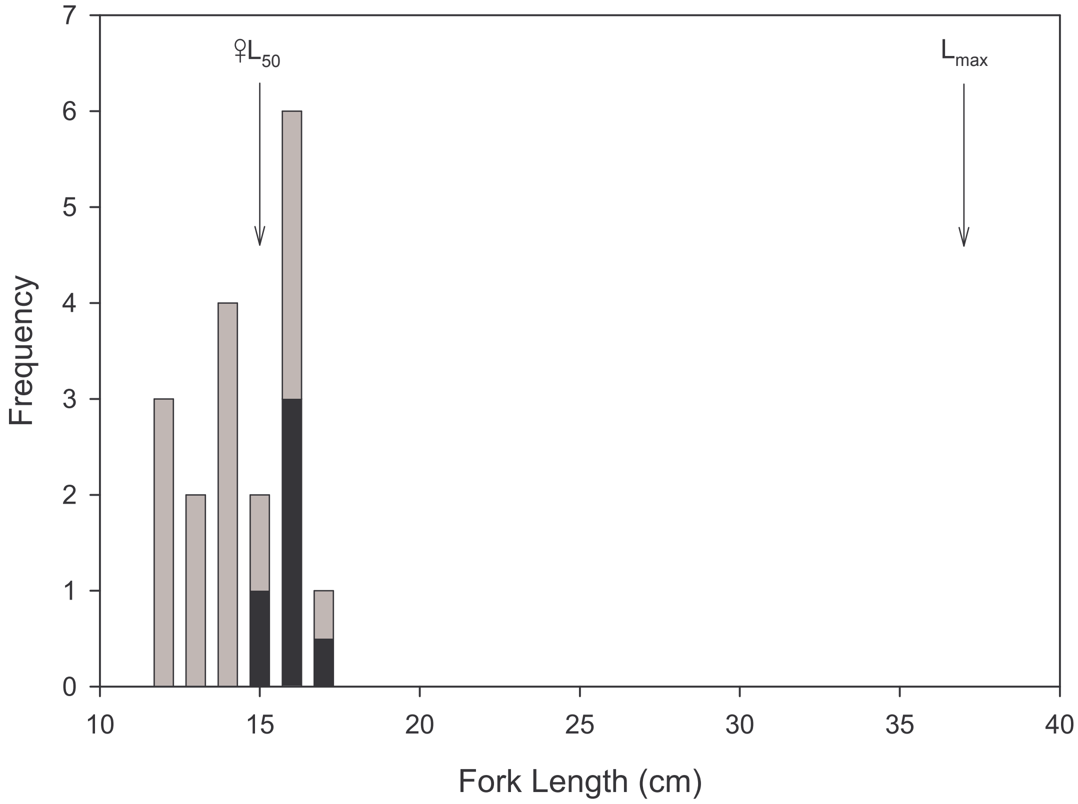

Figure 52. Size structure of *Lutjanus vitta*. The dark portion of bars represent estimated number of mature females, light portion represents all other individuals.

Macolor macularis Fowler, 1931. Figure 53.

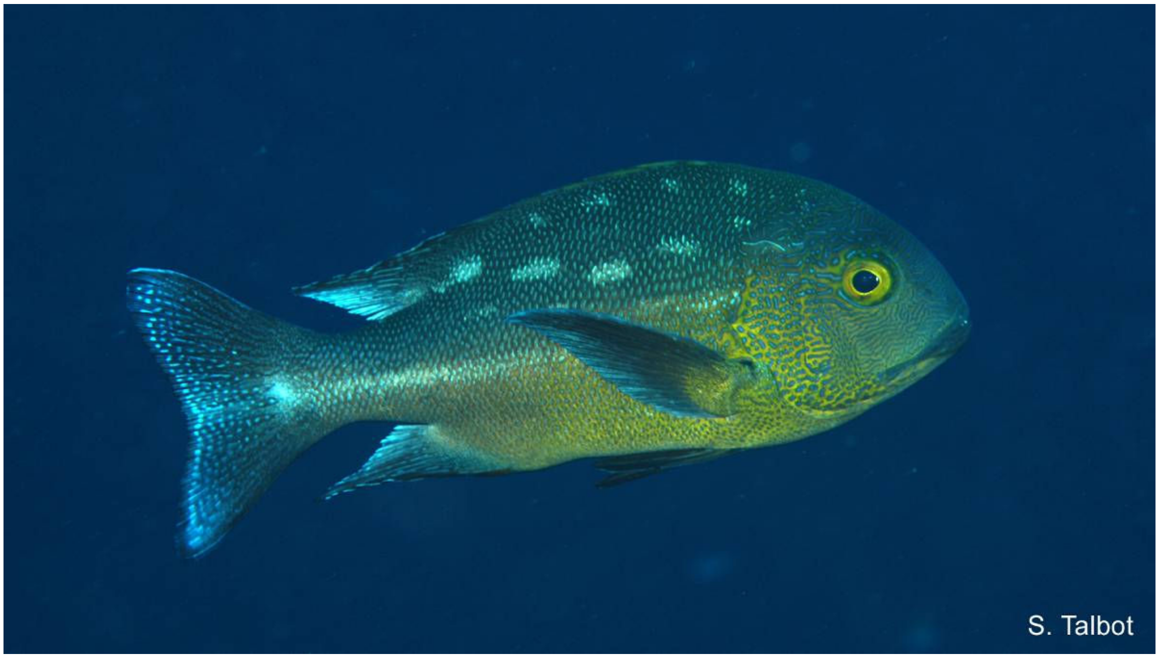

Figure 53. *Macolor macularis*.

