A Preliminary Assessment of Exploited Reef-fish Populations at Kamiali Wildlife Management Area, Papua New Guinea

Ken Longenecker, Allen Allison, Holly Bolick, Shelley James, Ross Langston,
Richard Pyle, David Pence, and Simon Talbot

Honolulu, Hawaii
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COVER

Conducting a laser-videogrammetry survey while ascending from a 67 m dive on an offshore pinnacle at Kamiali Wildlife Management Area. Photograph by Simon Talbot.

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Ken Longenecker,
Allen Allison,
Holly Bolick,
Shelley James,
Ross Langston,
and
Richard Pyle

Pacific Biological Survey
Bishop Museum
Honolulu, Hawaii 96817, USA

David Pence

University of Hawaii Diving Safety Program
Honolulu, Hawaii 96822, USA

Simon Talbot

University of Tasmania & Tasmanian Aquaculture and Fisheries Institute
Hobart, Tasmania 7001, Australia

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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 success of this effort is contingent upon Kamiali villagers preserving the natural environment such that biological field researchers are motivated to work in the area. Coral reef fishes may represent the biggest conservation challenge; fishes 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 used a combination of advanced diving technology and laser videogrammetry to describe the size structure of exploited species. We used the results of a literature review estimate the reproductive portion of each population and, where possible, the portion that is mature females. Finally, we used a series of interviews and observations to suggest factors that may influence the status of fishery resources at Kamiali.

A total 783 individuals representing 33 reef-fish species from 10 families were captured on video and analyzed. 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 27% of the species studied. Of these, mean individual length was at least 99% of female reproductive size. Sex-ratios are known for only four species. Considering only these species, an average 24% of individuals are mature females.

Kamiali does not have gear restrictions, creel limits, minimum or maximum size limits, or seasonal closures for any species. Nor are any areas closed to fishing. However, the effort required by Kamiali fishers to obtain a sufficient fish catch appears low. Overfishing may be prevented by several characteristics of the village and its fishery, such as: customary tenure, distance to commercial markets, a subsistence economy, 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

Bishop Museum is leading the Kamiali Initiative, 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. In 1996, the village established the Kamiali Wildlife Management Area, encompassing 32,000 ha of terrestrial habitat and 15,000 ha of the adjacent marine environment. Subsistence fishing and farming are the basis of the Kamiali economy and the focus of village life. However, residents need cash for basic supplies and services such as medicine and education. In 2006, 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 bench fees for laboratory use and room and board fees at the existing lodge. These fees will cover operating costs 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).

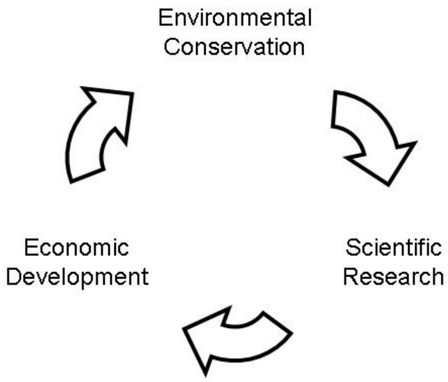

Figure 1. Conceptual illustration of Bishop Museum’s conservation initiative at Kamiali Wildlife Management Area.

A crucial requirement for the above model is that conservation efforts by Kamiali villagers must be sufficiently effective to ensure the natural environment continues to attract biological field researchers to the area. Coral reef fishes may represent the biggest challenge; fishes 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.

Evaluating the population status of Kamiali’s exploited reef fishes is challenging. Although the wildlife management area’s fringing and patch reefs are easily accessible, the majority of fishing occurs in depths beyond the limits of conventional open-circuit SCUBA (Longenecker *et al*. 2008a). Thus, there is a logistical obstacle to characterizing exploited reef-fish populations. We have addressed this difficulty by employing advanced diving techniques to access habitats targeted by village fishers.

Kamiali residents are intensely interested in the state of their marine environment and its fishes. The purpose of this study is to provide size-structure and life-history information about exploited reef fishes in Kamiali Wildlife Management Area. This information will allow residents to address basic questions such as, “has the fish I’m eating for dinner had the chance to reproduce?” or “will our community have an ample supply of food fish in the future?” The information will also serve as the basis for detecting changes in exploited reef-fish populations, including those brought about by 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.

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 94 m. Due to the lengthy decompression obligations incurred while working at these depths (*e.g.*, 3.25 hours for a 15-minute dive to 94 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).

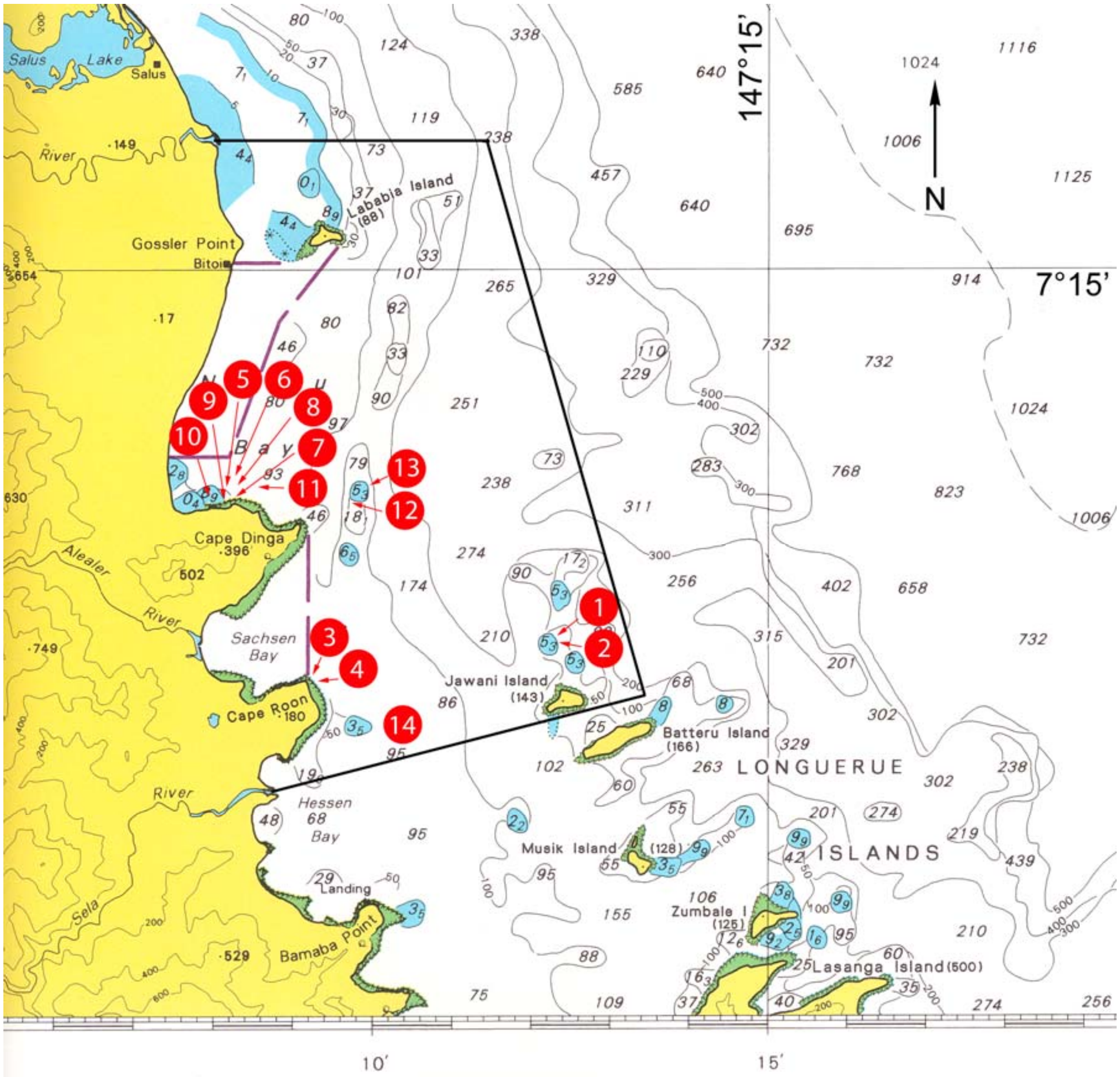

Figure 2. The marine portion of Kamiali Wildlife Management Area (circumscribed in black). Red dots indicate locations of survey sites (coordinates are given in Table 1). Adapted from chart Aus 523, published by the Australian Hydrographic Service. Depths are in meters.

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 ImageJ software (National Institutes of Health). Longenecker & Langston (2008) have demonstrated a nearly 1:1 relationship between estimated and actual fish lengths.

Table 1. List of marine sites surveyed at Kamiali Wildlife Management Area during 2009. Latitude and longitude were estimated by GPS using the WGS84 datum.

Survey	Date	Latitude	Longitude	Habitat	Max Depth (m)
1	30-Jul-09	7°19'47.00"S	147°12'24.57"E	Offshore Pinnacle	61
2	31-Jul-09	7°19'47.00"S	147°12'24.57"E	Offshore Pinnacle	67
3	1-Aug-09	7°20'06.03"S	147° 09'15.58"E	Nearshore Pinnacle to Fringing Reef	61
4	2-Aug-09	7°20'06.03"S	147° 09'15.58"E	Fringing Reef	30
5	5-Aug-09	7°17'54.65"S	147° 08'06.66"E	Nearshore Pinnacle to Fringing Reef	35
6	6-Aug-09	7°17'48.30"S	147° 08'06.29"E	Nearshore Pinnacle to Fringing Reef	57
7	7-Aug-09	7°17'53.34" S	147°08'13.80" E	Fringing Reef	27
8	8-Aug-09	7°17'50.16"S	147° 08'14.06"E	Fringing Reef	29
9	9-Aug-09	7°17'57.31"S	147° 07'58.89"E	Fringing Reef	20
10	9-Aug-09	7°17'56.18"S	147° 07'54.51"E	Fringing Reef	28
11	10-Aug-09	7°17'47.30"S	147° 08'41.51"E	Nearshore Pinnacle to Fringing Reef	73
12	11-Aug-09	7°18'30.11"S	147° 09'58.64"E	Offshore Pinnacle	34
13	12-Aug-09	7°18'30.11"S	147° 09'58.64"E	Offshore Pinnacle	94
14	13-Aug-09	7°20'37.30"S	147°10'07.51"E	Offshore Pinnacle	32

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 33 species representing 10 families (Caesionidae, Carangidae, 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 caesionids, carangids, 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.

Life History Information

A systematic literature review was conducted using the methods of Longenecker *et al*. 2008b to obtain estimates of maximum length (L_∞), 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

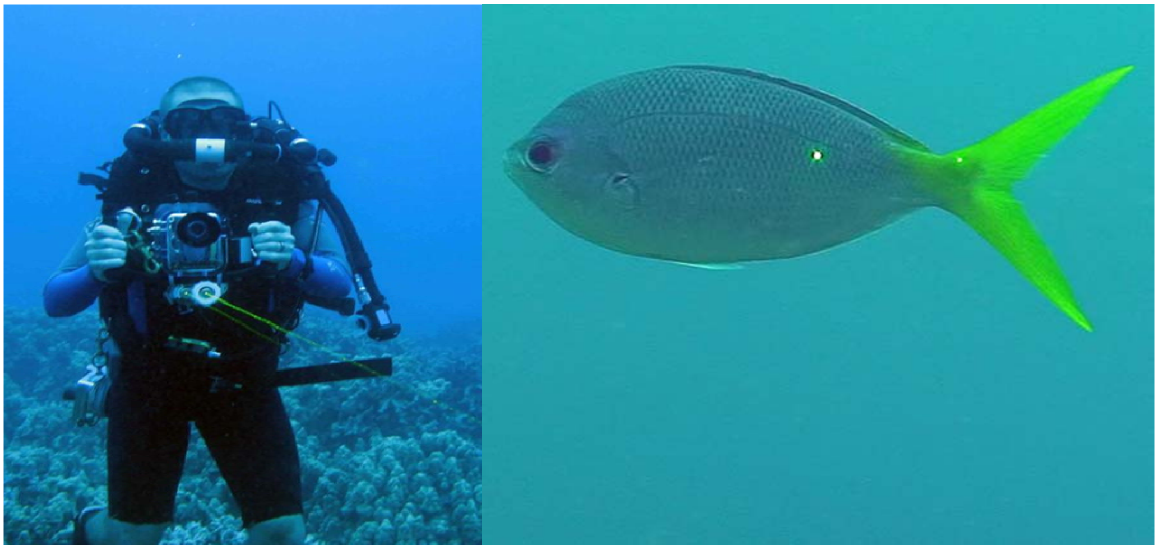

Figure 3. Laser videogrammetry, a non-destructive technique to estimate fish length. A diver operates a video camera fitted with parallel lasers (left); the lasers superimpose a measurement scale on the side of *Caesio cuning* (right).

