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REPRODUCTIVE PATTERNS OF THREE ECONOMICALLY IMPORTANT SURGEONFISH SPECIES ON GUAM

by

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INTRODUCTION

Field observations of seasonal spawning behaviors and recruitment among reef fishes have been made in many parts of the world including the Caribbean (Munro et al., 1973; Powles, 1975), Hawaii (Miller and Geibel, 1979), Indian Ocean (Wourms and Bayne, 1973), Great Barrier Reef (Russell et al., 1974, 1977), Micronesia (Johannes, 1978), and Guam (Molina, 1983). Nonetheless, the seasonal spawning activities of many reef fish species are not well known.

In 1978 and 1979, Molina (1983) conducted a study on Guam documenting the seasonal variations of juvenile and adult assemblages of coral-reef fishes from outer reef habitats. Molina noted that total fish abundances peaked in May, while peak abundances for all types of surgeonfish (Acanthuridae) occurred in the winter months (September-December). The increase in surgeonfish abundance at this time of year may be related to aggregations of adults, possibly for spawning activities, or to increased recruitment of young during this period.

The present study was designed to investigate spawning periodicities of three common species of surgeonfishes on Guam to determine whether spawning aggregations or enhanced recruitment were responsible for higher abundances of these species in the winter months. An objective of this study is to document spawning capacities and frequencies of three of Guam's economically important surgeonfishes (Acanthurus triostegus, Acanthurus lineatus, and Naso lituratus). This study provides information on seasonal spawning periodicities as well as other biological aspects of these species related to seasonality. The biological information acquired is used to suggest appropriate management strategies for these species.

Guam's shallow water fish stocks are harvested primarily for subsistence. The surgeonfishes have a long history as an economically important food source for Guam's people. The three surgeonfish selected for this project are among the most frequently caught species from this family (Kami, 1968). These three species are found commonly in reef flat, reef margin, and inner reef slope zones along most of Guam's fringing reefs. They are strict herbivores, active by day and dormant at night. The relative abundances of the three species under study peak in November on Guam (Molina, 1983). A. triostegus and N. lituratus are both schooling fish that generally swim along the inner reef slope and move on to the reef flat to feed. A. lineatus is a semi-territorial fish that lives in the honeycomb region along the reef margin. The reproductive patterns suggested for these species (Lobel, 1978; Randall, 1961; Robertson, 1983; Johannes, 1978) coincide with lunar cycles and water circulation patterns. Robertson (1983) documented observations of A. triostegus and A.

lineatus exhibiting spawning behaviors in individual pairs and spawning aggregations in Aldabra and Palau. These observations coincided with the full moon phase and the ebb tide period. Johannes (1978) also noted that similar activities occurred during the new moon phase in Palau. During these lunar phases, spawning activities occur during dusk or dawn. Lobel (1978) hypothesized that crepuscular spawning activities presumably reduce predation upon eggs and larvae because of reduced planktivore activities. Spawning at the new or full moon allows the maximum dispersion of eggs and larvae by the associated strong tidal currents.

METHODS

An 8-month period (May-December) was selected to incorporate November, the month in which peaks in abundance occurred for the species under study (Molina 1983). Samples were collected for three species of surgeonfish during 16 night snorkel spear-fishing trips over the 8-month period. Collections of at least 10 specimens of each species were made during the first and third quarter moon phases each month within one day of the appropriate moon phase. The collection area (Shark's Hole) is on Guam's northwest shoreline. The extensive reef flat, well developed reef margin, and channel areas provide all the habitats in which these species commonly reside (Fig. 1). After the night collections, the specimens were refrigerated until morning. At that time fork length, total blotted wet weight, blotted wet gonad weight, and sex were recorded for each specimen.

During different collection periods, ovaries were removed for egg counts in all three species. On three separate occasions, three subsamples were taken from a single ovary from each species. The subsamples were weighed and the eggs counted. Mean eggs-per-gram values for a single ovary were obtained by averaging the three subsample values.

RESULTS

One hundred eighty-five specimens of A. triostegus, 199 specimens of A. lineatus, and 201 specimens of N. lituratus were collected over the 8-month period. Fork lengths ranged from 71 to 164 mm for A. triostegus, from 71 to 231 mm for A. lineatus, and from 66 to 224 mm for N. lituratus (Figs. 2-4). Counts of males, females, immatures (individuals lacking identifiable gonads), and spents (individuals with mature gonads from which gametes had been expelled) in 5 mm size classes are shown in Tables 1-3. Eighty-eight percent of A. triostegus were mature of which 7 % were spent, while 77 % of A. lineatus were mature of which 12 % were spent, and 84 % of N. lituratus were mature of which 13 % were spent. Sex ratios for all three species indicate a 1:1 relationship between the numbers of males and females (Table 4).

Linear regression analyses were conducted separately for males and females for the $\log_{10}$ of the fork length vs. the $\log_{10}$ of the total blotted wet weight for all three species (Table 5). The slopes of males vs. females within the same species were compared for equivalence using ANCOVA (Table 5). A. triostegus and N. lituratus were determined to have identical slopes for males and females and thus male and female data were combined to create a single regression equation for each of these species. _A. lineatus_ was found to have differing slopes for males and females and therefore separate regression lines were calculated for each sex. The linear equations calculated were used to generate length/weight curves for each species (Figs. 5 and 6).

To determine whether seasonal peaks in spawning occurred during the study period, temporal variations in gonad size, number of spent (spawned) individuals, and the proportion of immature individuals in the population were examined.

The average gonad weight to fish weight for each collection (Tables 6-8) for the first vs. the third quarter lunar phase were compared by t-test for males and females. The results of these tests revealed no lunar spawning peaks (Table 9).

Comparisons of the mean gonad weight to fish weight ratio for males and females between sample periods revealed no apparent seasonal peaks (Tables 6-8). Similarly, the relative percentage of spent males and females per sample period did not display any apparent seasonal peaks in spawning (Tables 10-12).

The percentages of spent males and females per collection period for all three species are presented in tables 10-12. Chi-square tests (Table 13) comparing the number of spent individuals during the first vs. the third lunar quarter determined that no obvious lunar peaks in spawning occurred during the study period.

Tables 14-16 present the calculation of the size-specific reproductive capacity of all three species using the variables shown in columns A through J.

The length-frequency histograms shown in Figs. 2-4 indicate that collections did not adequately represent the smaller individuals. To estimate the number of smaller individuals, the slopes of the descending limb of the length-frequency histograms were projected backwards by fitting a regression line to the descending limb using the midpoint values for the respective size classes. Column A of Tables 14-16 shows calculated relative abundances of individuals of various size classes based on these regression lines (Table 17).

As the sex ratios of each species are not significantly different from 1:1, the number of females (column B) is taken to be half of the total number of individuals (column A).

For size classes above 110 mm for *A. triostegus*, 135 mm for *A. lineatus*, and 120 mm for *N. lituratus* all females had mature gonads; below these sizes only a fraction of the females were mature (column D).

The calculated number of mature females (column D) was obtained by multiplying the number of females (column B) by the fraction of f .ales which were mature (column C).

Dividing the values of column D by the sum of column D and multiplying by 100 yielded the percentage of total mature females (column E).

The calculated ovary weights in column F were obtained by using the regression equations relating ovary weight to female length (Table 18).

The mean number of eggs per gram were 30,700 for A. triostegus , 26,200 for A. lineatus, and 23,100 for N. lituratus (Tables 19-21). When multiplied by the ovary weights in column F, the product yielded the calculated number of eggs per female (column G).

The size-specific reproductive index (column H) was calculated by multiplying the proportion of total mature females (column E) times the number of eggs per female (column G).

Column I represents the values of column H divided by the sum of column H or the size-specific reproductive contribution.

The cumulative reproductive contribution (column J) was calculated by summing the values of column I from the smallest size class to the largest.

DISCUSSION

Robertson (1983) and Johannes (1978) observed spawning behaviors among several species of acanthurids during the full and new moon phases on separate occasions. During the present study, collections of specimens were always made during the first and third quarter lunar phases to determine whether these species exhibited spawning cycles related to the full or new moon phases. There was, however, no significant difference in the ratio of gonad weight to fish weight between the first and third quarter lunar phases. In addition, there was no significant difference in the number of spent individuals between the first and third quarter moon phases. These results indicate that lunar patterns of reproduction are not apparent for these species on Guam.