An additional three (3) specimens were added to our data set in 2010, yielding a combined total 13 individuals captured on video suitable for length estimation. Due to low sample size, a size distribution is not presented. The additional data shifted mean fork length from 29 to 30 cm. The updated mean size estimate is 54% of the maximum reported length of 55 cm.

Mullidae

Parupeneus barberinus (Lacepède, 1801). Figure 54.

Figure 54. *Parupeneus barberinus*. Laser dots are separated by 39 mm.

An additional 42 specimens were added to our data set in 2010, yielding a combined total 85 individuals captured on video suitable for length estimation. The additional data shifted mean fork length from 16 to 15 cm. Because the relationship between total and fork lengths has not been published for this species, we constructed a length-length relationship from Hawaiian specimens of *Parupeneus multifasciatus* (Longenecker & Langston, unpublished data). We applied this relationship (FL = 0.2121 + 0.8736(TL); $r^2 = 0.993$; n = 67) to estimate a maximum fork length of 44 cm. Results suggest the updated mean size of this population is 35% of the maximum length (Figure 55). Mean length is 128% of minimum female size at maturity of 12 cm, and 82% of individuals had attained this size. Sex ratios have not been examined in this species, so the proportion of mature females cannot be estimated.

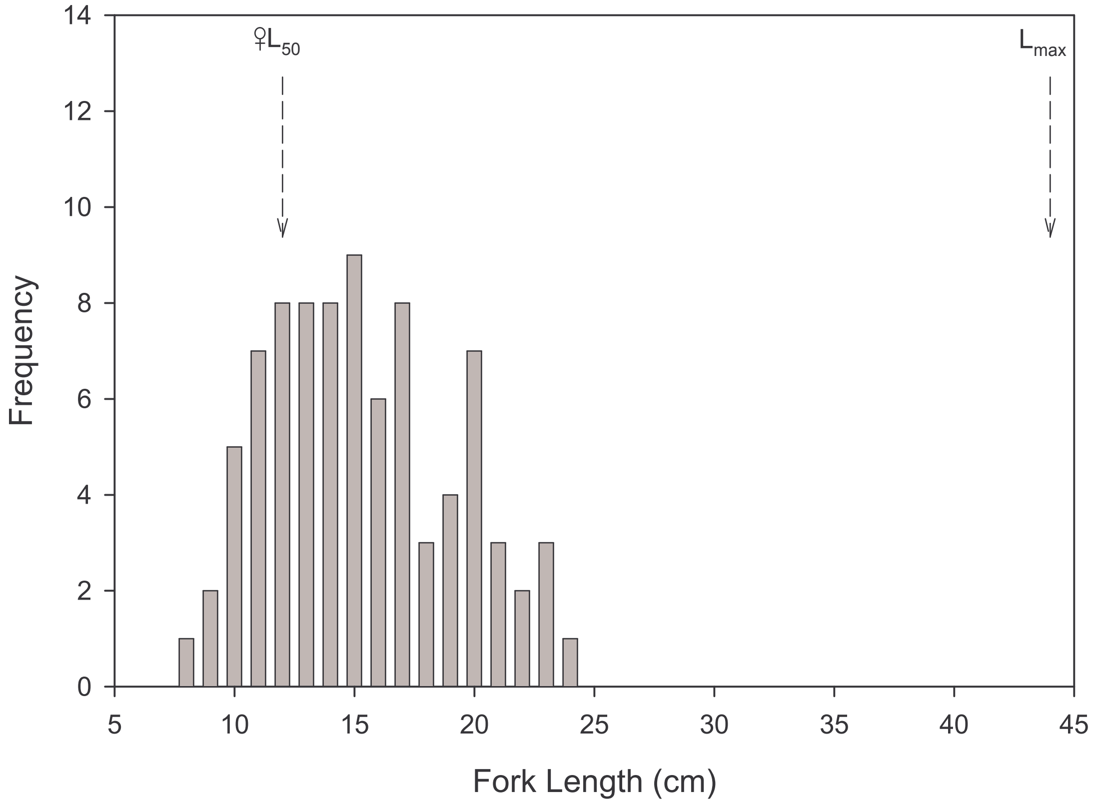

Figure 55. Size structure of *Parupeneus barberinus*.

Parupeneus cyclostomus (Lacepède, 1801). Figure 56.

Figure 56. ***Parupeneus cyclostomus*****.**

An additional four (4) specimens were added to our data set in 2010, yielding a combined 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 fork length from 17 to 19 cm. Because the relationship between total and fork lengths has not been published for this species, we constructed a length-length relationship from Hawaiian specimens of *Parupeneus multifasciatus* (Longenecker & Langston, unpublished data). We applied this relationship (FL = 0.2121 + 0.8736(TL); $r^2 = 0.993$; n = 67) to estimate a maximum fork length of 44 cm. Results suggest the mean size of the few individuals captured on video is 43% of the maximum length.

Parupeneus multifasciatus (Quoy & Gaimard, 1825). Figure 57.