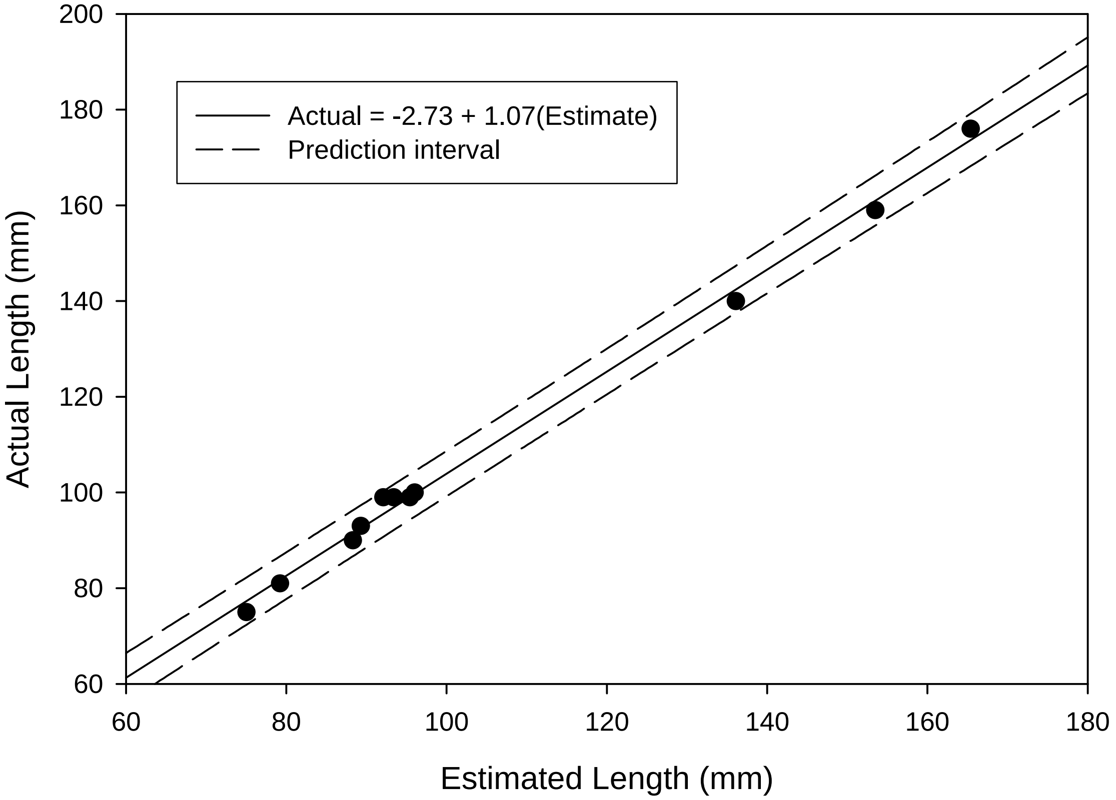

Figure 4. The relationship between estimated and actual lengths of specimens "captured" on videotape for laser videogrammetry and subsequently speared. The prediction interval suggests that 95% of length estimates will be within 0.5 cm of actual fish length (from Longenecker & Langston 2008).

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.

Fishing Practices

Local fishing practices were described through a combination of informal interviews and opportunistic observations during a two-week period from late June through early July, 2009. This information is included in the discussion section and presented in the context of conservation recommendations rather than forming a distinct section of the results.

RESULTS

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 33 species in Table 2. A total 783 individuals were captured on video and analyzed. The mean length of all individuals was 19 cm, representing 52% of the weighted mean maximum length of all 33 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 27% of the species studied. Of this subset, an individual *Lutjanus carponotatus*, *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 *Caranx melampygus* or *Plectropomus areolatus* had reached maturity. For all species combined, mean individual length was at least 99% of female reproductive size.

For three of the four species for which sex ratios have been published (*Lutjanus gibbus, Lutjanus vitta, Parupeneus multifasciatus)*, larger size classes are increasingly male dominated. For the fourth 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 studies of serranids, 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. Applying known size-specific sex ratios to the size structure information generated from laser-videogrammetry surveys study suggests, on average, 24% of the exploited reef fish population is composed of mature females.

Demographic information for each of 33 species is presented below. Each species account, with the exception of *Cephalopholis boenak*, includes an *in situ* image from Kamiali Wildlife Management Area. These accounts also include, when appropriate, size-frequency histograms for the individuals captured on video.

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

Taxon	n	Mean length (cm)	L_∞ (cm)	Female L_{50} (cm)	Male L_{50} (cm)	Sex ratio	Spawning season	Reproductive mode
CAESIONIDAE								
Caesio cuning	164	16	42[a,b]					Dioecious[c]
CARANGIDAE								
Carangoides bajad	23	26	51[a,b]					
Caranx melampygus	16	23	72[a,b]	31[d]				Dioecious[d]
Caranx papuensis	6	47	66[b,e]					
HAEMULIDAE								
Plectorhinchus lineatus	10	50	50[a]					
HOLOCENTRIDAE								
Myripristis adusta	13	18	32[a,f] (TL)					Dioecious[g]

Myripristis kuntee	41	12	19[a,f] (TL)					Dioecious[g]
Myripristis violacea	34	13	20[a,f] (TL)					Dioecious[g]
Neoniphon sammara	7	14	32[a,f] (TL)					Dioecious[g]
KYPHOSIDAE								
Kyphosus cinerascens	49	30	41[b,e]					
LETHRINIDAE								
Monotaxis grandoculis	19	20	60[a,f] (TL)					
LUTJANIDAE								
Lutjanus biguttatus	58	15	20[a,b]					
Lutjanus boutton	66	14	28[a,b]					Dioecious[h]
Lutjanus carponotatus	8	22	38[a,b]	19[i]		~1:1[i]	Oct – Dec[i]	
Lutjanus fulvus	18	18	39[a,b]					Dioecious[h]

Lutjanus gibbus	6	18	42[a,b]	<23[j]		Increasingly male-biased with length[k]		Dioecious[h]
Lutjanus russellii	39	22	43[a,b]	22[l]			Aug – Feb[m]	Dioecious[h]
Lutjanus semicinctus	13	20	34[a,b]					
Lutjanus vitta	18	15	37[a,b]	15[n]		Increasingly male-biased above 29 cm[o]	Sep – Apr[o,p]	Dioecious[h]
Macolor macularis	10	29	55[a,b]					
MULLIDAE								
Parupeneus barberinus	43	16	50[a,f] (TL)					
Parupeneus trifasciatus	7	20	35[a,f] (TL)					
Parupeneus cyclostomus	6	17	50[a,f] (TL)					
Parupeneus multifasciatus	21	14	26[a,q]	15[r]	15[r]	Increasingly male-biased with length[r]		Dioecious[r]
SERRANIDAE								
Anyperodon leucogrammicus	7	26	52[a]					Protogynous[s]

Cephalopholis boenak	10	17	24[a]	15[t]	16[t]	Apr – Oct[t]	Protogynous[t]
Cephalopholis cyanostigma	22	19	35[a]	<14[u]			Protogynous[s]
Cephalopholis microprion	3	12	23[a]				Protogynous[s]
Cephalopholis urodeta	3	17	27[a]				Protogynous[s]
Plectropomus areolatus	5	15	70[a]	40[v]	48[v]	Jan – May[v]	Protogynous[s]
Plectropomus oligacanthus	16	31	65[a]				Protogynous[s]
SIGANIDAE							
Siganus javus	16	24	53[e,f] (TL)				
Siganus lineatus	6	25	41[a,b]	>23[w]		Year round[x]	Dioecious[t]

(a) Allen & Swainston 1993; (b) using length-length relationship from Froese & Pauly 2009; (c) Carpenter 1998; (d) Sudekum *et al*. 1991; (e) Randall *et al*. 1990; (f) no length-length relationship available; (g) Thresher 1984 ; (h) Allen 1985; (i) Kritzer 2004; (j) Heupel *et al*. 2009 (all females > 23 cm FL were mature); (k) results from Heupel *et al*. 2009 suggest the proportion of females is inversely related to size; (l) Kritzer in Williams *et al*. 2002; (m) authors' interpretation of GSI and developmental stages in Sheaves 1995; (n) Davis & West 1993; (o) 1:1 to 29 cm, then %F = 1.986 – 0.00534(FL) based on authors' interpretation of data in Davis & West 1992; (p) Loubens 1980; (q) Longenecker & Langston unpublished data: FL = 0.2121 + 0.8736(TL), $r^2 = 0.993$, n = 67; (r) Longenecker & Langston 2008, %F = 141.3 – 0.6167(FL in mm) with all individuals male above 225 mm; (s) Heemstra & Randall 1993; (t) Chan & Sadovy 2002; (u) 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; (v) Rhodes & Tupper 2007; (w) Woodland 1990 reports the smallest individual to spawn was 23 cm; (x) Hamilton *et al*. 2004 report year-round spawning aggregations during the first quarter of the moon phase.

Species Accounts

Caesionidae

Caesio cuning (Bloch, 1791). Figure 5.

Figure 5. *Caesio cuning*.

A total 164 individuals were captured on video suitable for length estimation. The mean fork length was 16 cm, which is 39% of the maximum reported length of 42 cm (Figure 6).

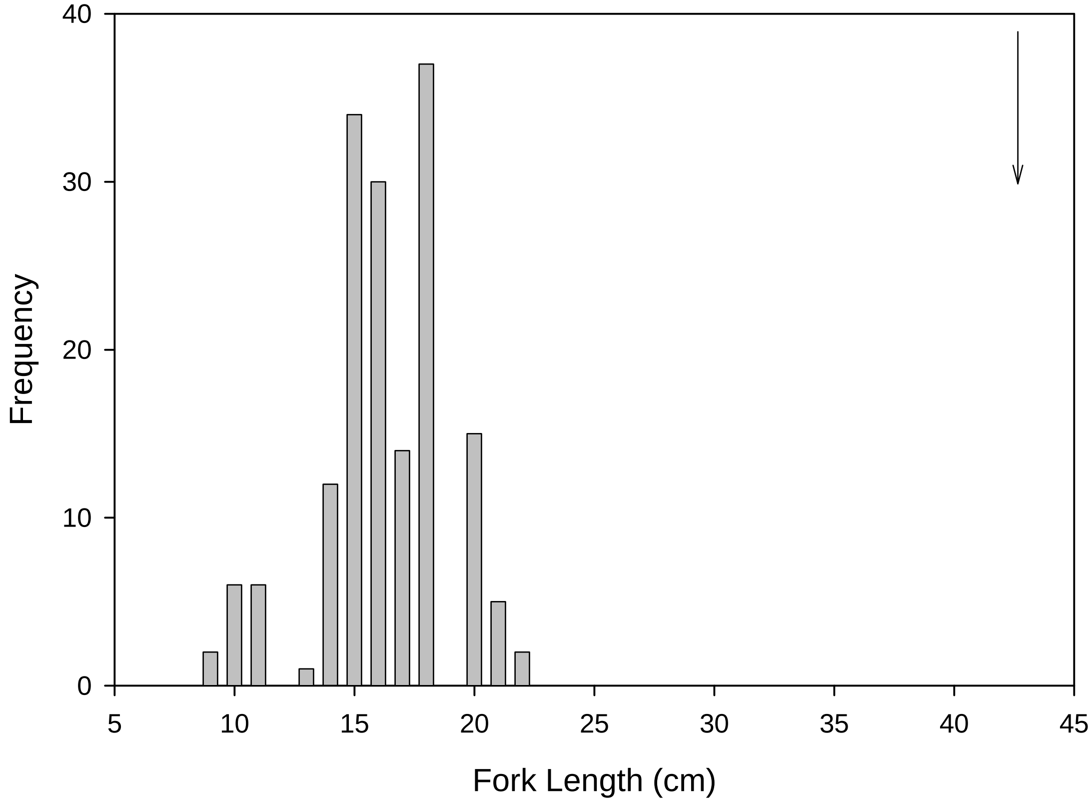

Figure 6. Size structure of *Caesio cuning*. The arrow at right indicates maximum reported fork length.