Another objective of this project was to investigate the existence of seasonal patterns of reproduction among these species. If a seasonal peak in reproductive activity had occurred during the 8-month study period, increases in the ratio of gonad weight to fish weight and in the number of spent individuals would be expected to occur at some time during the study period. If a seasonal peak of reproduction had occurred during a time period prior to the study period, a peak in the number of immature individuals would be expected, followed by a progression of size-frequency modes as the young fish grew. This was not the case (Figs. 7-9).

Thus the November peaks in abundance of these surgeonfish species documented by Molina (1983) are apparently not caused by spawning aggregations or by heavy recruitment.

The need for management of tropical coral-reef fish assemblages increases as modern fishing techniques improve and as human populations grow. Many tropical areas rely on their coral-reef fisheries as major economic resources. In many areas these factors have generated extensive fishing pressures to a point of overexploitation.

Management of coral-reef fish populations requires an understanding of a multispecies fishery that is harvested by a wide range of fishing methods. This makes development of appropriate management strategies difficult.

The fundamental objective of an efficient management strategy is to assure the preservation of the reproductive potential of the population. Without this, the population is destined for decline and, conceivably extinction. There are a variety of management techniques which can be applied to preserve the reproductive potential of the stock.

Sanctuaries, where no fishing is permitted, provide areas where recruiting and adult individuals can maintain a reproductive pool which may increase recruitment to other areas.

Seasonal closures during reproductive peaks permit mature fish the opportunity to spawn, assuring recruitment. Escapement techniques, including the use of minimum size restrictions to protect a portion of the reproductive pool, maximum size restrictions to maintain a portion of the reproductive pool, and other periodic closures, can permit adequate levels of spawning to maintain the populations.

Each of these management strategies has practical applications to specific cases, but each are limited by the biological, environmental, and fisheries parameters involved. The results of this project provide some suggestions for efficient management of these species.

These species exhibit no seasonal spawning peaks, and thus seasonal closures to protect spawning would not be particularly appropriate. Applying a maximum size restriction would be difficult to enforce because convincing fishermen to release a large fish is unrealistic. The most realistic option is to protect spawning by establishing appropriate minimum size limits for these fish.

The reproductive capacities calculated in Tables 14-16 indicate the relative reproductive contribution of each size class for each species. The cumulative reproductive contribution indices in column J of these tables provide the means to select a minimum size limit for these fishes. This will guarantee the survival of some percentage of the total reproductive potential of the population. For example, if the optimum harvest of *A. triostegus* requires maintaining 50% of reproductive potential, Fig. 10 (plots of fork length vs. cumulative reproductive contribution for all species) indicates that restriction of harvest of individuals below 128 mm would retain 50% of the reproductive capacity for this species. Determinations of this type can be obtained for any desired retention percentage for all of these species using the same procedure (Fig. 10). The 20, 50, and 80 percent retention values are displayed in Table 22.

The methods suggested in this project for proper management of these three species provide one potential method of adequate management. Other management measures, such as sanctuaries, may provide additional protection for these species.

Table 1. Length frequencies of male, female, and immature *Acanthurus triostegus* in 5 mm size classes. Number of spent individuals is indicated in parentheses.

Size Classes (5 mm)	Males	Females	Immatures	Totals
160	4	2	-	6
155	3	1	-	4
150	1	1	-	2
145	6	3	-	9
140	5	8(1)	-	13
135	7(1)	9(1)	-	16
130	5(2)	11(2)	-	16
125	9(2)	13(1)	-	22
120	6	17	-	23
115	9	6(2)	-	15
110	9	6	-	15
105	11	5	3	19
100	1	3	1	5
95	1	1	6	8
90	-	-	3	3
85	-	-	3	3
80	-	-	4	4
75	-	-	1	1
70	-	-	1	1
Totals	77(5)	86(7)	22	185

Table 2. Length frequencies of male, female, and immature *Acanthurus lineatus* in 5 mm size classes. Number of spent individuals is indicated in parentheses.

Size Classes (5 mm)	Males	Females	Immatures	Totals
230	-	1	-	1
225	-	-	-	-
220	-	-	-	-
215	-	1	-	-
210	-	-	-	-
205	2	1	-	3
200	-	2	-	2
195	2	1	-	3
190	3	1	-	4
185	3	2	-	5
180	3	3	-	6
175	2	1	-	3
170	5	6(1)	-	11
165	4(1)	5	-	9
160	5	7	-	12
155	4	5(2)	-	9
150	3	5	-	8
145	12(1)	14(2)	-	26
140	12(4)	17(5)	-	29
135	9(4)	6(2)	-	15
130	2	2(1)	1	5
125	-	2(1)	1	3
120	-	1	7	8
115	-	-	9	9
110	-	-	5	5
105	-	-	3	3
100	-	-	3	3
95	-	-	2	2
90	-	-	6	6
85	-	-	3	3
80	-	-	3	3
75	-	-	1	1
70	-	-	1	1
Totals	71(10)	83(14)	45	199

Table 3. Length frequencies of male, female, and immature *Naso lituratus* in 5 mm size classes. Number of spent individuals is indicated in parentheses.

Size Classes (5mm)	Males	Females	Immatures	Totals
220	1	1	-	2
215	1	1	-	2
210	4(1)	1	-	5
205	-	1	-	1
200	1	2	-	3
195	2	3	-	5
190	1	3	-	4
185	2	2	-	4
180	1	2	-	3
175	3	5	-	8
170	5	5(1)	-	10
165	4(1)	9(1)	-	13
160	3	7(1)	-	10
155	5(1)	8(3)	-	13
150	11	5	-	16
145	8(2)	9(1)	-	17
140	8(2)	4(1)	-	12
135	3	3	-	6
130	10(2)	3(2)	1	14
125	9(2)	5(1)	1	15
120	3(2)	1(1)	-	4
115	1	1	4	5
110	-	1	5	6
105	-	-	4	4
100	1	-	2	3
95	-	-	1	1
90	-	-	3	3
85	-	-	1	1
80	-	-	6	6
75	-	-	2	2
70	-	-	2	2
65	-	-	1	1
Totals	87(13)	82(13)	32	201

Table 4. Chi-square test (X^2) for expected 1:1 sex ratios of _Acanthurus triostegus_, _Acanthurus lineatus_, and _Naso lituratus_.

Species	Frequency of Males	Frequency of Females	Chi-square Statistic
A. triostegus	77	87	0.61 ns
A. lineatus	71	81	0.66 ns
N. lituratus	88	82	0.21 ns

Table 5. ANCOVA test of slopes between males and females for _Acanthurus triostegus_, _Acanthurus lineatus_, and _Naso lituratus_ for $\log_{10}$ transformation of fork length vs. weight.

Species	Slope of Males	Slope of Females	ANCOVA F-value
A. triostegus	2.56	2.39	$F_{(1,159)}=0.66$ ns
	combined	$Y = 2.49(X) + (-3.52)$	
A. lineatus	2.98	3.17	$F_{(1,160)}= 4.97$ s
	Males	$Y = 2.98(X) + (-4.64)$	
	Females	$Y = 3.17(X) + (-5.04)$	
N. lituratus	2.42	2.42	$F_{(1,151)}=0.00$ ns
	combined	$Y = 2.41(X) + (-3.26)$	

Table 6. Mean gonad weight and mean fish weight calculated for males and females of *Acanthurus triostegus* for all collection periods. The ratio of these values x 100 is also shown.