Figure 57. *Parupeneus multifasciatus*.

An additional 29 specimens were added to our data set in 2010, yielding a combined total 50 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 and 93% of the female L_{50} of 15 cm (Figure 58). The above information, when considered in light of size-specific sex ratios and maximum female size, suggests that about 17% of the population is mature females.

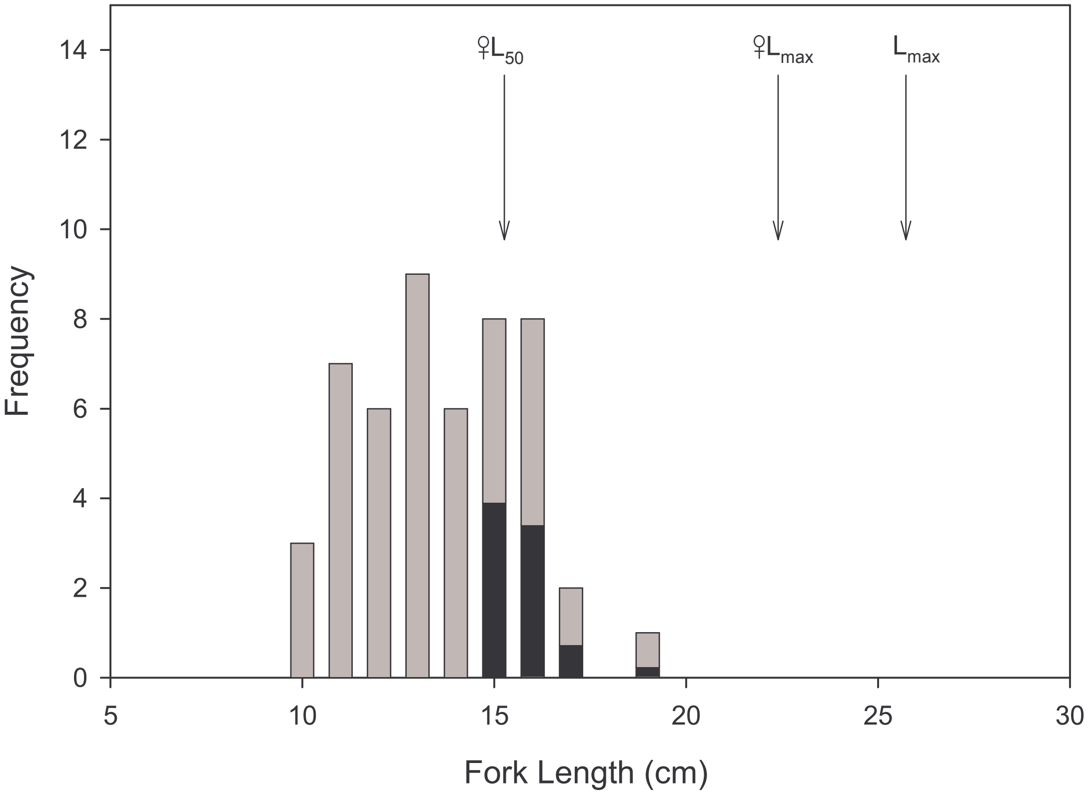

Figure 58. Size structure of *Parupeneus multifasciatus*. The dark portion of bars represent estimated number of mature females, light portion represents all other individuals.

Parupeneus trifasciatus (Lacepède, 1801). Figure 59.

Figure 59. *Parupeneus trifasciatus*. Laser dots are separated by 39 mm.

An additional five (5) specimens were added to our data set in 2010, yielding a total 12 individuals captured on video suitable for length estimation. Due to low sample size, a size distribution is not presented. The additional data did not change the mean fork length estimate of 20 cm. Because the relationship between total and fork lengths has not been published for this species, we constructed a length-length relationship from Hawaiian specimens of *Parupeneus multifasciatus* (Longenecker & Langston, unpublished data). We applied this relationship (FL = 0.2121 + 0.8736(TL); $r^2 = 0.993$; n = 67) to estimate a maximum fork length of 31 cm. Results suggest the mean size of the individuals captured on video is 66% of the maximum length. Mean length is 203% of minimum female size at maturity of 10 cm, and 100% of individuals had attained this size. Sex ratios have not been examined in this species, so the proportion of mature females cannot be estimated.

Serranidae

Anyperodon leucogrammicus (Valenciennes, 1828). Figure 60.