<u>Carangidae</u>

Carangoides bajad (Forsskål, 1775). Figure 7.

Figure 7. *Carangoides bajad* (left of center). Laser dots are separated by 3.9 mm.

A total 23 individuals were captured on video suitable for length estimation. The mean fork length was 26 cm, which is 52% of the maximum reported length of 51 cm (Figure 8).

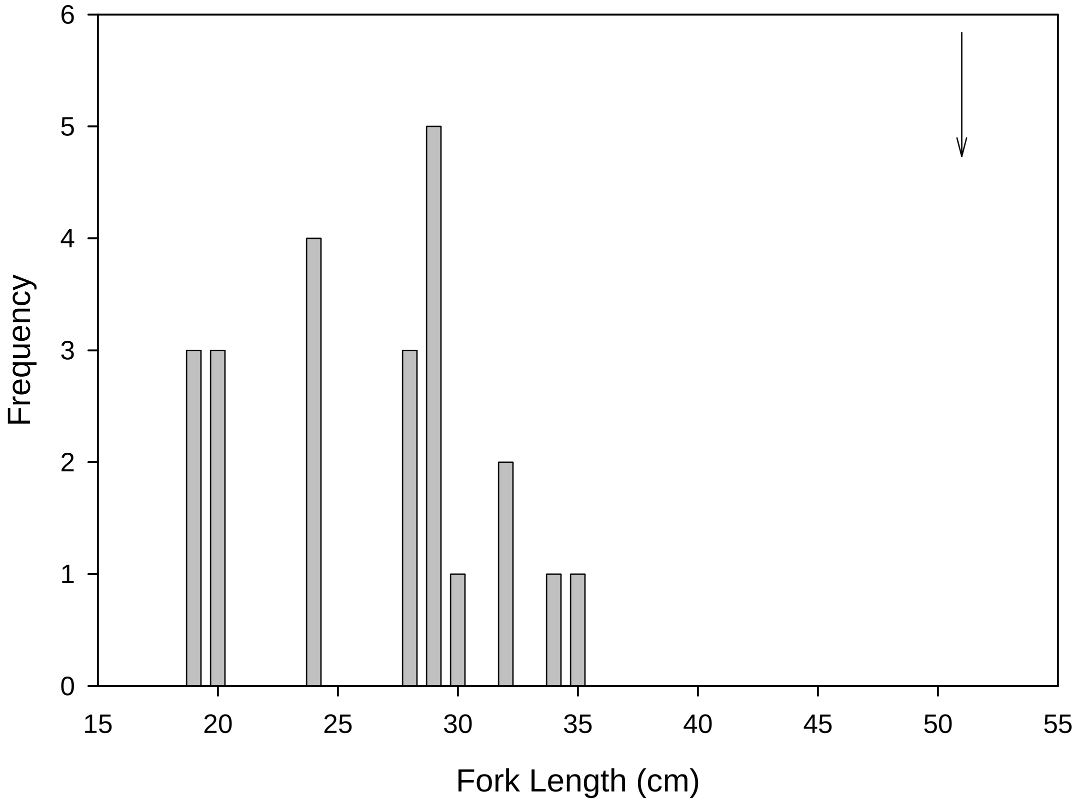

Figure 8. Size structure of *Carangoides bajad*. The arrow at right indicates maximum reported fork length.

Caranx melampygus Cuvier, 1833. Figure 9.

Figure 9. *Caranx melampygus*.

A total 16 individuals were captured on video suitable for length estimation. The mean fork length was 23 cm, which is 32% of the maximum reported length of 72 cm and 74% of the female L_{50} of 35 cm (Figure 10). None of these individuals had attained the reported female reproductive size.

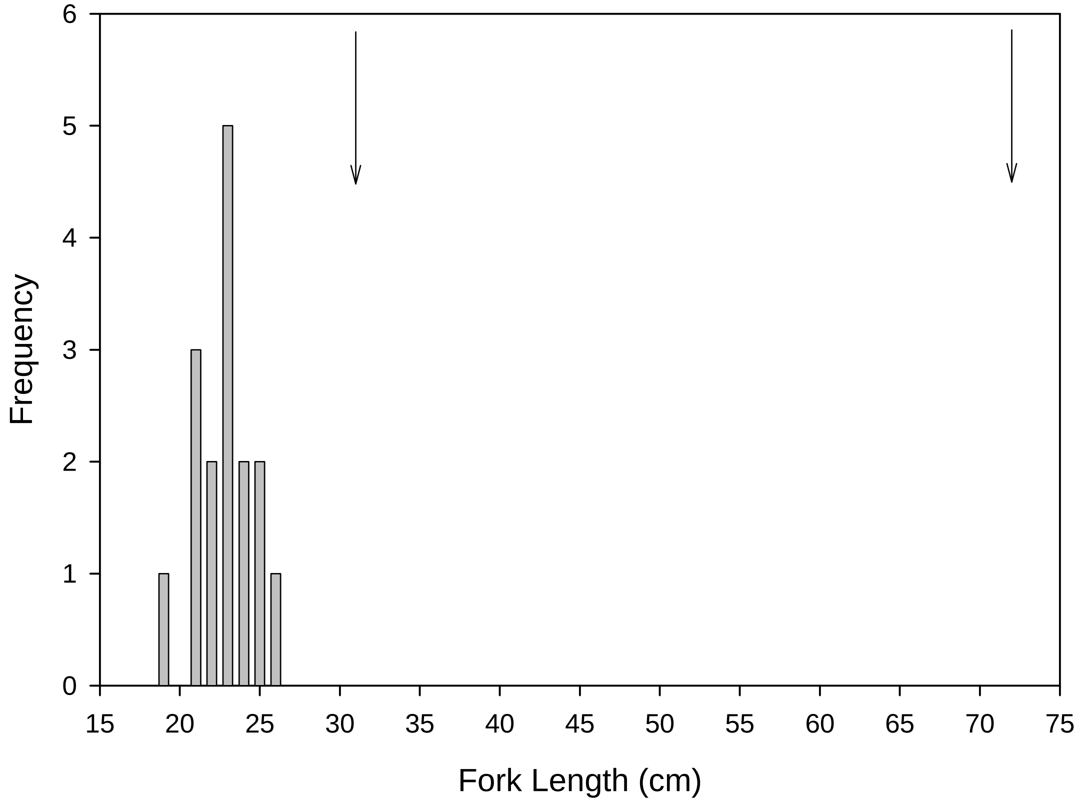

Figure 10. Size structure of *Caranx melampygus*. The arrows indicate female L_{50} (left) and maximum reported fork length (right).

Caranx papuensis Alleyne & MacLeay, 1877. Figure 11.

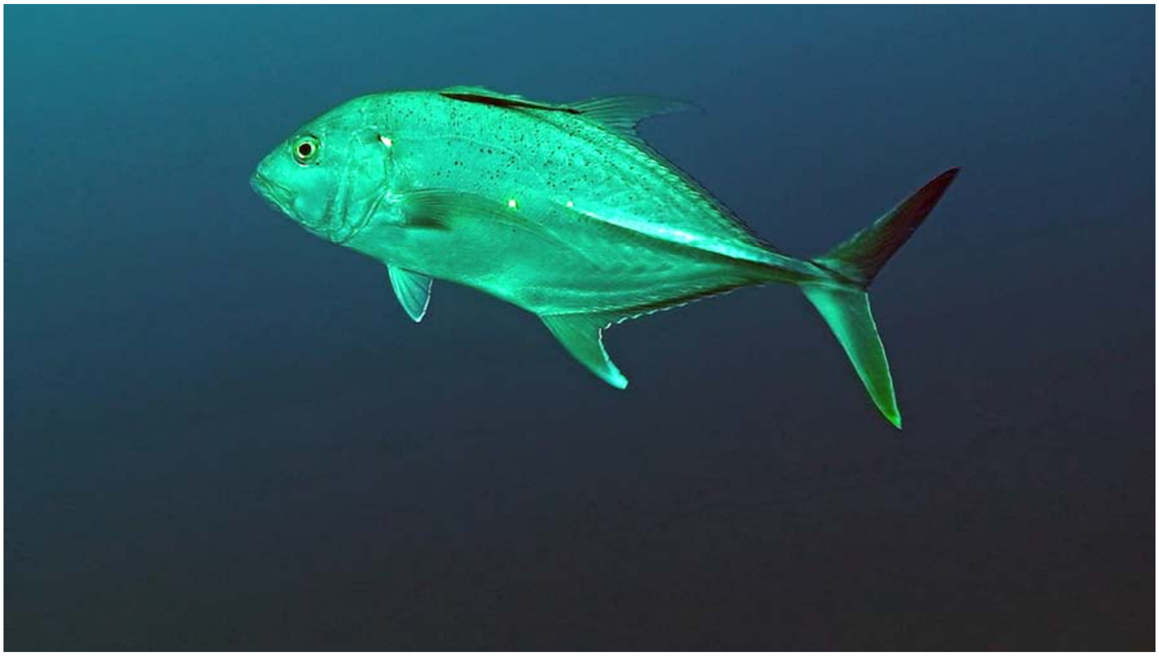

Figure 11. *Caranx papuensis* (with a remora attached near the origin of the first dorsal fin). Laser dots are separated by 3.9 mm.

A total six (6) individuals were 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.

Haemulidae

Plectorhinchus lineatus (Linnaeus, 1758). Figure 12.

Figure 12. *Plectorhinchus lineatus*. Laser dots are separated by 3.9 mm.

A total ten (10) 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 35 cm, which is 70% of the maximum reported length of 50 cm.

Holocentridae

Myripristis adusta Bleeker, 1853. Figure 13.

Figure 13. *Myripristis adusta*.

A total 13 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 18 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 = 0.7938 + 0.9255(TL); $r^2 = 0.726$; n = 13) to published maximum length, yielding a maximum fork length of 30 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 60% of the maximum length.

Myripristis kuntee Valenciennes, 1831. Figure 14.

Figure 14. *Myripristis kuntee*. Laser dots are separated by 3.9 mm.

A total 41 individuals were captured on video suitable for length estimation. Mean fork length was 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 15).