		Males			Females		
Date	Lunar phase	(a) Mean gonad wt.	(b) Mean fish wt.	(a/b) x 100	(c) Mean gonad wt.	(d) Mean fish wt.	(c/d) x 100
May 8	1	1.67	60.07	2.78	0.91	47.70	1.91
May 22	3	0.58	62.58	0.93	0.88	54.40	1.62
Jun 6	1	1.08	36.12	2.99	0.51	39.80	1.28
Jun 21	3	1.34	79.37	1.69	0.59	66.98	0.88
Jul 4	1	0.86	48.18	1.79	0.85	50.22	1.69
Jul 21	3	0.49	74.48	0.66	0.54	51.55	1.04
Aug 4	1	0.78	53.78	1.45	0.49	52.04	0.94
Aug 20	3	1.69	62.54	2.70	1.54	46.12	3.34
Sep 3	1	1.24	86.15	1.44	1.11	53.17	2.09
Sep 18	3	1.75	67.85	7.00	0.63	50.76	1.24
Oct 2	1	0.63	46.12	1.37	0.66	52.14	1.27
Oct 16	3	1.13	45.80	2.47	1.01	57.74	1.74
Oct 31	1	0.58	45.20	1.28	0.58	48.12	1.21
Nov 16	3	0.40	42.06	0.95	0.49	58.65	0.84
Nov 30	1	0.24	53.00	0.45	0.63	60.56	1.04
Dec 16	3	0.14	47.85	0.29	0.52	61.30	0.85

Lunar phases: The no. 1 indicates the first quarter moon while the no. 3 indicates third quarter moon.

Table 7. Mean gonad weight and mean fish weight calculated for males and females of *Acanthurus lineatus* for all collection periods. The ratio of these values x 100 is also shown.

		Males			Females		
Date	Lunar phase	(a) Mean gonad wt.	(b) Mean fish wt.	(a/b) x 100	(c) Mean gonad wt.	(d) Mean fish wt.	(c/d) x 100
May 8	1	0.10	85.40	0.12	1.06	121.92	0.87
May 22	3	0.56	134.74	0.42	1.15	141.14	0.81
Jun 6	1	0.64	134.05	0.48	1.52	172.22	0.88
Jun 21	3	0.34	136.60	0.25	0.98	139.64	0.70
Jul 4	1	0.30	111.94	0.27	0.51	113.22	0.45
Jul 21	3	0.81	143.40	0.56	0.31	100.93	0.31
Aug 4	1	1.17	132.80	0.88	0.73	128.72	0.36
Aug 20	3	1.04	108.26	0.96	0.55	103.68	0.53
Sep 3	1	0.97	117.70	0.82	0.58	108.58	0.53
Sep 18	3	0.52	116.28	0.45	0.45	86.92	0.52
Oct 2	1	0.04	103.83	0.04	0.25	110.12	0.23
Oct 16	3	1.44	102.30	1.41	1.61	90.19	1.70
Oct 31	1	0.12	95.18	0.13	1.13	102.80	1.10
Nov 16	3	0.70	100.28	0.70	0.31	107.08	0.46
Nov 30	1	0.35	124.08	0.28	0.41	91.58	0.46
Dec 16	3	0.65	105.73	0.61	0.82	113.63	0.72

Lunar phases: The no. 1 indicates the first quarter moon while the no. 3 indicates third quarter moon.

Table 8. Mean gonad weight and mean fish weight calculated for males and females of *Naso lituratus* for all collection periods. The ratio of these values x 100 is also shown.

		Males			Females		
Date	Lunar phase	(a) Mean gonad wt.	(b) Mean fish wt.	(a/b) x 100	(c) Mean gonad wt.	(d) Mean fish wt.	(c/d) x 100
May 8	1	0.21	85.40	0.25	0.40	68.71	0.58
May 22	3	0.29	43.80	0.66	0.57	58.90	0.96
Jun 6	1	0.77	69.42	1.11	0.82	102.70	0.80
Jun 21	3	0.29	117.63	0.25	0.72	74.57	0.97
Jul 4	1	0.62	74.11	0.84	1.04	82.41	1.26
Jul 21	3	0.28	82.78	0.34	0.88	122.33	0.72
Aug 4	1	1.11	110.13	1.01	0.79	90.50	0.87
Aug 20	3	0.25	73.44	0.34	0.66	103.98	0.63
Sep 3	1	0.66	67.44	0.98	0.93	118.00	0.78
Sep 18	3	0.18	57.94	0.31	0.67	90.18	0.74
Oct 2	1	0.05	76.80	0.07	0.46	90.30	0.51
Oct 16	3	1.23	112.26	1.10	1.53	137.13	1.12
Oct 31	1	0.76	170.48	0.44	0.44	153.56	0.29
Nov 16	3	0.74	76.65	0.97	0.24	81.82	0.29
Nov 30	1	0.45	59.80	0.75	0.51	88.62	0.58
Dec 16	3	0.25	81.81	0.31	0.15	70.25	0.21

Lunar phases: The no. 1 indicates the first quarter moon while the no. 3 indicates third quarter moon.

Table 9. The average gonad weight values of the first vs. the third quarter moon phase were compared by t-test for each lunar cycle for *Acanthurus triostegus*, *Acanthurus lineatus*, and *Naso lituratus* by sex.

	Males		Females	
	df	t-value	df	t-value
A. triostegus	7	-0.47	7	-0.04
A. lineatus	7	-1.55	7	-0.50
N. lituratus	7	0.59	7	-0.27

$t_{7(.05)} = 2.365$

Table 10. Respective numbers of male, female, and immature *Acanthurus triostegus* collected during each sample period, the percentage of spent individuals, and the corresponding lunar phases.

Date	Lunar phase	No. males	% spent	No. females	% spent	Imm.	Tot.
May 8	1	7	28.6	2	0.0	1	10
May 22	3	5	40.0	5	0.0	0	10
Jun 6	1	5	0.0	4	25.0	3	12
Jun 21	3	8	0.0	4	25.0	0	12
Jul 4	1	4	0.0	5	0.0	1	10
Jul 21	3	4	0.0	6	33.3	1	11
Aug 4	1	4	0.0	5	20.0	4	13
Aug 20	3	5	0.0	6	0.0	0	11
Sep 3	1	5	20.0	7	0.0	0	12
Sep 18	3	2	0.0	8	12.5	2	12
Oct 2	1	5	0.0	7	0.0	0	12
Oct 16	3	4	0.0	9	0.0	1	14
Oct 31	1	4	0.0	4	0.0	2	10
Nov 16	3	6	0.0	4	0.0	2	12
Nov 30	1	5	0.0	5	20.0	2	12
Dec 16	3	4	0.0	4	0.0	3	11
Totals		77	6.5	86	8.1	22	185

Lunar phases: The no. 1 indicates the first quarter moon while the no. 3 indicates third quarter moon.

Table 11. Respective numbers of male, female, and immature Acanthurus lineatus collected during each sample period, the percentage of spent individuals, and the corresponding lunar phases.

Date	Lunar phase	No. males	% spent	No. females	% spent	Imm.	Tot.
May 8	1	4	25.0	6	16.6	3	13
May 22	3	5	0.0	5	20.0	2	12
Jun 6	1	4	0.0	6	16.6	6	16
Jun 21	3	6	16.6	5	0.0	1	12
Jul 4	1	5	40.0	6	0.0	1	12
Jul 21	3	4	0.0	4	50.0	3	11
Aug 4	1	6	0.0	6	33.0	2	14
Aug 20	3	5	20.0	4	0.0	3	12
Sep 3	1	5	0.0	4	0.0	4	13
Sep 18	3	5	20.0	5	20.0	2	12
Oct 2	1	4	50.0	5	20.0	3	12
Oct 16	3	5	0.0	5	20.0	4	14
Oct 31	1	4	25.0	6	16.6	3	13
Nov 16	3	4	0.0	5	20.0	3	12
Nov 30	1	4	0.0	5	16.6	3	12
Dec 16	3	4	25.0	6	16.6	2	12
Totals		71	14.1	83	15.7	45	199

Lunar phases: The no. 1 indicates the first quarter moon while the no. 3 indicates the third quarter moon.

Table 12. Respective numbers of male, female, and immature <u>Naso lituratus</u> collected during each sample period, the percentage of spent individuals, and the corresponding lunar phases.