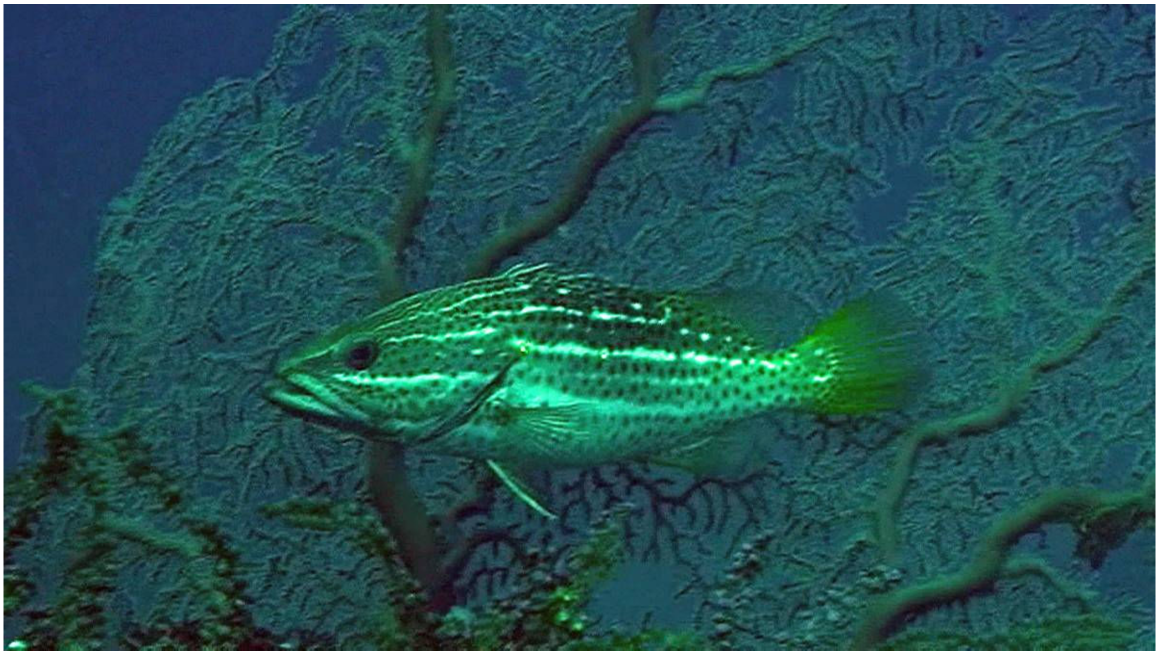

Figure 60. *Anyperodon leucogrammicus*. Laser dots are separated by 39 mm.

An additional one (1) specimen was added to our data set in 2010, yielding a combined total eight (8) individuals captured on video suitable for length estimation. Due to low sample size, a size distribution is not presented. However, the additional datum shifted mean total length from 26 to 25 cm. The updated means size is 48% of the maximum reported length of 52 cm.

Cephalopholis boenak (Bloch, 1790). Figure 61.

Figure 61. ***Cephalopholis boenak*.**

No new specimens were added to our data set in 2010, 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 was 17 cm, which is 70% of the maximum reported length of 24 cm and 111% of the female L_{50} of 15 cm. Because sex change occurs in this species (~ 16 cm) and size-specific sex ratios are not known, the proportion of mature females cannot be estimated reliably.

Cephalopholis cyanostigma (Valenciennes, 1828). Figure 62.

Figure 62. *Cephalopholis cyanostigma*.

An additional 24 specimens were added to our data set in 2010, yielding a combined total 46 individuals captured on video suitable for length estimation. The additional data did not change the mean total length estimate of 19 cm, which is 55% of the maximum reported length of 35 cm and at least 137% of female reproductive size of 14 cm (the study providing reproductive information found all individuals at least this size to be mature, however none smaller were collected so this is an over-estimate of female size at maturity). Maximum female size is 26 cm, raising the possibility that all but one of the individuals represented here (Figure 63) are mature females (however, size-specific sex ratios are not known).

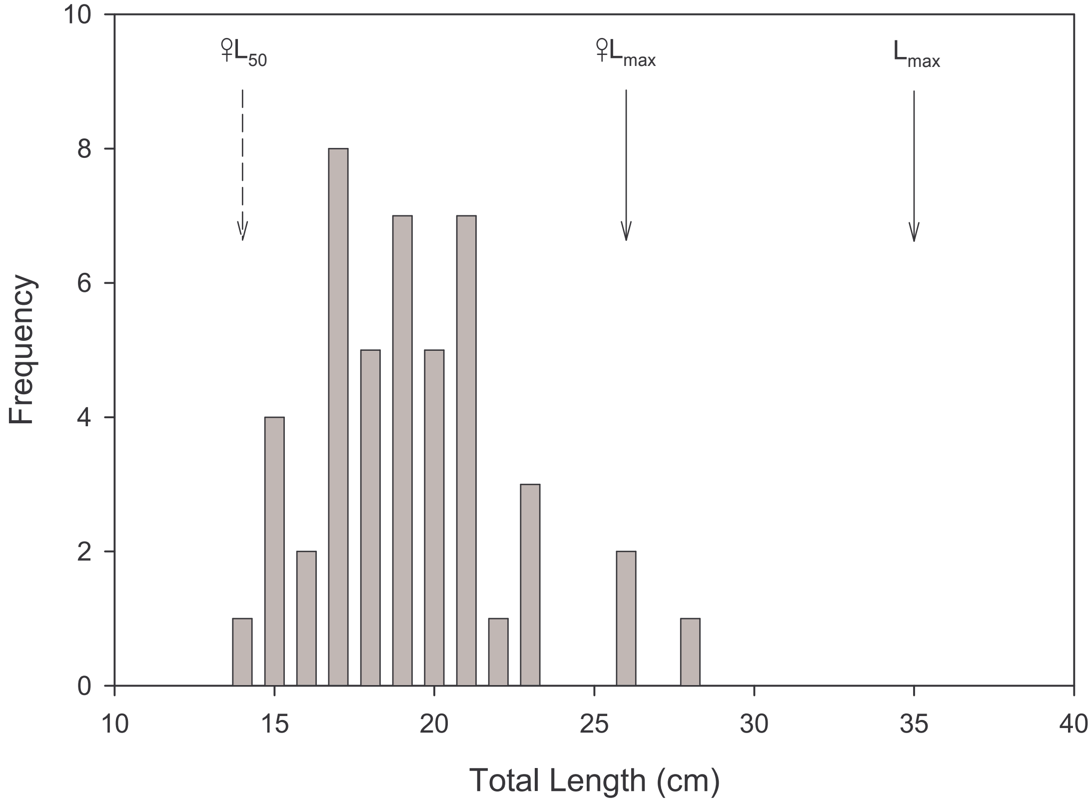

Figure 63. Size structure of *Cephalopholis cyanostigma*.