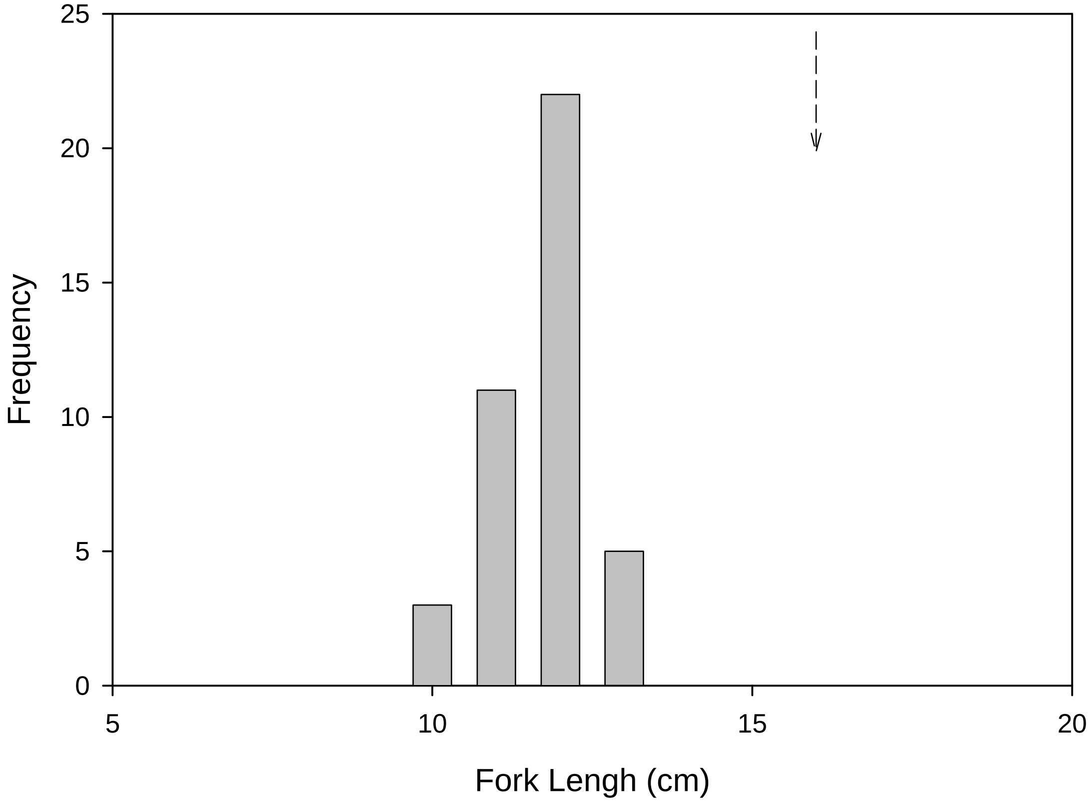

Figure 15. Size structure of *Myripristis kuntee*. The arrow at right indicates estimated maximum fork length.

Myripristis violacea Bleeker, 1851. Figure 16.

Figure 16. *Myripristis violacea*.

A total 34 individuals were captured on video suitable for length estimation. Mean fork length was 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 17).

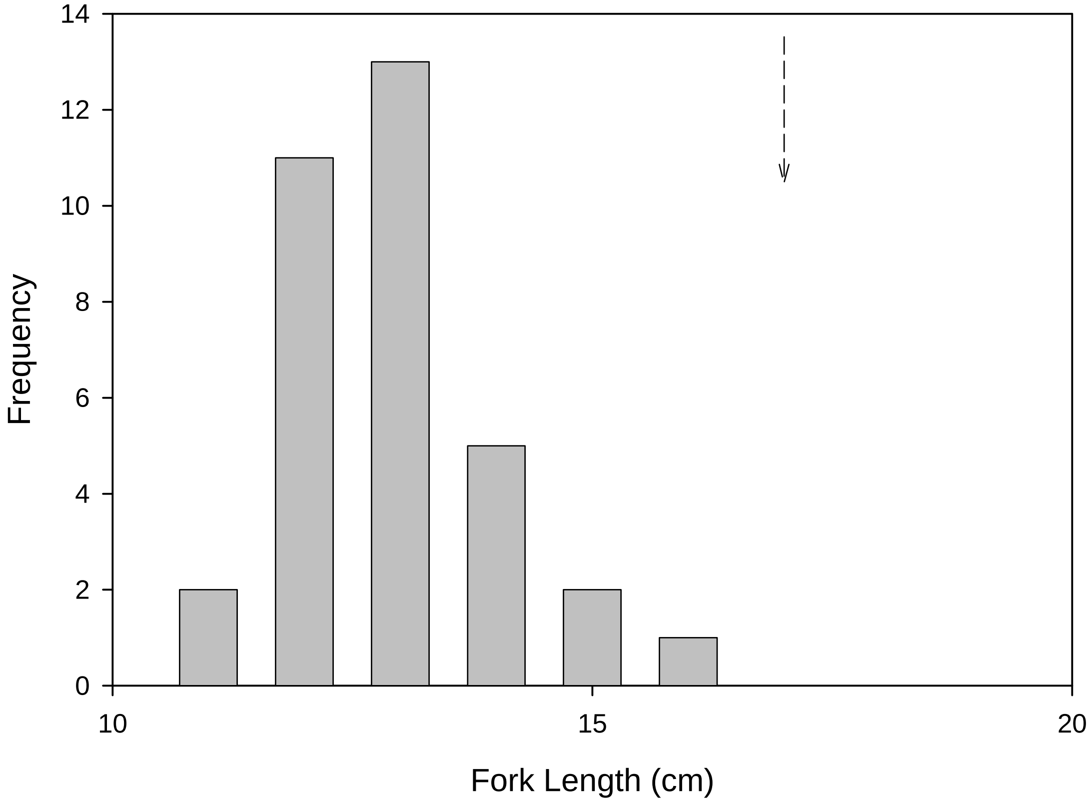

Figure 17. Size structure of *Myripristis violacea*. The arrow at right indicates estimated maximum fork length.

Neoniphon sammara (Forsskål, 1775). Figure 18.

Figure 18. *Neoniphon sammara*. Laser dots are separated by 3.9 mm.

A total seven (7) 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 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.

Kyphosidae

Kyphosus cinerascens (Forsskål, 1775). Figure 19.

Figure 19. *Kyphosus cinerascens*. Laser dots on the fish near center are separated by 3.9 mm.

A total 49 individuals were captured on video suitable for length estimation. The mean fork length was 30 cm, which is 72% of the maximum reported length of 41 cm (Figure 20).

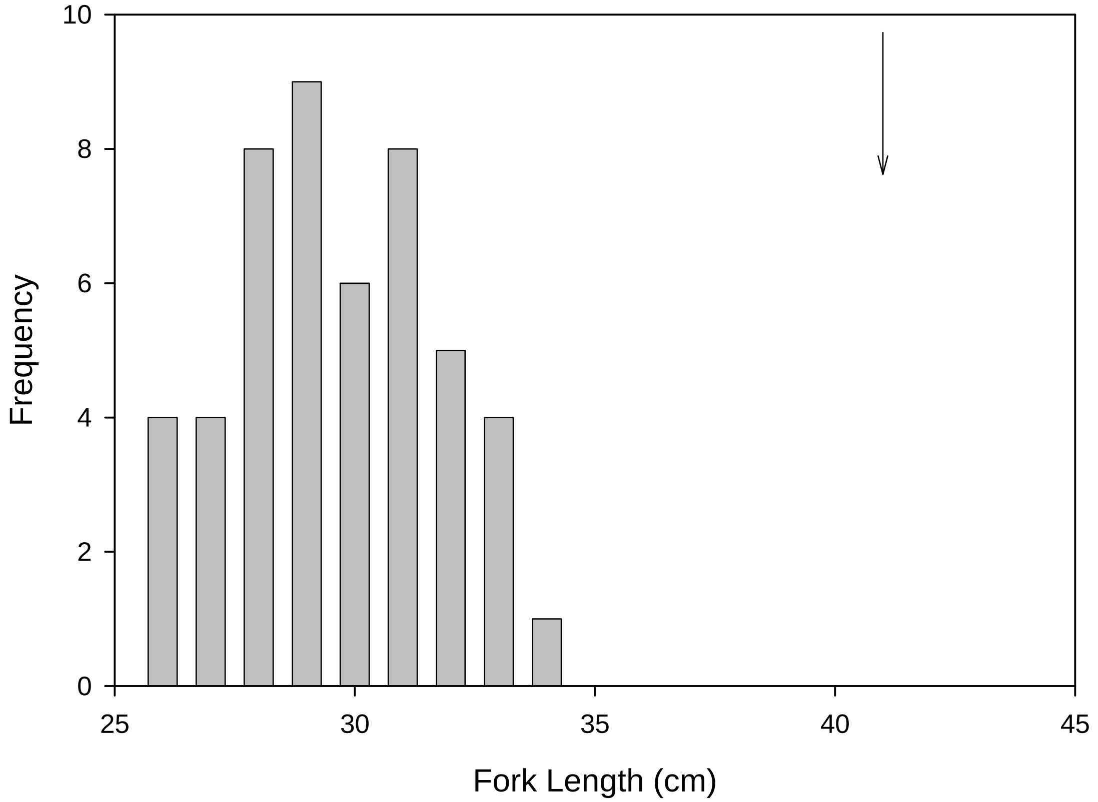

Figure 20. Size structure of *Kyphosus cinerascens*. The arrow at right indicates maximum reported fork length.

Lethrinidae

Monotaxis grandoculis (Forsskål, 1775). Figure 21.

Figure 21. *Monotaxis grandoculis* juvenile (left) and adult (right).

A total 19 individuals were captured on video suitable for length estimation. Mean fork length was 20 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 35% of the maximum length (Figure 22).

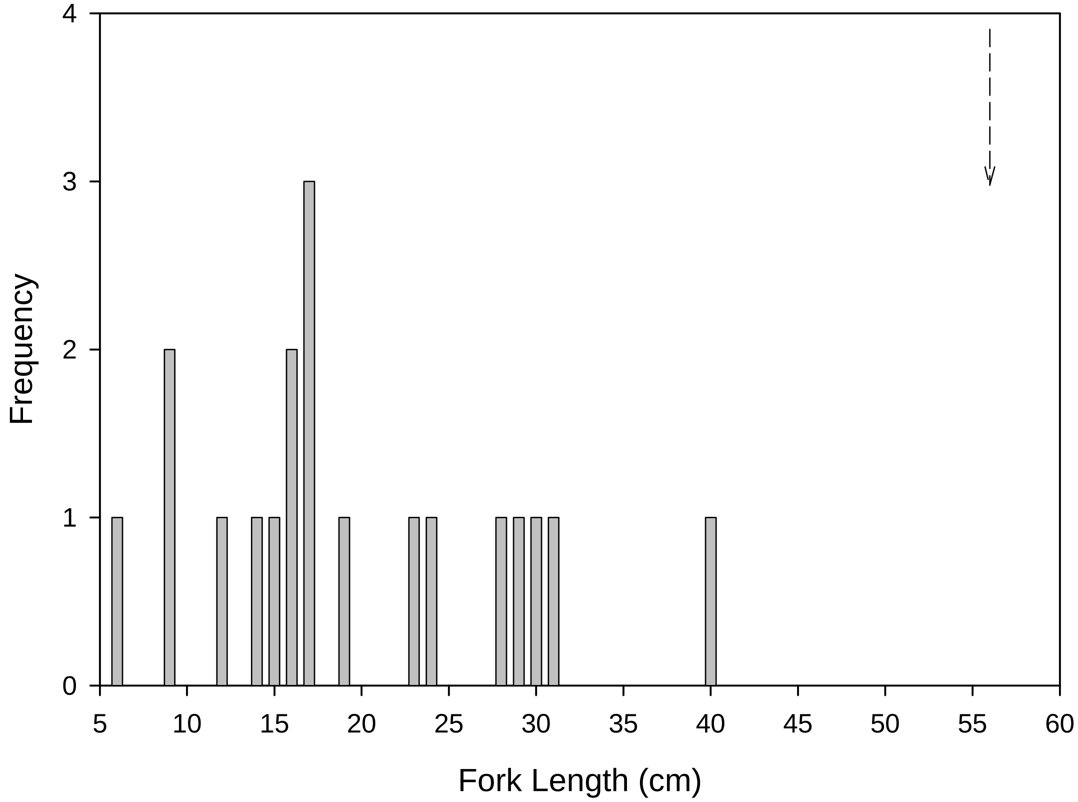

Figure 22. Size structure of *Monotaxis grandoculis*. The arrow at right indicates estimated maximum fork length.

Lutjanidae

Lutjanus biguttatus (Valenciennes, 1830). Figure 23.

Figure 23. *Lutjanus biguttatus*. Laser dots on the fish above left of center are separated by 3.9 mm.

A total 58 individuals were captured on video suitable for length estimation. The mean fork length was 15 cm, which is 77% of the maximum reported length of 20 cm (Figure 24).