Date	Lunar phase	No. males	% spent	No. females	% spent	Imm.	Tot.
May 8	1	6	16.6	3	33.3	3	12
May 22	3	6	16.6	7	14.2	1	13
Jun 6	1	6	16.6	6	33.3	1	13
Jun 21	3	7	28.6	6	0.0	1	14
Jul 4	1	8	25.0	5	0.0	0	13
Jul 21	3	5	20.0	6	16.6	3	14
Aug 4	1	6	16.6	6	0.0	2	14
Aug 20	3	5	40.0	5	0.0	2	12
Sep 3	1	5	0.0	4	0.0	3	12
Sep 18	3	5	20.0	5	20.0	2	12
Oct 2	1	3	0.0	6	16.6	3	12
Oct 16	3	5	0.0	6	16.6	1	12
Oct 31	1	5	0.0	5	20.0	3	13
Nov 16	3	4	0.0	5	40.0	2	11
Nov 30	1	4	0.0	5	20.0	2	11
Dec 16	3	7	14.3	2	0.0	3	12
Totals		87	14.9	82	14.6	32	201

Lunar phases: The no. 1 indicates the first quarter moon while the no. 3 indicates the third quarter moon.

Table 13. Chi-square test comparing the number of spent individuals during the first quarter moon to that of the third quarter moon for <u>Acanthurus triostegus</u>, <u>Acanthurus lineatus</u>, and <u>Naso lituratus</u>.

Species	First Quarter	Third Quarter	Chi-square Statistic
<u>A. triostegus</u>	6	6	0.00 ns
<u>A. lineatus</u>	13	11	0.16 ns
<u>N. lituratus</u>	11	14	0.36 ns

Table 14a. Variables and calculations for determining the size-specific reproductive potential of *Acanthurus triostegus*.

Size class mm	A Calc. no. of ind.	B Calc. no. of females (A/2)	C Prop. of females mature	D Calc. no. of mature females (B x C)	E % of tot. mature females (D/Sum D x 100)
160-164	2.91	1.46	1.00	1.46	1.24
155-159	5.53	2.78	1.00	2.78	2.37
150-154	8.15	4.08	1.00	4.08	3.47
145-149	10.76	5.38	1.00	5.38	4.57
140-144	13.38	6.69	1.00	6.69	5.70
135-139	16.00	8.00	1.00	8.0	6.81
130-134	18.61	9.31	1.00	9.31	7.93
125-129	21.23	10.62	1.00	10.62	9.04
120-124	23.84	11.92	1.00	11.92	10.14
115-119	26.46	12.23	1.00	12.23	10.41
110-114	29.08	14.54	1.00	14.54	12.38
105-109	31.70	15.85	0.71	11.25	9.57
100-104	34.31	17.16	0.85	14.59	12.42
95- 99	36.93	18.47	0.25	4.62	3.93
Tot.	278.87	138.49		117.47	99.98

Table 14b. Variables and calculations for determining the size-specific reproductive potential of *Acanthurus triostegus* (continued).

	E	F	G	H	I	J
Size class mm	% of tot. mature females	Calc. ovary wt. g.	Calc. no. of eggs	Reprod. index (E x G)	Reprod. contr. H/Sum H x 100 %	Cum. reprod. contr.
160-164	1.24	1.04	31,900	39,600	2.6	100.0
155-159	2.37	1.00	30,700	72,800	4.8	97.4
150-154	3.47	0.87	26,700	92,600	6.2	92.6
145-149	4.57	0.79	24,300	111,000	7.4	86.4
140-144	5.70	0.71	21,800	124,000	8.3	79.0
135-139	6.81	0.64	19,600	139,000	9.3	70.7
130-134	7.93	0.58	17,800	141,000	9.4	61.4
125-129	9.04	0.52	16,000	145,000	9.7	52.0
120-124	10.14	0.46	14,100	143,000	9.5	42.3
115-119	10.41	0.41	12,600	131,000	8.7	32.8
110-114	12.38	0.36	11,100	137,000	9.1	24.1
105-109	9.57	0.31	9,520	91,100	6.1	15.0
100-104	12.42	0.28	8,600	107,000	7.1	8.9
95- 99	3.93	0.23	7,060	27,700	1.8	1.9
Tot.	99.98			1501800	100.0	

Table 15a. Variables and calculations for determining the size-specific reproductive potential of *Acanthurus lineatus*.

	A	B	C	D	E
Size class mm	Calc. no. of ind.	Calc. no. of females (A/2)	Prop. of females mature	Calc. no. of mature females (B x C)	% of tot. mature females (D/Sum D x 100)
220-224	0.29	0.15	1.00	0.15	0.15
215-219	1.30	0.65	1.00	0.65	0.67
210-214	2.30	1.15	1.00	1.15	1.19
205-209	3.31	1.66	1.00	1.66	1.71
200-204	4.32	2.16	1.00	2.16	2.23
195-199	5.32	2.66	1.00	2.66	2.74
190-194	6.33	3.17	1.00	3.17	3.27
185-189	7.34	3.67	1.00	3.67	3.78
180-184	8.34	4.17	1.00	4.17	4.30
175-179	9.35	4.68	1.00	4.68	4.82
170-174	10.36	5.18	1.00	5.18	5.34
165-169	11.36	5.68	1.00	5.68	5.85
160-164	12.37	6.19	1.00	6.19	6.38
155-159	13.38	6.69	1.00	6.69	6.89
150-154	14.38	7.19	1.00	7.19	7.41
145-149	15.38	7.69	1.00	7.69	7.93
140-144	16.39	8.20	1.00	8.20	8.45
135-139	17.40	8.70	1.00	8.70	8.97
130-134	18.41	9.21	0.80	7.37	7.60
125-129	19.41	9.71	0.80	7.77	8.00
120-124	20.42	10.21	0.22	2.25	2.32
Tot.		108.77		97.03	100.00

Table 15b. Variables and calculations for determining the size-specific reproductive potential of _Acanthurus lineatus_ (continued).

Size class mm	E % of tot. mature females	F Calc. ovary wt. g.	G Calc. no. of eggs	H Reprod. index (E x G)	I Reprod. contr. (H/Sum H x 100) %	J Cum. reprod. contr.
220-224	0.15	5.33	140,000	21,000	1.6	100.0
215-219	0.67	4.30	113,000	75,700	5.9	98.4
210-214	1.19	3.45	90,400	108,000	8.4	92.5
205-209	1.71	2.76	72,300	123,000	9.6	84.2
200-204	2.23	2.19	57,400	128,000	10.0	74.6
195-199	2.74	1.73	45,300	124,000	9.7	64.6
190-194	3.27	1.36	35,600	116,000	9.1	53.9
185-189	3.78	1.06	27,800	105,000	8.2	44.8
180-184	4.30	0.82	21,500	92,500	7.2	36.6
175-179	4.82	0.63	16,500	79,500	6.2	29.4
170-174	5.34	0.48	12,600	67,300	5.2	23.9
165-169	5.85	0.37	9,690	56,700	4.4	18.7
160-164	6.38	0.28	7,340	46,800	3.7	14.3
155-159	6.89	0.20	5,240	36,100	2.8	10.6
150-154	7.41	0.15	3,930	29,100	2.3	7.8
145-149	7.93	0.11	2,880	22,800	1.8	5.5
140-144	8.45	0.08	2,100	17,700	1.4	3.7
135-139	8.97	0.06	1,570	14,100	1.1	2.3
130-134	7.60	0.04	1,050	7,980	0.7	1.2
125-129	8.00	0.03	786	6,290	0.5	0.6
120-124	2.32	0.02	524	1,220	0.1	0.1
Tot.	100.00			1,278,790	100.0	

Table 16a. Variables and calculations for determining the size-specific reproductive potential of *Naso lituratus*.