Cephalopholis microprion (Bleeker, 1852). Figure 64.

Figure 64. *Cephalopholis microprion*. Laser dots are separated by 39 mm.

An additional 10 specimens were added to our data set in 2010, yielding a combined total 13 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 from 12 to 13 cm. The updated mean size is 56% of the maximum reported length of 23 cm.

Cephalopholis urodeta (Forster, 1801). Figure 65.

Figure 65. *Cephalopholis urodeta*. Laser dots are separated by 39 mm.

An additional one (1) specimen was added to our data set in 2010, 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. However, the additional data did not change the mean total length estimate of 17 cm, which is 61% of the maximum reported length of 27 cm.

Plectropomus areolatus (Rüppell, 1830). Figure 66.

Figure 66. *Plectropomus aureolatus*. Laser dots are separated by 39 mm.

No new specimens were added to our data set in 2010, leaving a total five (5) individuals were captured on video suitable for length estimation. Due to low sample size, a size distribution is not presented. However, mean total length was 15 cm, which is 22% of the maximum reported length of 70 cm and 40% of the female L_{50} of 40 cm. None of the individuals captured on video had attained the reproductive size.

Plectropomus leopardus (Lacepède, 1802). Figure 67.

Figure 67. *Plectropomus leopardus*. Laser dots are separated by 36 mm.

A total three (3) individuals were captured on video suitable for length estimation. Due to low sample size, a size distribution is not presented. However, mean total length was 30 cm, which is 44% of the maximum reported length of 68 cm and 94% of the female L_{50} of 32 cm. The above information, when considered in light of size-specific sex ratios, suggests that about 55% of the individuals are mature females.

Plectropomus oligacanthus (Bleeker, 1854). Figure 68.

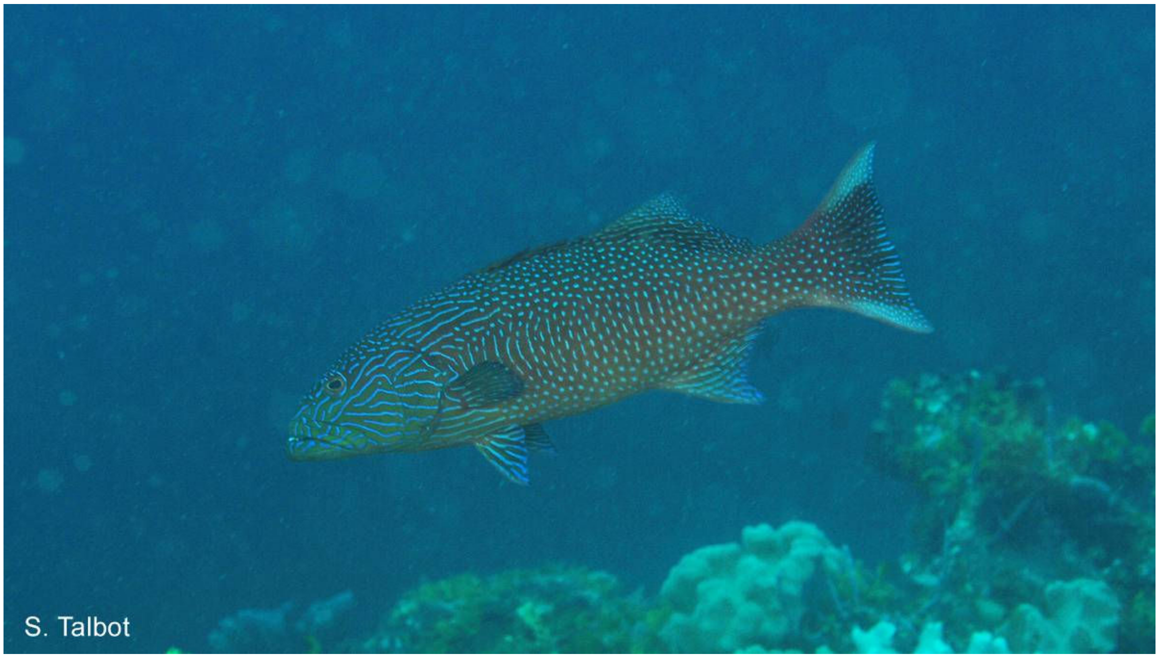

Figure 68. *Plectropomus oligacanthus*.

An additional 21 specimens were added to our data set in 2010, yielding a combined total 37 individuals captured on video suitable for length estimation. The additional data did not change the mean fork length estimate of 31 cm, which is 48% of the maximum reported length of 65 cm (Figure 69).