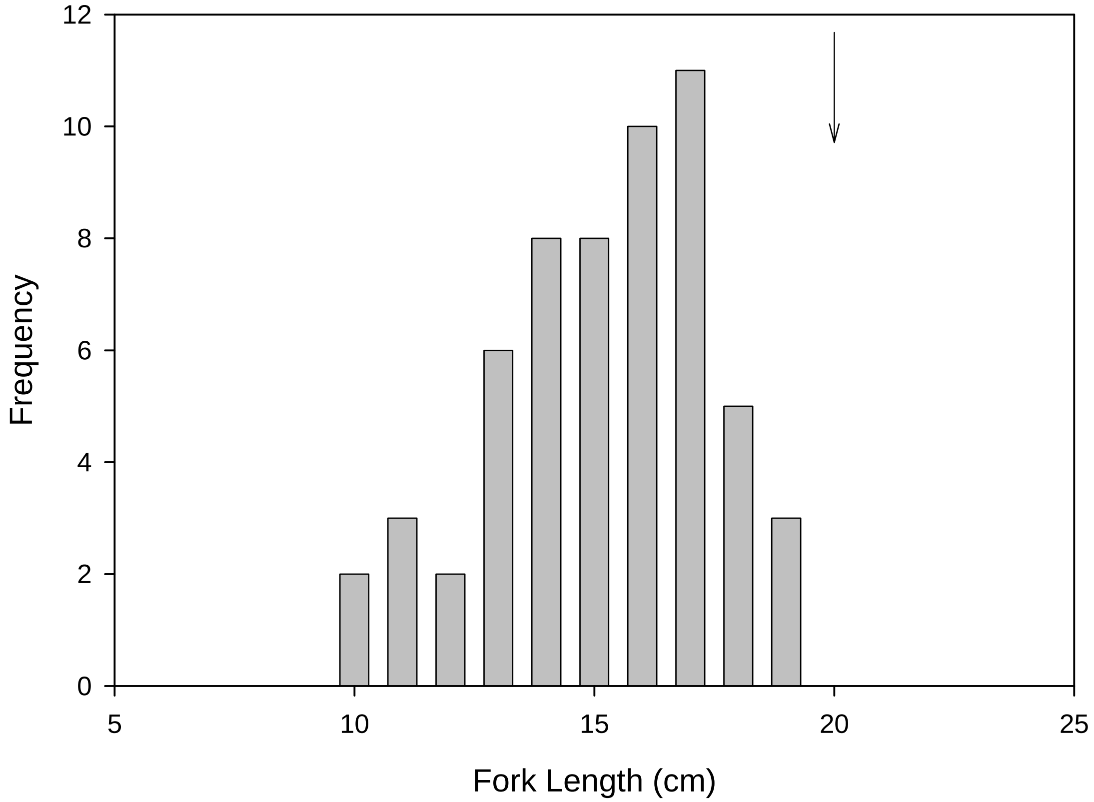

Figure 24. Size structure of *Lutjanus biguttatus*. The arrow at right indicates maximum reported fork length.

Lutjanus boutton (Lacepède, 1802). Figure 25.

Figure 25. *Lutjanus boutton*. Laser dots are separated by 3.9 mm.

A total 66 individuals were captured on video suitable for length estimation. The mean fork length was 14 cm, which is 48% of the maximum reported length of 28 cm (Figure 26).

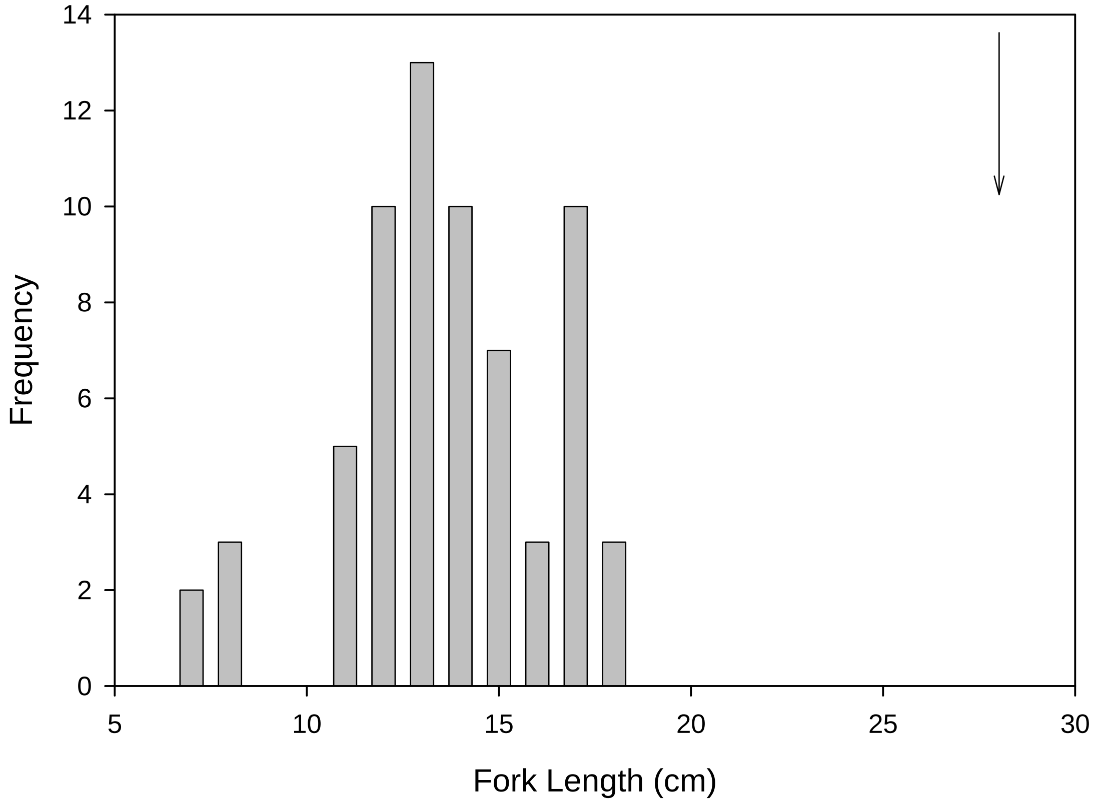

Figure 26. Size structure of *Lutjanus boutton*. The arrow at right indicates maximum reported fork length.

Lutjanus carponotatus (Richardson, 1842). Figure 27.

Figure 27. *Lutjanus carponotatus*.

A total eight (8) 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 22 cm, which is 58% of the maximum reported length of 38 cm and 117% of the female L_{50} of 19 cm. The above information, when considered in light of the approximately 1:1 sex-ratio, suggests that about 38% of the population is mature females.

Lutjanus fulvus (Forster, 1801). Figure 28.


S. Talbot

Figure 28. *Lutjanus fulvus*.

A total 18 individuals were captured on video suitable for length estimation. The mean fork length was 18 cm, which is 47% of the maximum reported length of 39 cm (Figure 29).

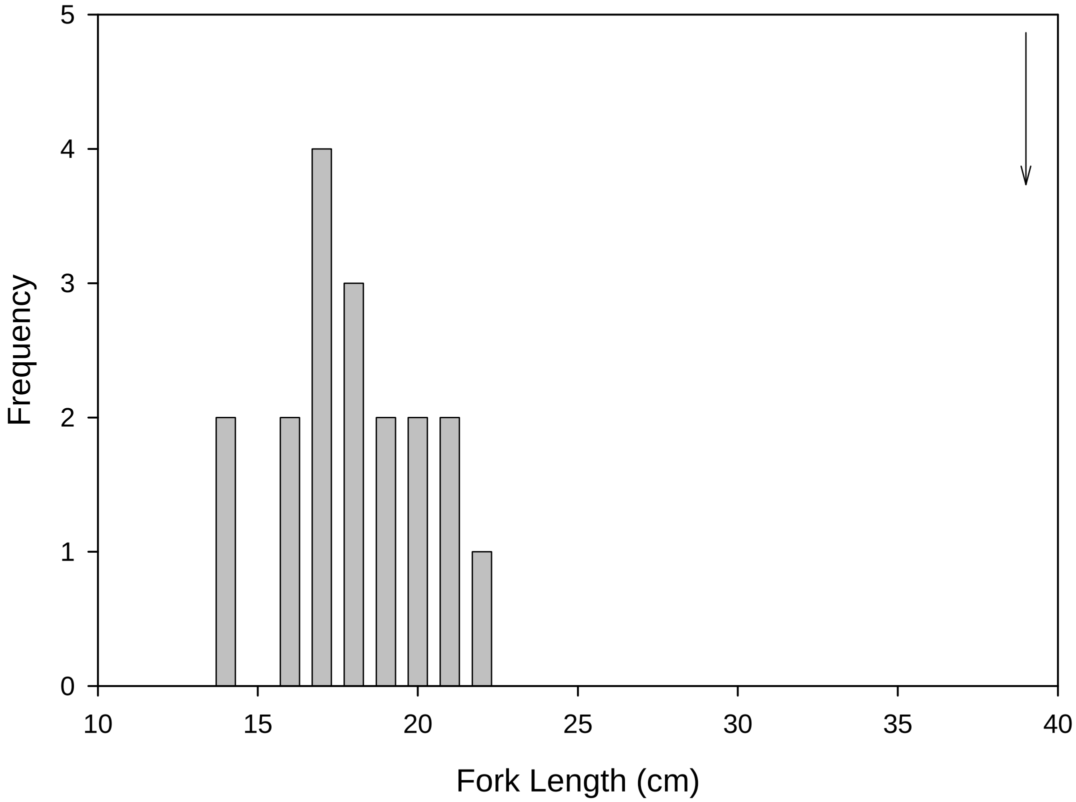

Figure 29. Size structure of *Lutjanus fulvus*. The arrow at right indicates maximum reported fork length.

Lutjanus gibbus (Forsskål, 1775). Figure 30.

Figure 30. *Lutjanus gibbus*. Laser dots are separated by 3.9 mm.

A total six (6) 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 18 cm, which is 43% of the maximum reported length of 42 cm and at least 80% of female reproductive size of 23 cm (the study providing reproductive information found all individuals of at least 23 cm to be mature, therefore this length is an over-estimate of female size at maturity). Approximately 25% of the individuals captured on video were mature females.

Lutjanus russellii (Bleeker, 1849). Figure 31.

Figure 31. *Lutjanus russellii*. Laser dots on the left fish are separated by 3.9 mm.

A total 39 individuals were captured on video suitable for length estimation. The mean fork length was 22 cm, which is 50% of the maximum reported length of 43 cm and 100% of the female L_{50} of 22 cm (Figure 32). The possibility of a size-specific sex ratio has not been examined for this species. However, if a 1:1 ratio is assumed, 23% of the population is mature females.