Size class mm	A Calc. no. of ind.	B Calc. no. of females (A/2)	C Prop. of females mature	D Calc. no. of mature females (B x C)	E % of tot. mature females (D/Sum D x 100)
210-214	0.4	0.2	1.00	0.2	0.1
205-209	1.7	0.9	1.00	0.9	0.7
200-204	3.1	1.6	1.00	1.6	1.3
195-199	4.4	2.2	1.00	2.2	1.7
190-194	5.7	2.9	1.00	2.9	2.3
185-189	7.0	3.5	1.00	3.5	2.8
180-184	8.3	4.2	1.00	4.2	3.3
175-179	9.7	4.9	1.00	4.9	3.9
170-174	11.0	5.5	1.00	5.5	4.3
165-169	12.3	6.2	1.00	6.2	4.9
160-164	13.6	6.8	1.00	6.8	5.4
155-159	15.0	7.5	1.00	7.5	5.9
150-154	16.3	8.2	1.00	8.2	6.5
145-149	17.6	8.8	1.00	8.8	7.0
140-144	18.9	9.5	1.00	9.5	7.5
135-139	20.3	10.2	1.00	10.2	8.1
130-134	21.6	10.8	1.00	10.8	8.5
125-129	22.9	11.5	1.00	11.5	9.0
120-124	24.2	12.1	1.00	12.1	9.6
115-119	25.2	12.8	0.40	5.1	4.0
110-114	26.9	13.5	0.29	3.9	3.1
Tot.		143.8		126.5	99.9

Table 16b. Variables and calculations for determining the size-specific reproductive potential of *Naso lituratus* (continued).

Size class mm	E % of tot. mature females	F Calc. ovary wt. g.	G Calc. no. of eggs	H Reprod. index (E x G)	I Reprod. contr. (H/Sum H x 100) %	J Cum. reprod. contr.
210-214	0.1	1.52	35,100	3,510	0.7	99.9
205-209	0.7	1.30	30,000	21,000	4.1	99.2
200-204	1.3	1.10	25,400	33,000	6.4	95.1
195-199	1.7	0.93	21,500	36,600	7.2	88.7
190-194	2.3	0.79	18,200	41,900	8.2	81.5
185-189	2.8	0.66	15,200	42,600	8.3	73.4
180-184	3.3	0.55	12,700	41,900	8.2	65.0
175-179	3.9	0.46	10,600	41,300	8.1	56.8
170-174	4.3	0.38	8,700	37,800	7.4	48.7
165-169	4.9	0.31	7,160	35,100	6.9	41.3
160-164	5.4	0.26	6,000	32,400	6.3	34.4
155-159	5.9	0.21	4,850	28,600	5.6	28.2
150-154	6.5	0.17	3,930	25,500	5.0	22.5
145-149	7.0	0.13	3,000	21,000	4.1	17.5
140-144	7.5	0.10	2,310	17,300	3.3	13.4
135-139	8.1	0.08	1,850	15,000	2.9	10.1
130-134	8.[illegible]	0.07	1,620	13,800	2.7	7.2
125-129	9.0	0.05	1,160	10,400	2.0	4.5
120-124	9.6	0.04	924	8,870	1.7	2.5
115-119	4.0	0.03	693	2,770	0.5	0.8
110-114	3.1	0.02	462	1,430	0.3	0.3
Tot.	99.9			511,780	99.9	

Table 17. Regression equations generated from the descending limb of the length-frequency histograms used to calculate number of individuals in each size class for all species.

Acanthurus triostegus

Number of individuals = 86.40 - (0.52)(fork length)

Acanthurus lineatus

Number of individuals = 44.57 - (0.20)(fork length)

Naso lituratus

Number of individuals = 55.96 - (0.26)(fork length)

Table 18. Linear regression equations for female *Acanthurus triostegus*, *Acanthurus lineatus*, and *Naso lituratus* for $\log_{10}$ transformation of ovary weight vs. fork length.

A. triostegus

$$\text{Ovary weight} = (4.669507 \times 10^{-7})(\text{fork length})^{2.873338}$$

A. lineatus

$$\text{Ovary weight} = (4.526474 \times 10^{-22})(\text{fork length})^{9.406435}$$

N. lituratus

$$\text{Ovary weight} = (5.887623 \times 10^{-16})(\text{fork length})^{6.624944}$$

Table 19. Egg counts and calculations of eggs-per-gram values for *A. triostegus*.

Date	Gonad	No. of eggs counted	Sample wt.(g)	Calc. eggs/gram	Mean
May 8	1	511	.0206	24,800	-
May 8	1	401	.0134	29,900	-
May 8	1	789	.0247	31,900	-
					28,800
Jul 21	2	448	.0152	29,400	-
Jul 21	2	622	.0179	34,800	-
Jul 21	2	327	.0112	26,800	-
					30,300
Oct 16	3	480	.0184	26,100	-
Oct 16	3	431	.0114	37,800	-
Oct 16	3	688	.0195	35,300	-
					33,100
			Grand	Avg.	30,700

Table 20. Egg counts and calculations of eggs-per-gram values for *Acanthurus lineatus*.

Date	Gonad	No. of eggs counted	Sample wt.(g)	Calc. eggs/gram	Mean
May 8	1	351	.0124	28,300	-
May 8	1	400	.0171	23,400	-
May 8	1	380	.0158	24,100	-
					25,300
Jul 21	2	444	.0162	27,400	-
Jul 21	2	301	.0101	29,800	-
Jul 21	2	367	.0143	25,700	-
					27,600
Oct 16	3	572	.0227	25,200	-
Oct 16	3	311	.0147	21,200	-
Oct 16	3	317	.0104	30,500	-
					25,600
			Grand	Avg.	26,200

Table 21. Egg counts and calculations of eggs-per-gram values for *Naso lituratus*.

Date	Gonad	No. of eggs counted	Sample wt.(g)	Calc. eggs/gram	Mean
May 8	1	440	.0188	23,400	-
May 8	1	502	.0226	22,200	-
May 8	1	409	.0226	23,900	-
					23,200
Jul 21	2	398	.0192	20,700	-
Jul 21	2	257	.0160	16,100	-
Jul 21	2	577	.0229	25,200	-
					20,700
Oct 16	3	581	.0249	23,300	-
Oct 16	3	497	.0200	24,900	-
Oct 16	3	502	.0181	27,700	-
					25,300
			Grand Avg.		23,100

Table 22. Minimum size restrictions (fork length) appropriate for retaining selected levels of reproductive capacity.

Species	20% fl	50% fl	80% fl
A. triostegus	112 mm	128 mm	144 mm
A. lineatus	170 mm	193 mm	208 mm
N. lituratus	152 mm	175 mm	193 mm