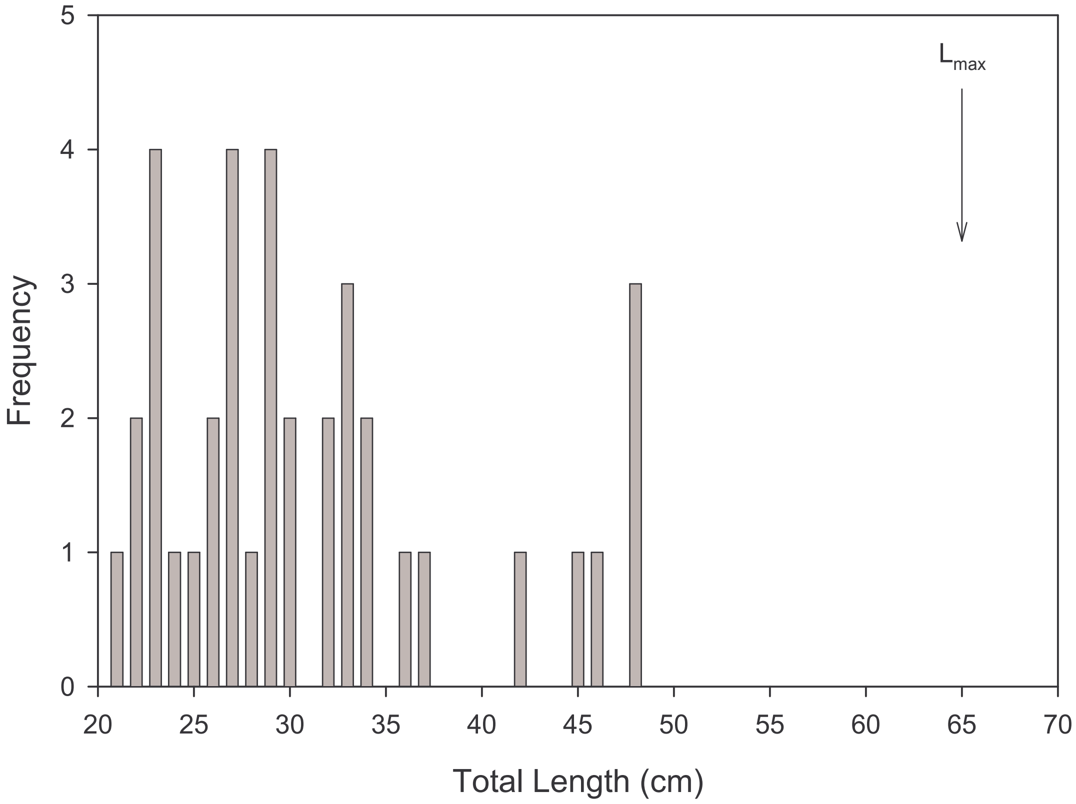

Figure 69. Size structure of *Plectropomus oligacanthus*.

Siganidae

Siganus javus (Linnaeus, 1766). Figure 70.

Figure 70. *Siganus javus*. Laser dots are separated by 39 mm.

An additional 17 specimens were added to our data set in 2010, yielding a combined total 33 individuals captured on video suitable for length estimation. The additional data included larger size classes than seen in 2009, and shifted mean "fork" length from 24 to 25 cm. The updated mean size is 47% of the maximum reported total length of 53 cm (Figure 71). The percentage presented here is a slight underestimate 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).