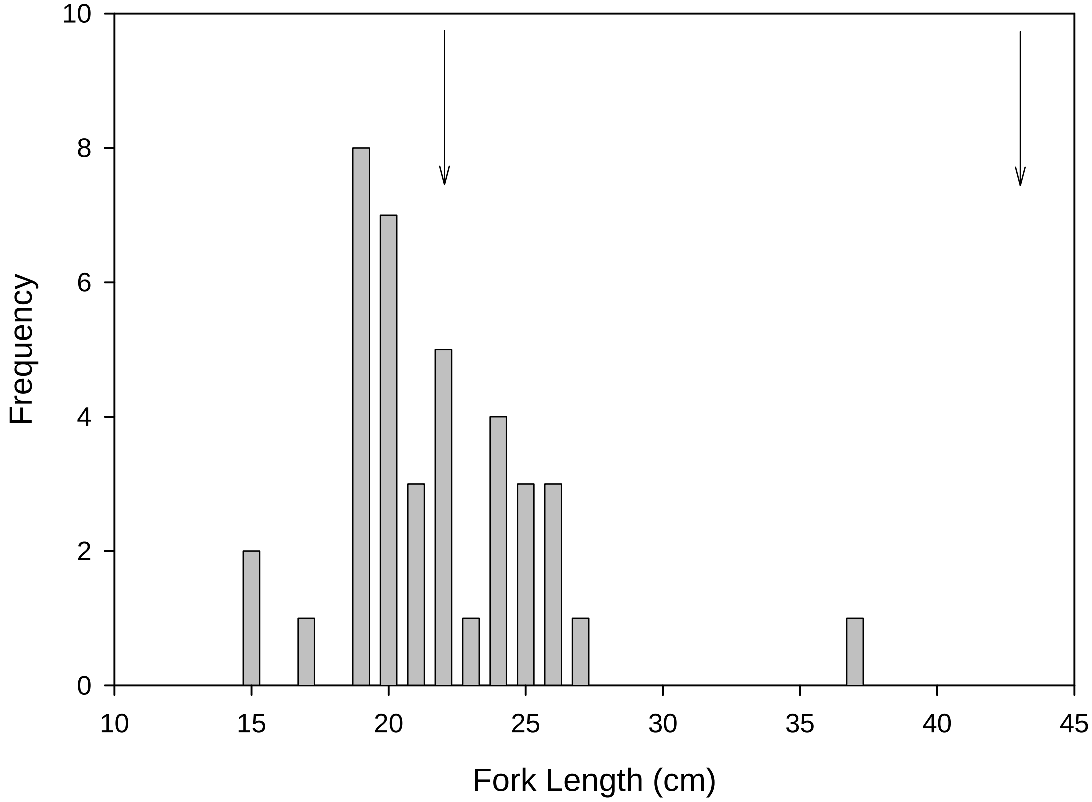

Figure 32. Size structure of *Lutjanus russellii*. The arrows indicate female L_{50} (left) and maximum reported fork length (right).

Lutjanus semicinctus Quoy & Gaimard, 1824. Figure 33.

Figure 33. *Lutjanus semicinctus*. Laser dots are separated by 3.9 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, mean fork length was 20 cm, which is 59% of the maximum reported length of 34 cm.

Lutjanus vitta (Quoy & Gaimard, 1824). Figure 34.

Figure 34. *Lutjanus vitta*. Laser dots are separated by 3.9 mm.

A total 18 individuals were 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 35). The above information, when considered in light of size-specific sex ratios, suggests that about 25% of the population is mature females.

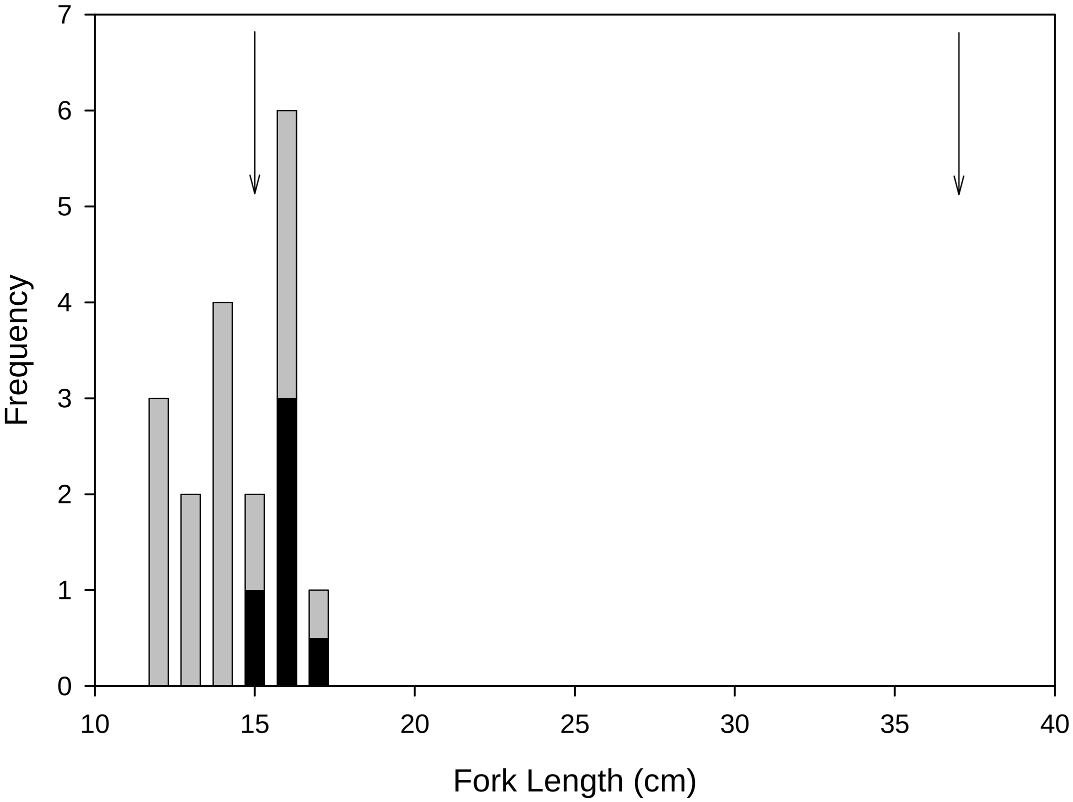

Figure 35. Size structure of *Lutjanus vitta*. The arrows indicate female L_{50} (left) and maximum reported fork length (right). The dark portion of bars represent estimated number of mature females, light portion represents all other individuals.

Macolor macularis Fowler, 1931. Figure 36.

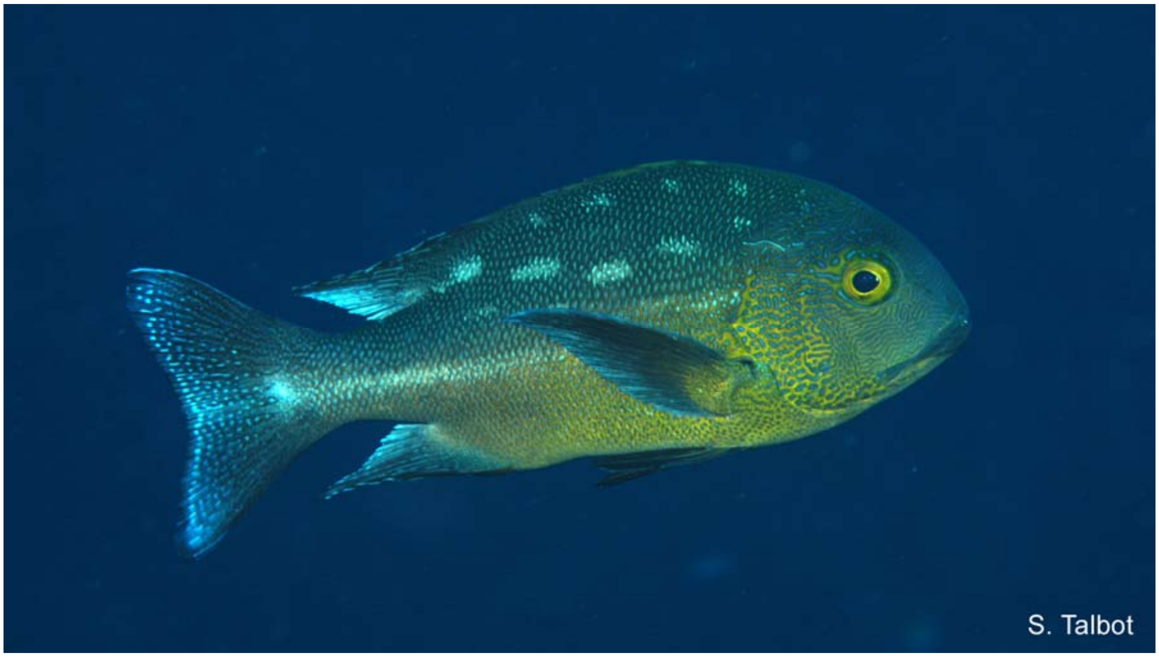

Figure 36. *Macolor macularis*.

A total ten (10) 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 29 cm, which is 52% of the maximum reported length of 55 cm.

Mullidae

Parupeneus barberinus (Lacepède, 1801). Figure 37.

Figure 37. *Parupeneus barberinus*. Laser dots are separated by 3.9 mm.

A total 43 individuals were captured on video suitable for length estimation. Mean fork length was 16 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 this population is 35% of the maximum length (Figure 38).

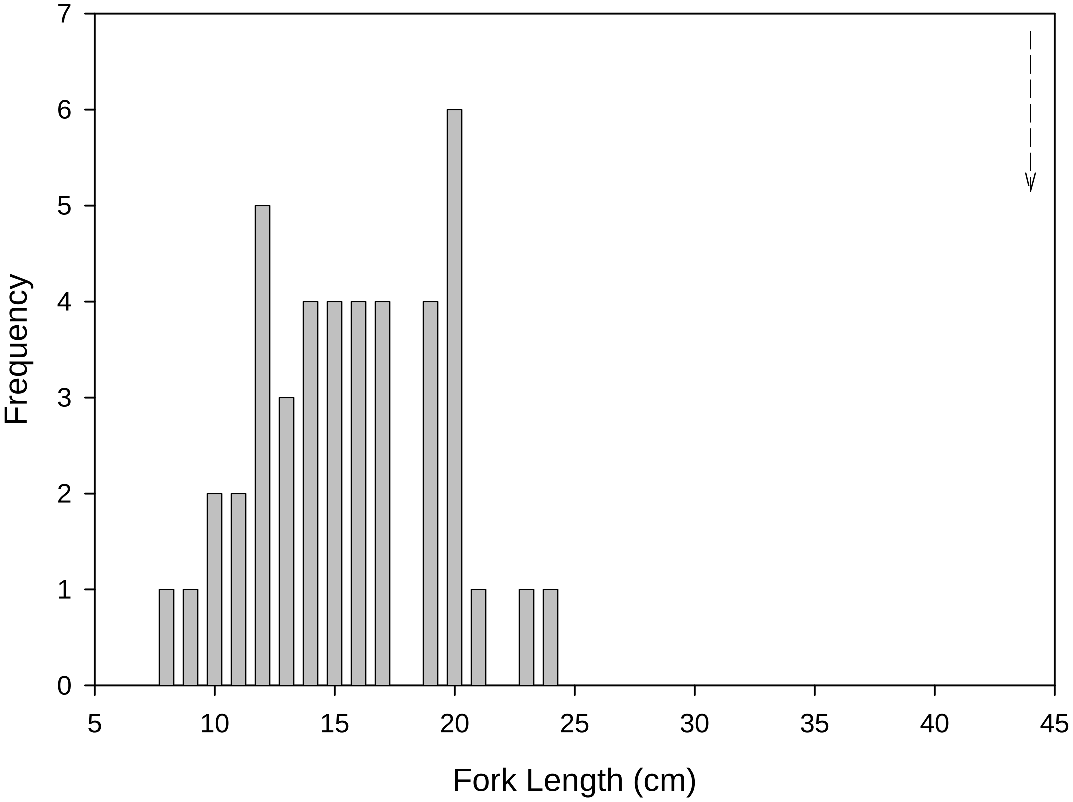

Figure 38. Size structure of *Parupeneus barberinus*. The arrow at right indicates estimated maximum fork length.

Parupeneus cyclostomus (Lacepède, 1801). Figure 39.

Figure 39. *Parupeneus cyclostomus*.

A total six (6) 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 17 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 39% of the maximum length.

Parupeneus multifasciatus (Quoy & Gaimard, 1825). Figure 40.

Figure 40. *Parupeneus multifasciatus*.

A total 21 individuals were captured on video suitable for length estimation. The mean fork length was 14 cm, which is 54% of the maximum reported length of 26 cm and 94% of the female L_{50} of 15 cm (Figure 41). The above information, when considered in light of size-specific sex ratios and maximum female size, suggests that about 18% of the population is mature females.