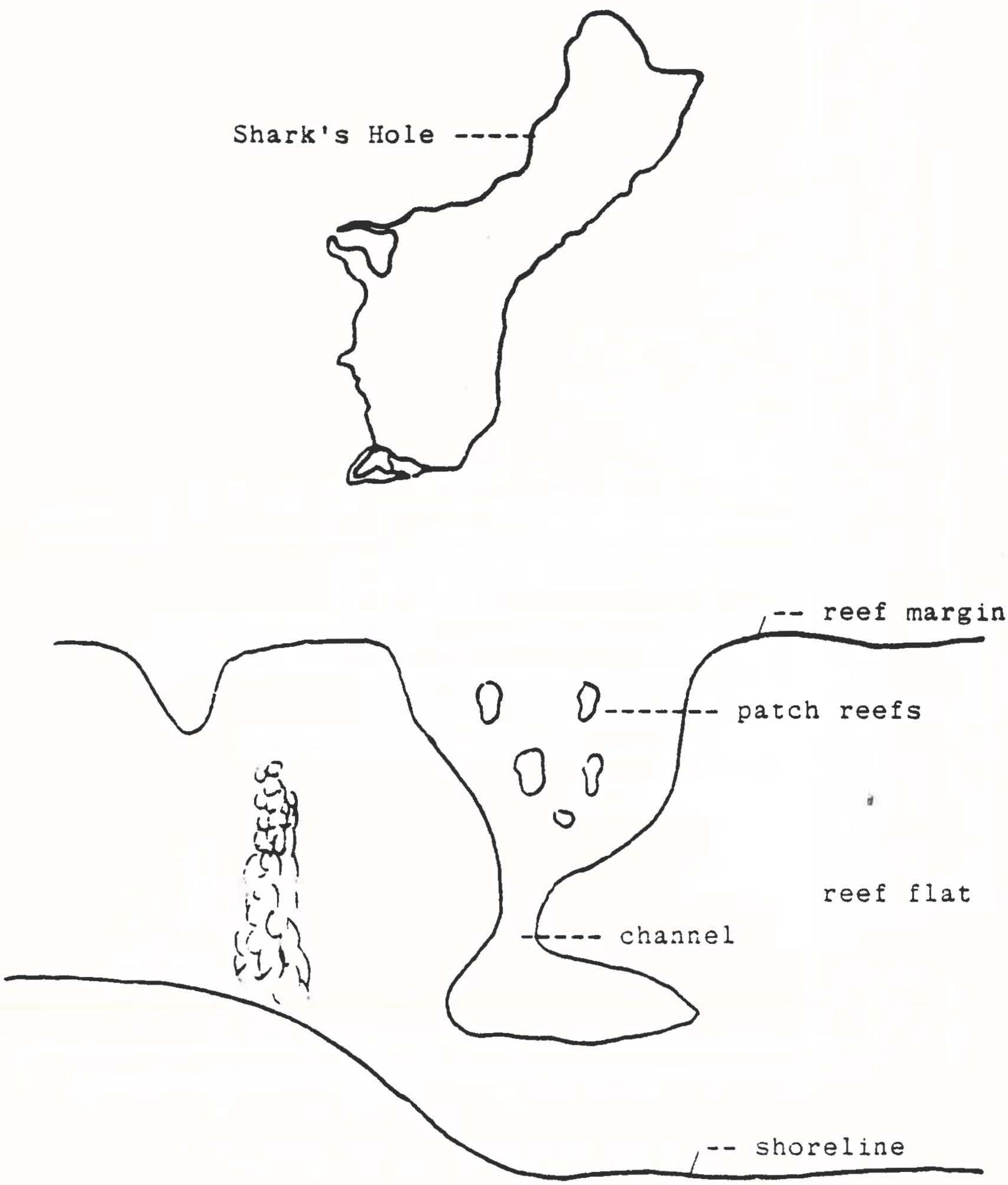

Figure 1. Collection site and reef morphology.

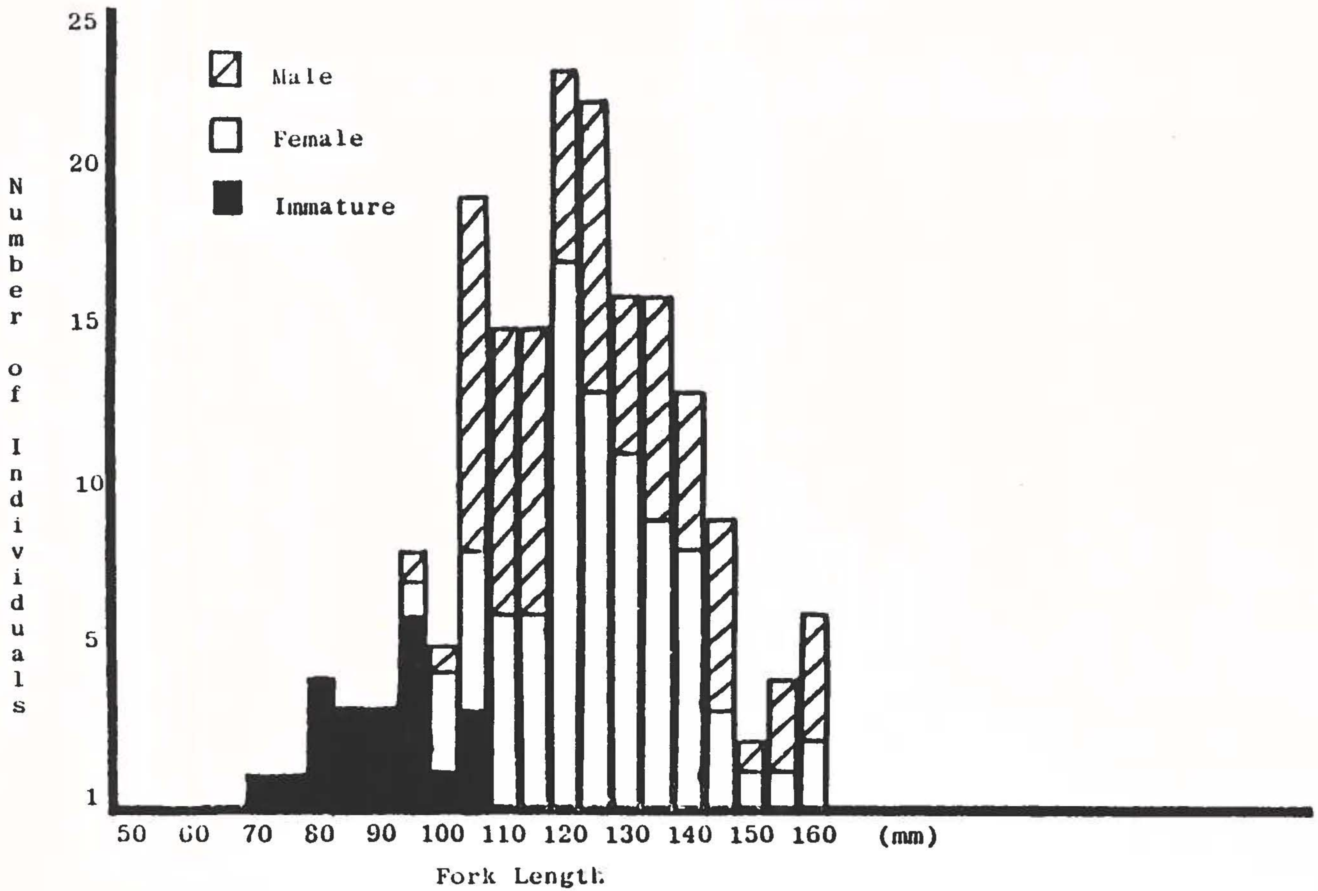

Figure 2. Size-class distribution of male, female, and immature *Acanthurus triostegus*.