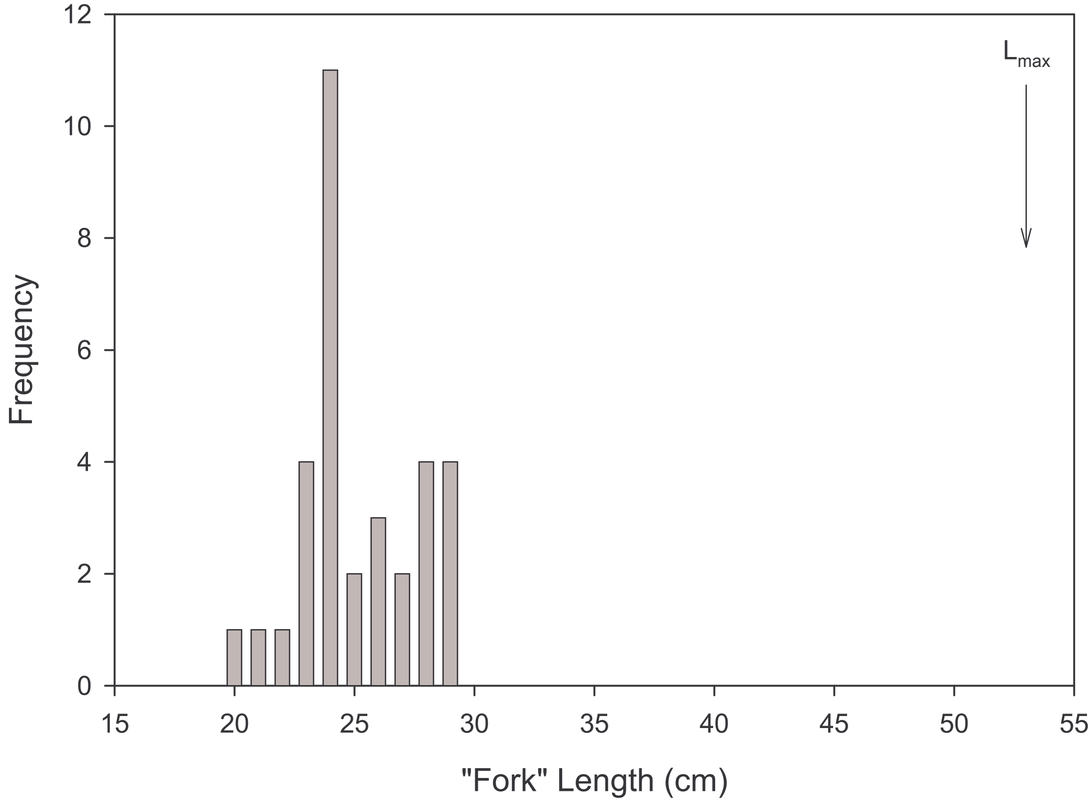

Figure 71. Size structure of *Siganus javus*.

Siganus lineatus (Valenciennes, 1835). Figure 72.

Figure 72. *Siganus lineatus*.

An additional 33 specimens were added to our data set in 2010, yielding a combined total 39 individuals captured on video suitable for length estimation. The additional data included larger size classes than seen in 2009, and shifted mean “fork” length from 25 to 26 cm. The updated mean size estimate is 64% of the maximum reported “fork” length of 41 cm (Figure 73).

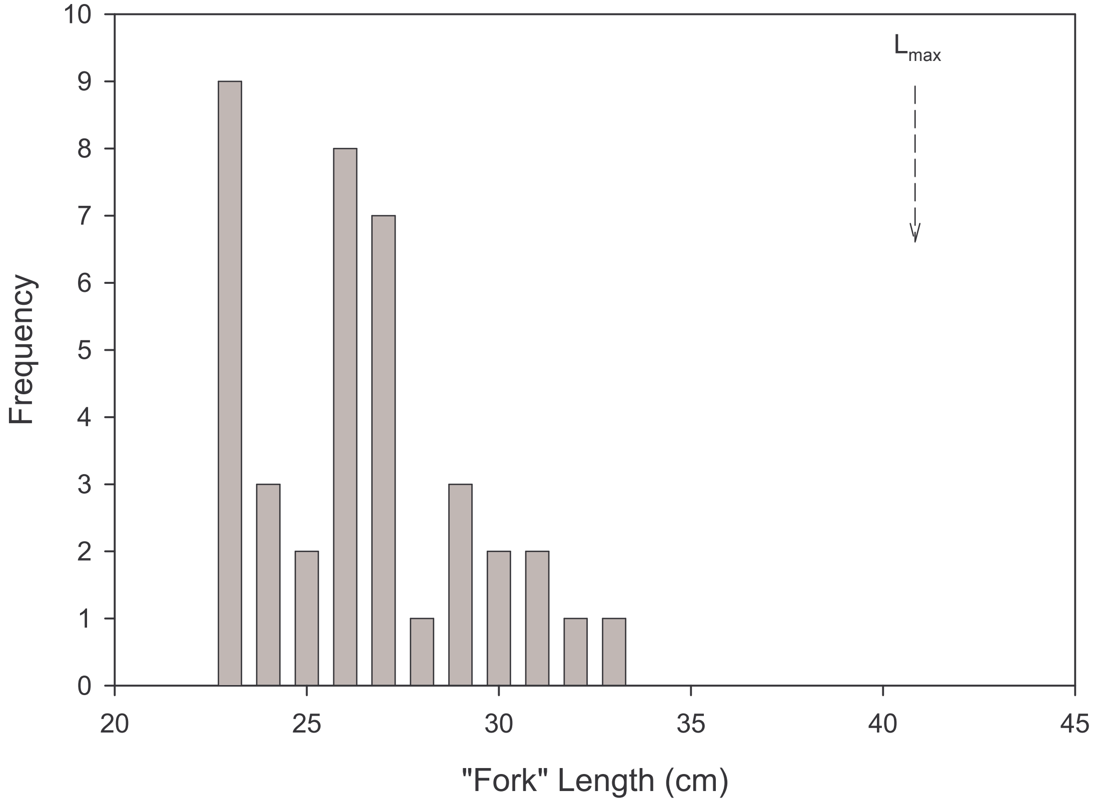

Figure 73. Size structure of *Siganus lineatus*.

DISCUSSION

Reproductive Analysis

The reproductive information we generated for *Lutjanus biguttatus* demonstrates that accurate, histology-based reproductive analysis can be performed in remote field locations. Importantly, the laboratory work and data analysis were accomplished over a three-week period during which we spent the majority of our time preparing for and conducting technical dive operations. Total time spent on histological processing and evaluation of gonad sections was approximately 18 hrs, or ~0.5 hr per fish processed. We found our work to be limited by number of available specimens, not the time necessary to process them. Suitably detailed life-history parameters can be generated concurrently with expeditionary research.

We did encounter several difficulties with our methods. Problems and potential solutions are discussed below.