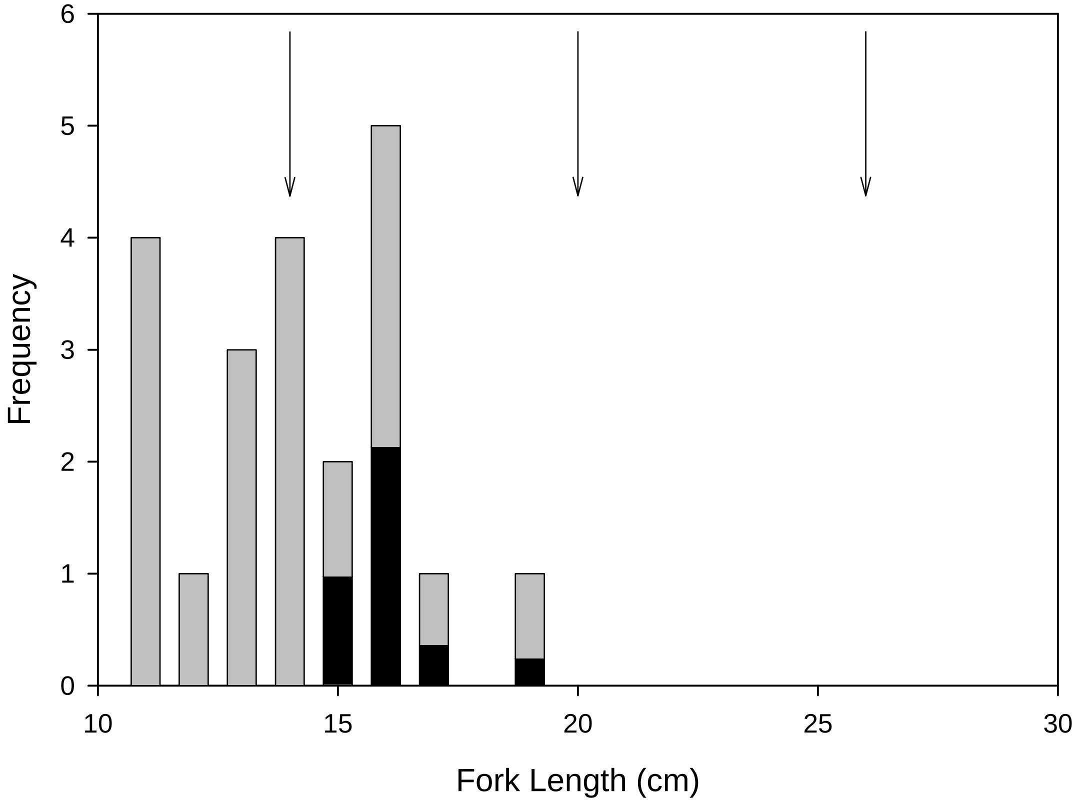

Figure 41. Size structure of *Parupeneus multifasciatus*. The arrows indicate female L_{50} (left), maximum female size (middle), and maximum reported fork length (right). The dark portion of bars represent estimated number of mature females, light portion represents all other individuals.

Parupeneus trifasciatus (Lacepède, 1801). Figure 42.

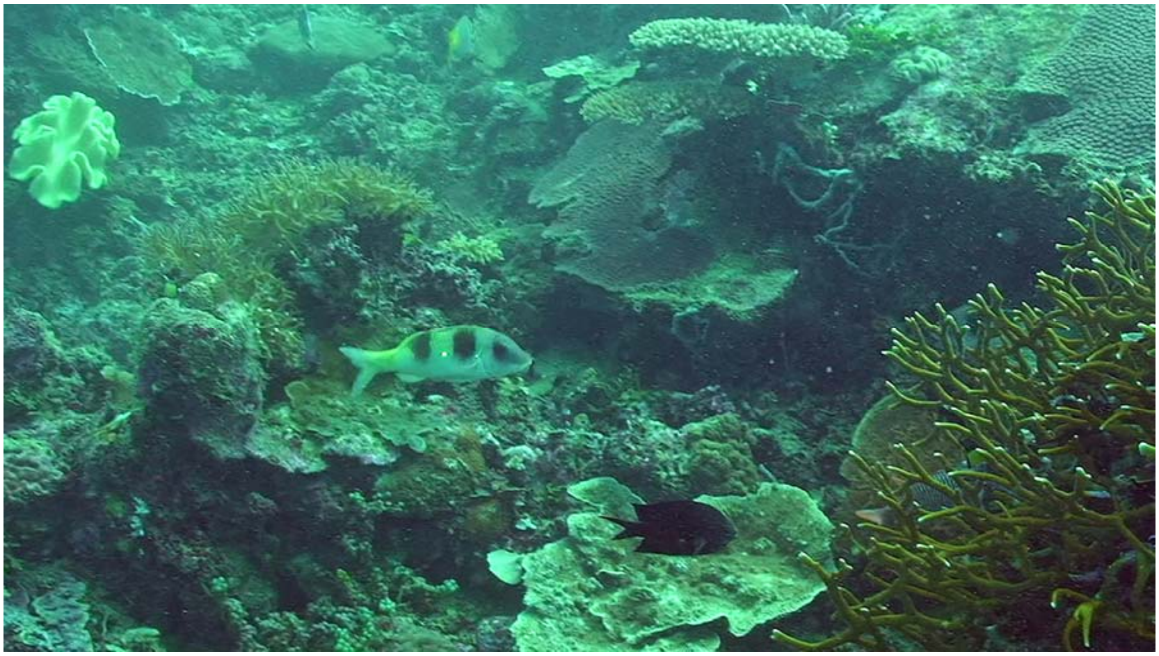

Figure 42. ***Parupeneus trifasciatus*****. Laser dots are separated by 3.9 mm.**

A total seven (7) 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 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 few individuals captured on video is 64% of the maximum length.

Serranidae

Anyperodon leucogrammicus (Valenciennes, 1828). Figure 43.

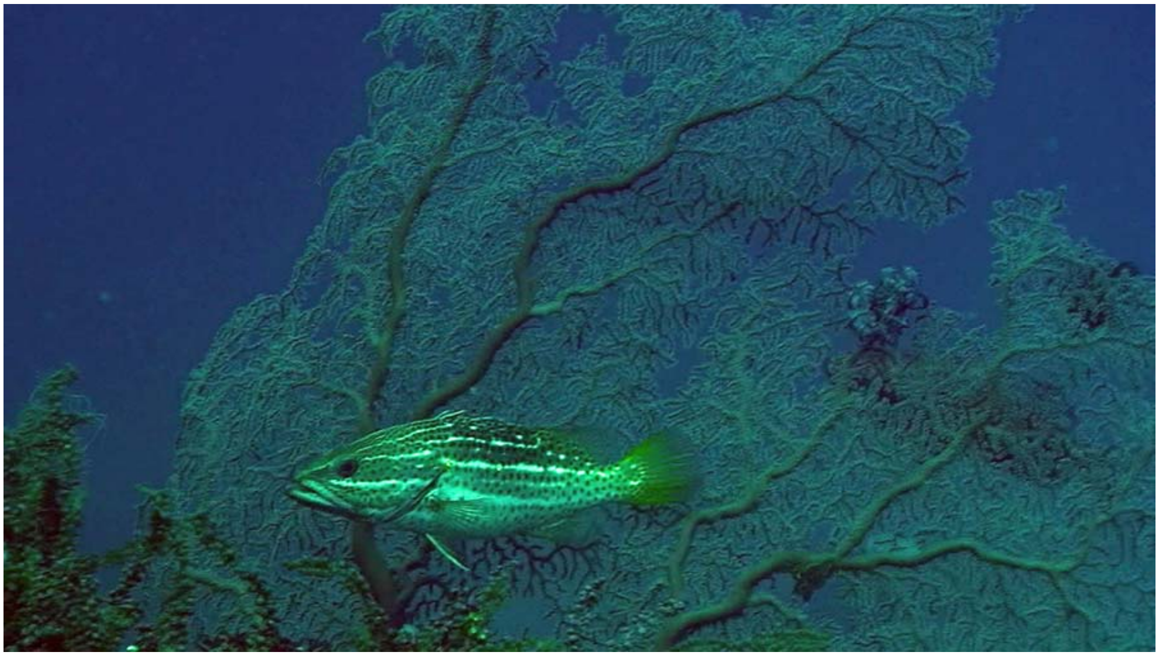

Figure 43. *Anyperodon leucogrammicus*. Laser dots are separated by 3.9 mm.

A total seven (7) 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 26 cm, which is 50% of the maximum reported length of 52 cm.

Cephalopholis boenak (Bloch, 1790). Figure 44.

Figure 44. *Cephalopholis boenak*.

A total ten (10) 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 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 45.

Figure 45. *Cephalopholis cyanostigma*.

A total 22 individuals were captured on video suitable for length estimation. The mean fork length was 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 individuals represented here (Figure 46) are mature females (however, size-specific sex ratios are not known).

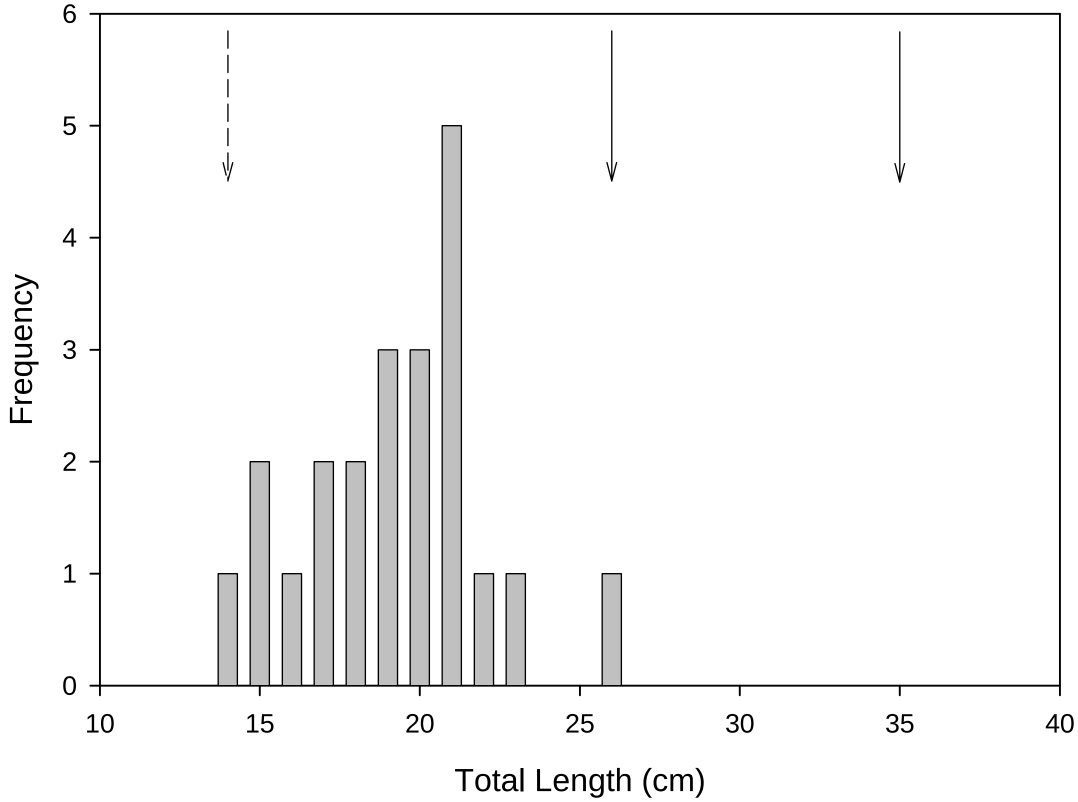

Figure 46. Size structure of *Cephalopholis cyanostigma*. The arrows indicate a length at which all females are mature (left), maximum female size (middle), and maximum reported total length (right).

Cephalopholis microprion (Bleeker, 1852). Figure 47.

Figure 47. *Cephalopholis microprion*. Laser dots are separated by 3.9 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 12 cm, which is 54% of the maximum reported length of 23 cm.

Cephalopholis urodeta (Forster, 1801). Figure 48.

Figure 48. *Cephalopholis urodeta*. Laser dots are separated by 3.9 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 17 cm, which is 63% of the maximum reported length of 27 cm.

Plectropomus areolatus (Rüppell, 1830). Figure 49.