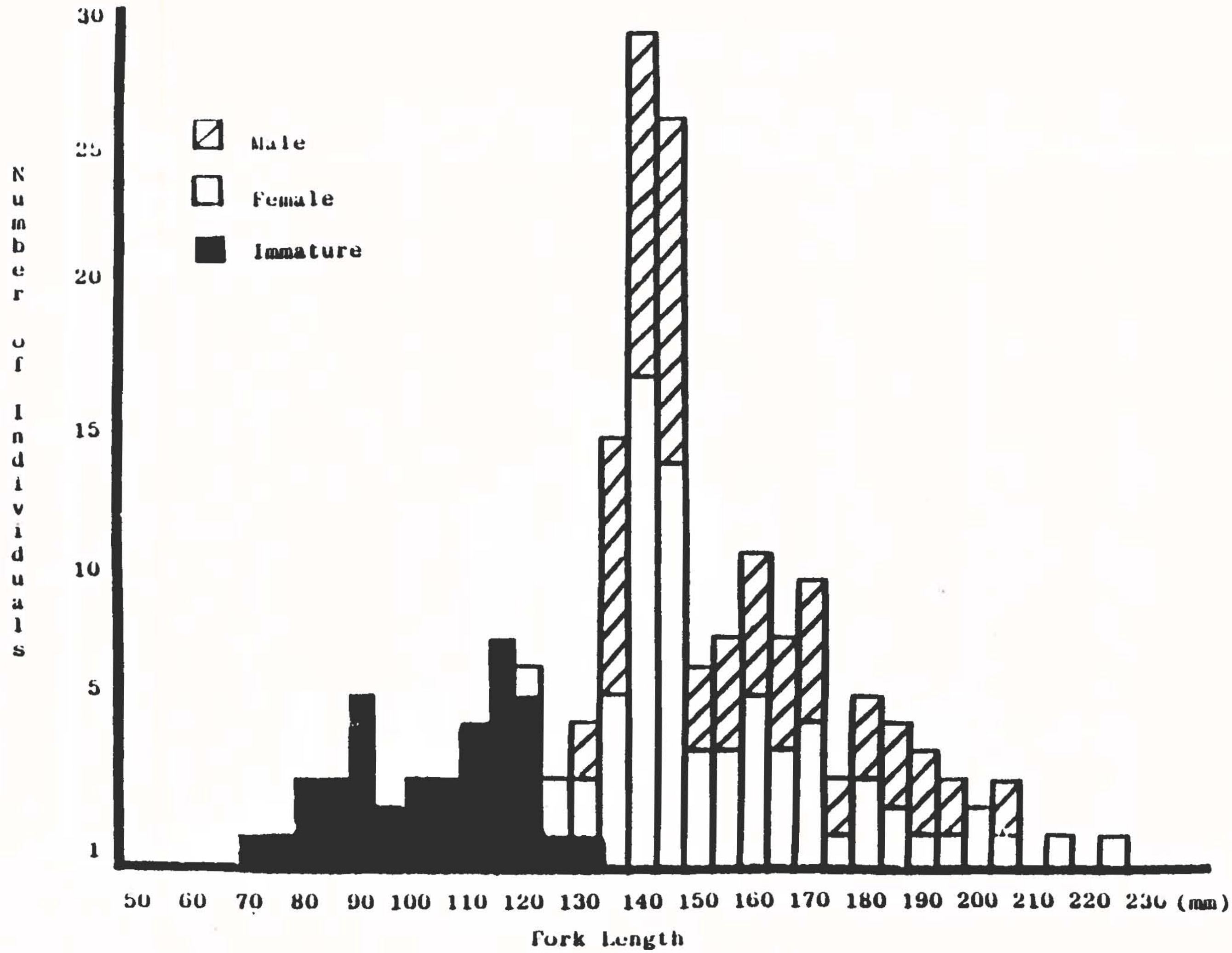

Figure 3. Size-class distribution of male, female, and immature *Acanthurus lineatus*.

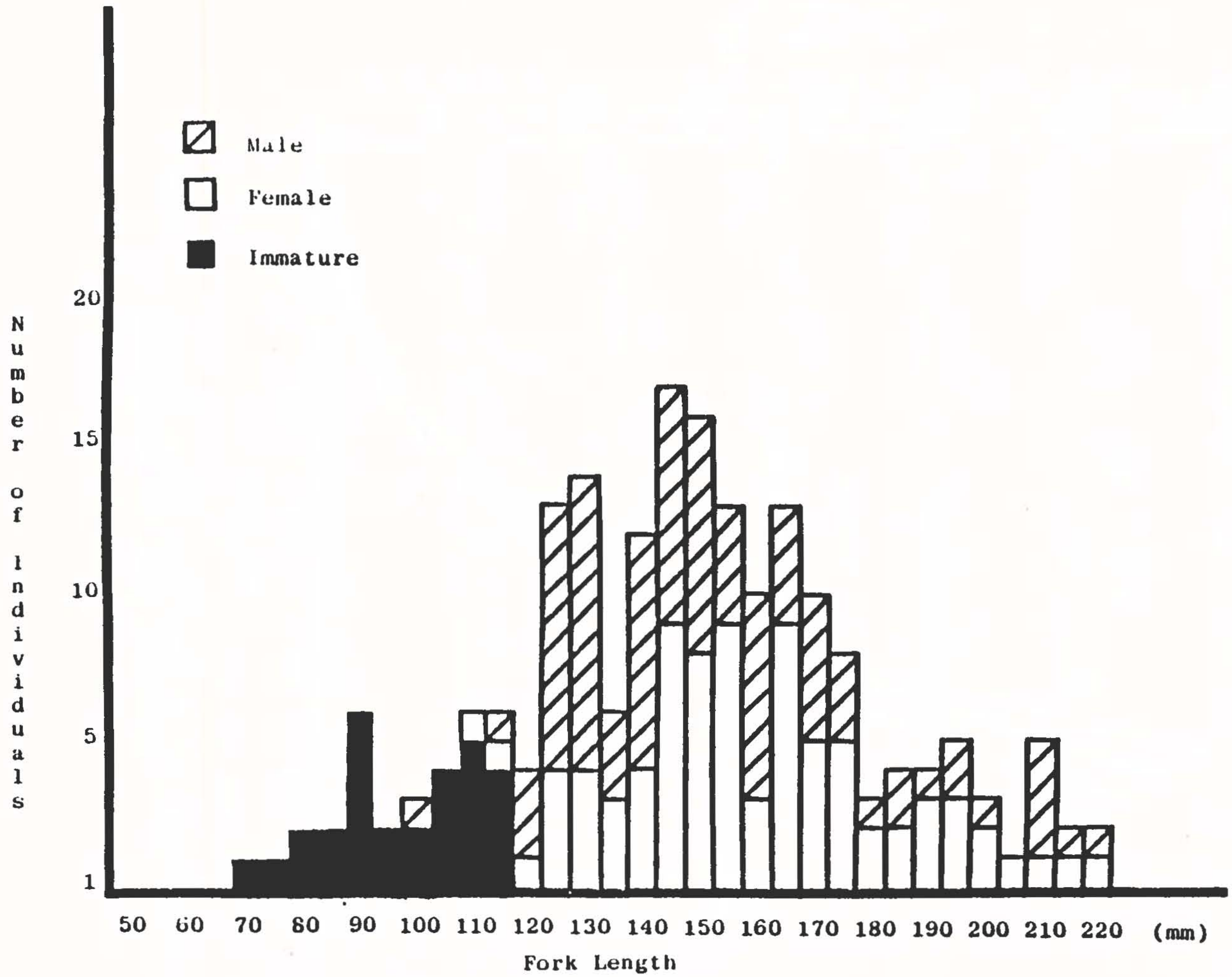

Figure 4. Size-class distribution of male, female, and immature *Naso lituratus*.

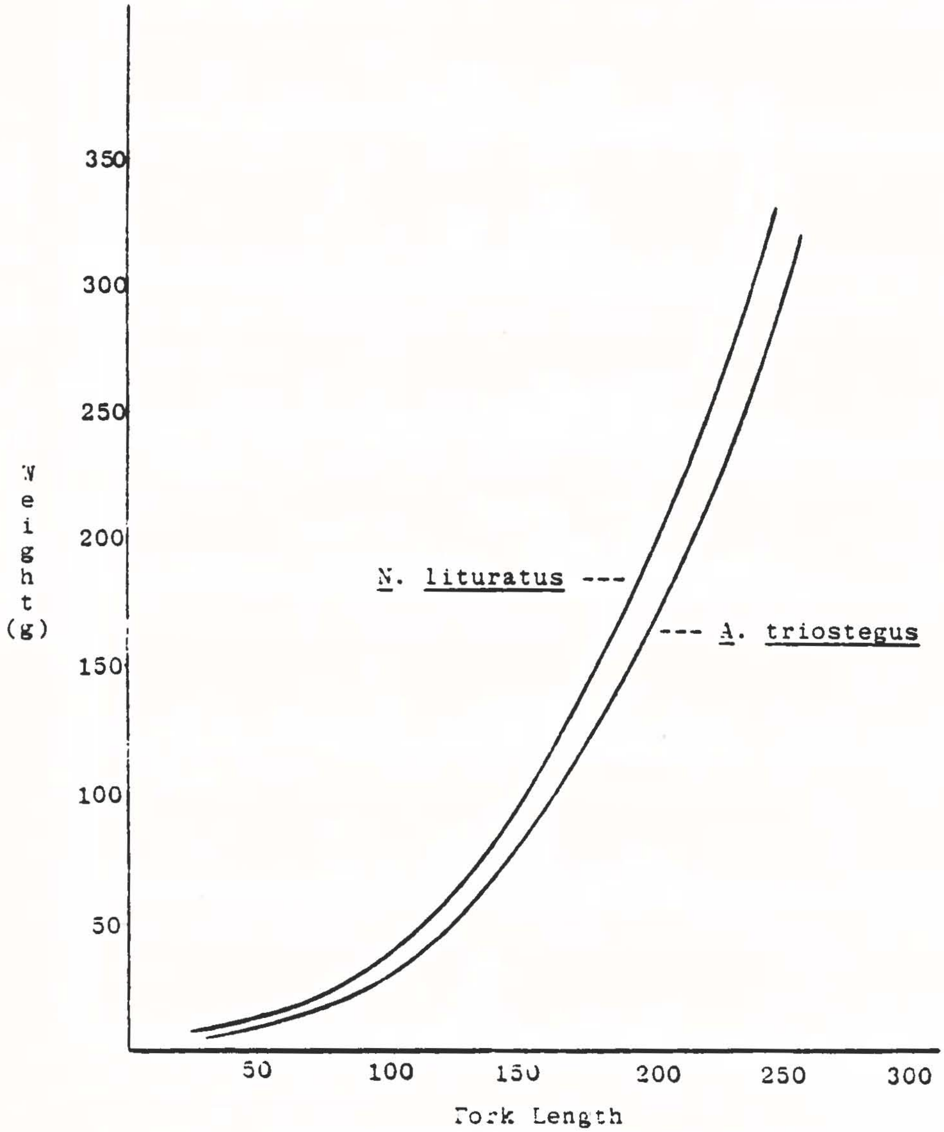

Figure 5. Length/weight relationships for *Acanthurus triostegus* and *Naso lituratus*.