The tissue embedding medium we used is water soluble. Because we were working outdoors and the humidity at Kamiali was high, our tissue blocks quickly became gummy, which made sectioning difficult. We attempted to overcome this problem by alternately sectioning tissue blocks on the microtome and replacing the block in the desiccating chamber until the block was once again firm, but the process was time consuming. We ultimately chose to place the desiccating chamber in full sunlight (thereby warming the chamber and further dehydrating the blocks), and found the method to work reasonably well. Others attempting similar work will not experience the same problems if working in an air-conditioned environment. If a high-humidity environment is anticipated, researchers may consider using a non-water soluble embedding kit; however, extra care will be necessary when dehydrating the tissues prior to infiltration and embedding.

Using gravimetric and volumetric methods, we also attempted to generate size-fecundity relationships. Because of equipment limitations (low precision in our battery-operated scale and our volumetric labware), we could not produce reliable batch fecundity estimates. A volumetric method using Gilson's fluid to liberate oocytes from ovaries, and Stempel pipettes to make accurate volumetric subsamples is described in Agger *et al*. (1974) and appears to be a viable option for generating important size-fecundity relationships in remote locations.

Finally, because our results are based on a low number of specimens, the reproductive parameters presented above should be considered preliminary. This is especially true with sex ratio estimates; the overall ratio is based on 22 individuals and no more than 5 individuals were present in any one size class used to evaluate the possibility of size-specific sex ratios. Further sex ratio patterns are variable within the lutjanids (Table 2); some species occur in a 1:1 ratio independent of size, whereas the sex ratio of other species varies predictably with size. We failed to detect other than a 1:1 sex ratio (within or across size classes) for *L. biguttatus*. However a larger sample size may lead to different conclusions.

Fishery Surveys

Most of the size structure information presented above should be viewed as preliminary. For 16 species, we captured too few individuals on video to describe population size structure. Size frequency plots for most of the remaining 25 species were based on relatively few individuals. In all cases, additional data would lead to more robust population characterizations. However, we have some evidence that the sample sizes on which our descriptions of population size structures are based are suitably large; for species captured on videotape in 2009 and 2010, the average change in length estimates between years (*i.e.*, resulting from additional data) was just 1 mm, or 0.5% of the 2009 average length estimate. For 14 species, there was no change in average length estimates between years.

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%. This increase is a result of locating additional reproductive studies for species examined in 2009, finding reproductive information for a high percentage of species added to our analysis in 2010, and the rapid reproductive analysis conducted in the present study. Despite the increase, reproductive parameters are unknown for nearly 60% of the exploited coral-reef 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*. (2008b) 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 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. In five of seven studies that examined sex ratios in species found at Kamiali (Davis & West 1992, Ferreira 1995, Kritzer 2004, Longenecker & Langston 2008, Huepel *et al*. 2009), data suggest the proportion of males in a population increases with length. The same trend would be expected for protogynous fishes (*e.g.*, Scaridae, Serranidae, and Labridae). Elsewhere in the Pacific the same pattern was found in each of three species examined (Longenecker & Langston 2008, Longenecker *et al*. 2008c) with a fourth species becoming increasingly female-biased with length (Langston *et al*. 2009). These results suggest 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. In the subset of species for which size at maturity is known, a typical individual is 104% of female reproductive size. Notably, no individual of one of the largest species considered in this subset (*Plectropomus areolatus*), was of mature size. Considering sex ratios (known for only seven species) suggests that approximately 20% of a population consists of reproductively mature females.

The above information provides important baselines that can be used to detect future shifts in reef-fish populations. To give the same information immediate conservation relevance, it must be viewed in the context of the village's subsistence fishing needs. Longenecker *et al*. (2008a) reported an average of two canoes engaged in fishing at any one time during the day. Kamiali's approximately 600 residents appear to obtain their primary source of dietary protein with relative ease. We suggest this observation is 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 the maximum and equal to female reproductive size can be used as evidence of robust fish populations.

Despite the apparent lack of overfishing at Kamiali Wildlife Management Area, residents do not consider themselves practitioners of reef-fish conservation. Longenecker *et al*. (2009) report a lack of gear restrictions, creel limits, minimum or maximum size limits, or seasonal closures for any species. Nor are Kamiali residents prohibited from fishing in any part of the wildlife management area. Finally, because of severe barotrauma to fish caught by handline in deeper water (Longenecker *et al*. 2008a), small individuals are not returned to the water. In other words, life-history-based fishery management methods are not currently used at Kamiali. We suggest that such methods would be appropriate for the larger-bodied species for which reproductively sized individuals are rare; however sufficient life-history information must first be generated for those species.

Until the time that life-history-based management techniques can be enacted, we think preserving aspects of village life consistent with marine conservation will be the most effective way to promote robust fish populations. Longenecker *et al*. (2009) outlined several characteristics of the village and its fishery that appear to reduce the risk of overfishing:

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). 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*. 2008a). 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*. 2008a). Catching fish by this method appears to be infrequent. Less common are homemade spearguns used while freediving. Because dive fins are not used, a depth refuge from spearing exists. Gillnets are rare, and we have not seen traps or weirs at Kamiali. Finally, lack of refrigeration reduces the motivation to catch more than can be used within a few days.

4) 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 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 Kamiali will be sustained by information necessary to make science-based environmental management decisions. There remains a scarcity of even the most-basic life history information for coral reef fishes. We suggest that more life history research is the most productive pathway to future reef-fish conservation at Kamiali Wildlife Management Area and throughout the extensive region where humans use coral reef fishes as the basis of their diet.

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