Figure 49. *Plectropomus aureolatus*. Laser dots are separated by 3.9 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, 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 oligacanthus (Bleeker, 1854). Figure 50.

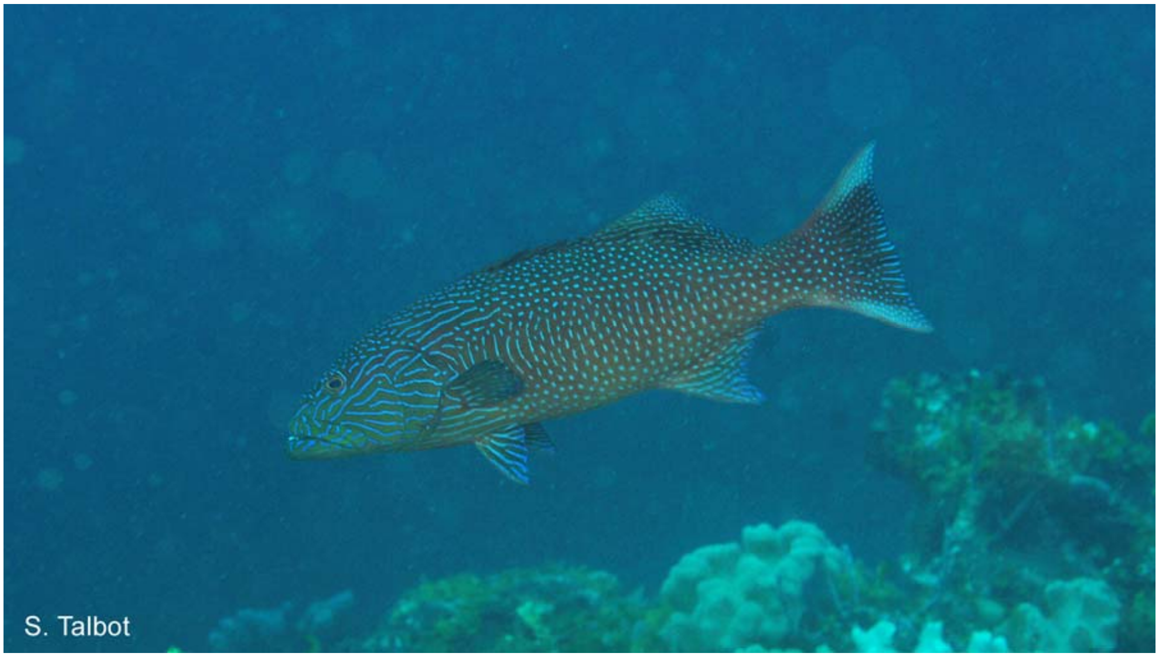

Figure 50. *Plectropomus oligacanthus*.

A total 16 individuals were captured on video suitable for length estimation. The mean fork length was 31 cm, which is 47% of the maximum reported length of 65 cm (Figure 51).

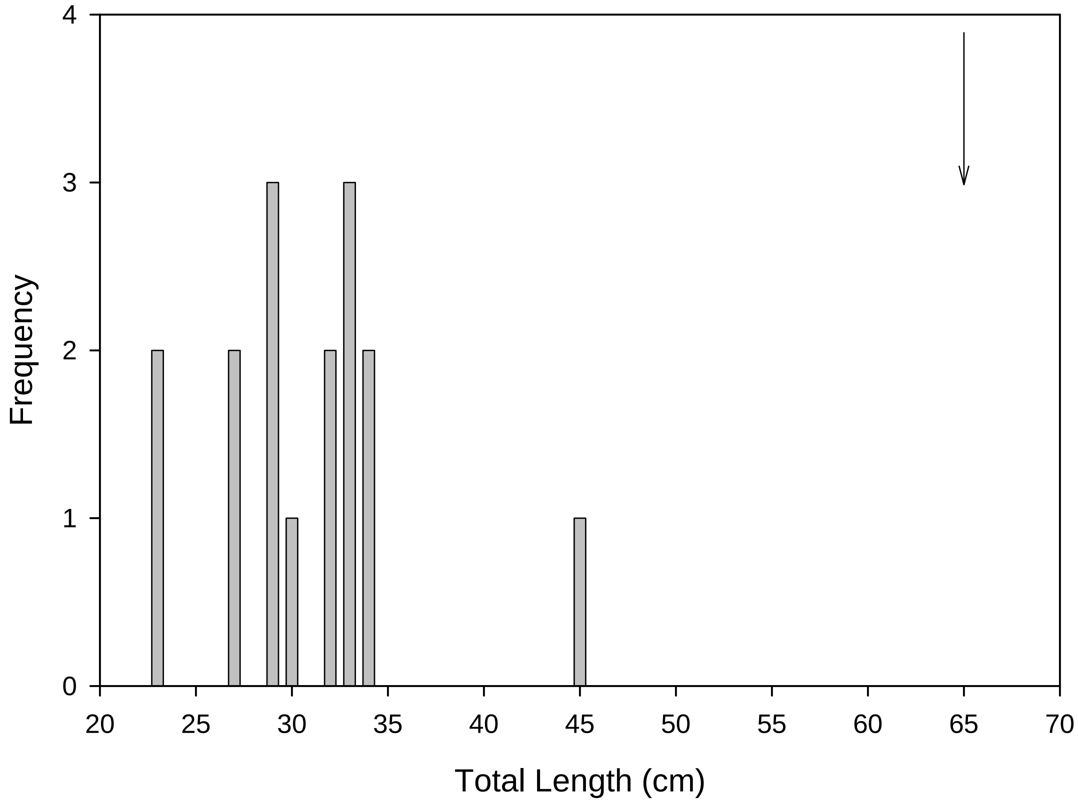

Figure 51. Size structure of *Plectropomus oligacanthus*. The arrow at right indicates maximum total length.

Siganidae

Siganus javus (Linnaeus, 1766). Figure 52.

Figure 52. *Siganus javus* (near center). Laser dots are separated by 3.9 mm.

A total 16 individuals were captured on video suitable for length estimation. The mean “fork” length was 24 cm, which is 46% of the maximum reported total length of 46 cm (Figure 53). The percentage presented here is a slight underestimate because the caudal fin of this species is emarginated, thus total length is longer than “fork” length (distance to the end of the middle caudal ray used throughout this study).

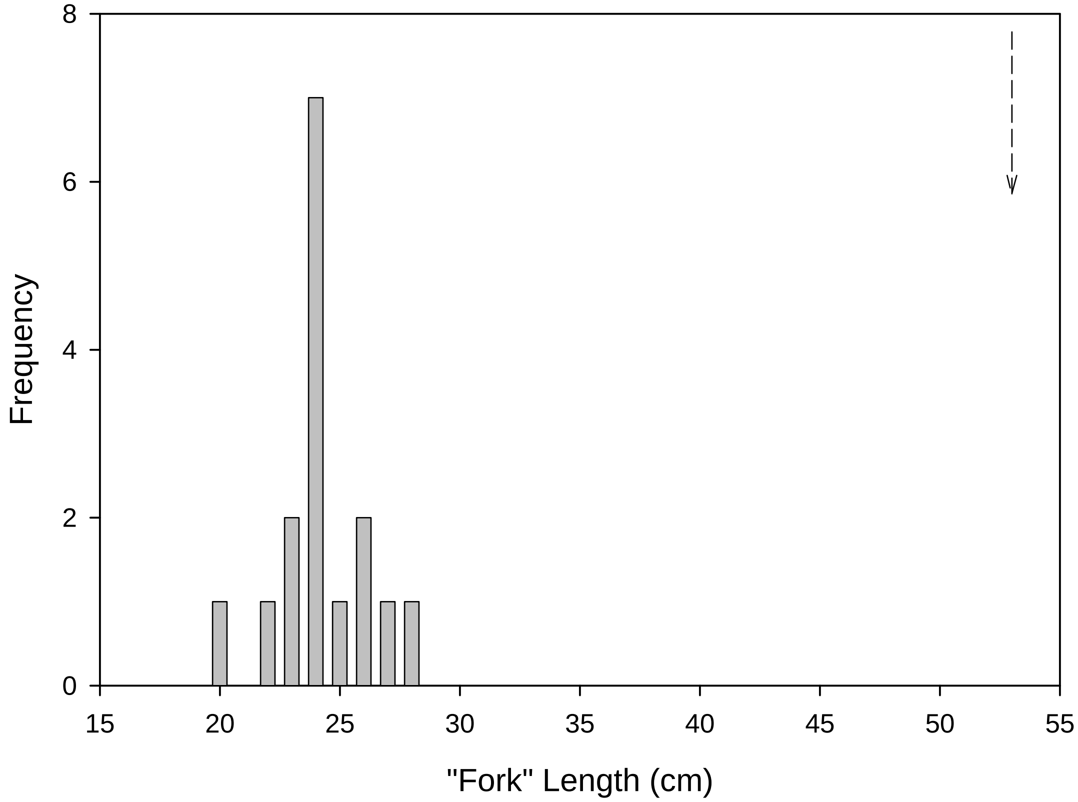

Figure 53. Size structure of *Siganus javus*. The arrow at right indicates maximum total length.

Siganus lineatus (Valenciennes, 1835). Figure 54.

Figure 54. *Siganus lineatus*.

A total six (6) 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 25 cm, which is 59% of the maximum reported “fork” length of 41 cm.

DISCUSSION

The demographic analyses presented above should be viewed as preliminary. For 17 species, we captured too few individuals on video to describe population size structure. Size frequency plots for the remaining 16 species were based on relatively few individuals. In all cases, additional data would lead to more robust population characterizations.

Results from a literature review also indicate that remarkably little is known about reproductive parameters for these coral reef fishes. This is a common problem for coral reef fisheries. 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 each of four studies that examined sex ratios in species found at Kamiali (Davis & West 1992, 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 and Serranidae). 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 99% of female reproductive size. Notably, no individual of either of the two largest species considered in this subset (*Caranx melampygus* and *Plectropomus areolatus*), were of mature size. Considering sex ratios (known for only four species) suggests that 24% of a population consists of reproductively mature females.

Also important in evaluating the population status of these fishes is the effort required by villagers to catch a meal. In this village of approximately 600 people, an average of two canoes are engaged in fishing at any one time during the day (Longenecker *et al*. 2008a). Residents appear to obtain their primary source of dietary protein with relative ease.

Despite the apparent lack of overfishing at Kamiali Wildlife Management Area, the residents we interviewed did not seem to consider themselves conservation practitioners with respect to coral-reef fishes. We were consistently told there are no gear restrictions, creel limits, minimum or maximum size limits, or seasonal closures for any species. Nor were Kamiali residents prohibited from fishing in any specific area.

Several characteristics of the village and its fishery appear to prevent overfishing:

1) Customary tenure. Outsiders are prohibited from fishing within Kamiali Wildlife Management Area. Although fishers may not consider customary tenure a conservation strategy, it is a *de facto* limited-entry fishery.

2) Distance to commercial markets. Kamiali is 64 km from the city of Lae, where fish can be sold commercially. Cinner & McClanahan (2006) suggest proximity to markets (<16 km) increases the likelihood of overfishing in Papua New Guinea. Although several Kamiali residents are engaged in commercial fishing ventures, distance presents an economic challenge. Because there are no roads between Kamiali and Lae, individuals selling fish must have a motorized vessel. The cost of operating these is high; a liter of fuel can cost up to $2 (US) and fuel costs are kept to a minimum by fishing from human-powered canoes in the wildlife management area. Because there is no electricity 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 vessels, but these are small, human-powered, handmade, outrigger canoes. 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. 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 traps and weirs do not appear to exist 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. However, this timing effectively prohibits the method during other tidal conditions.

The factors listed above do not act in isolation. Cinner (2005) found 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. For instance, 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). Also, the community is eagerly awaiting mobile telephone coverage. When unlimited communication with commercial buyers is available, fishing pressure may increase in attempts to rapidly satisfy demand. 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 starts with environmental conservation, is an effective buffer to those shifts.

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