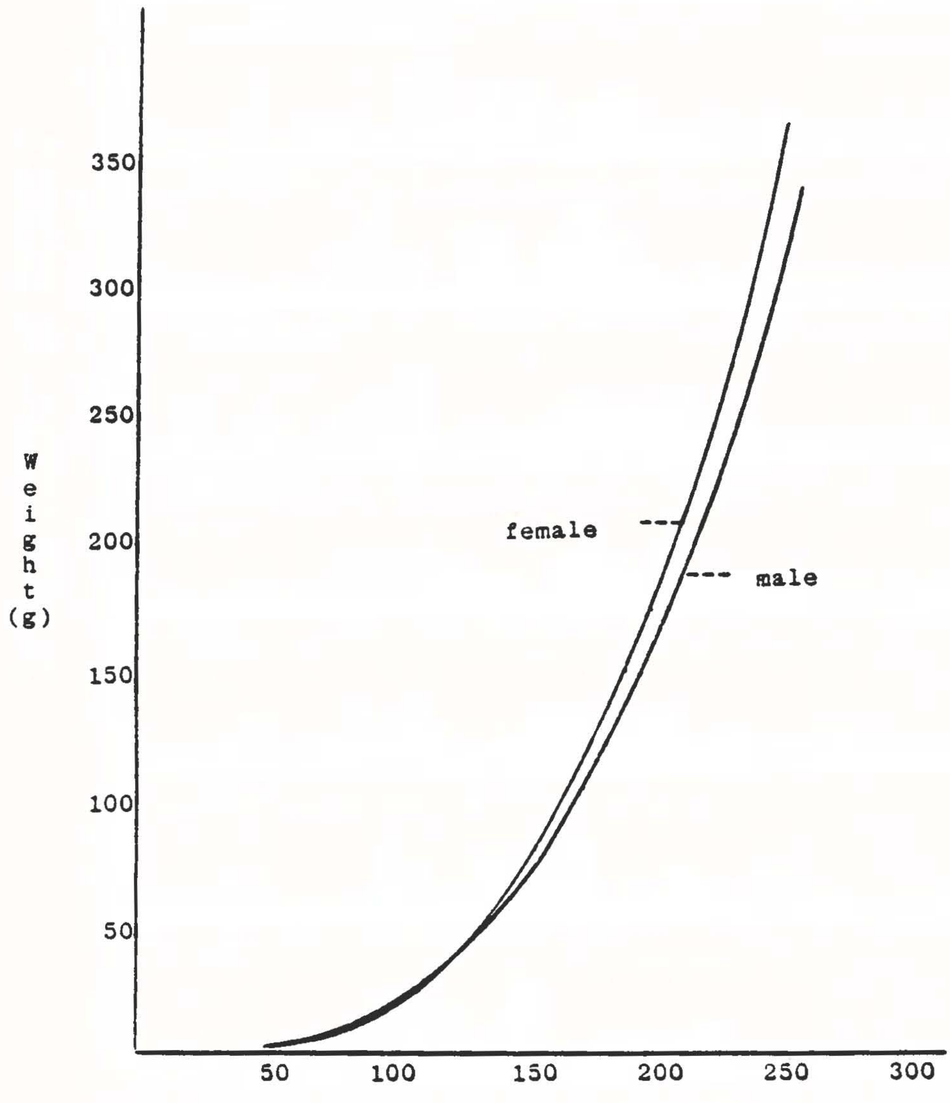

Figure 6. Length/weight relationships for male, and female *Acanthurus lineatus*.

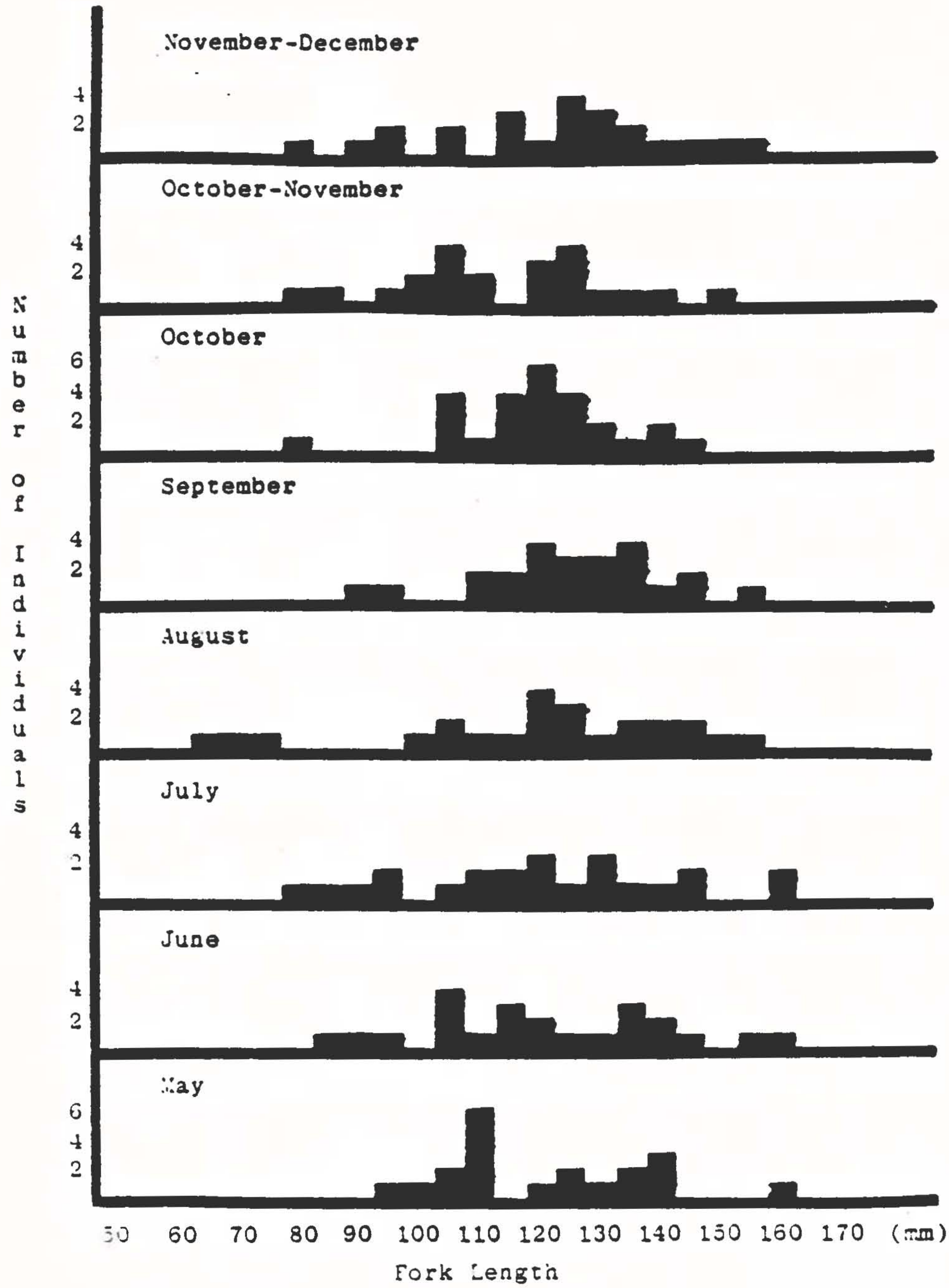

Figure 7. Size-class distribution for <u>Acanthurus triostegus</u>.

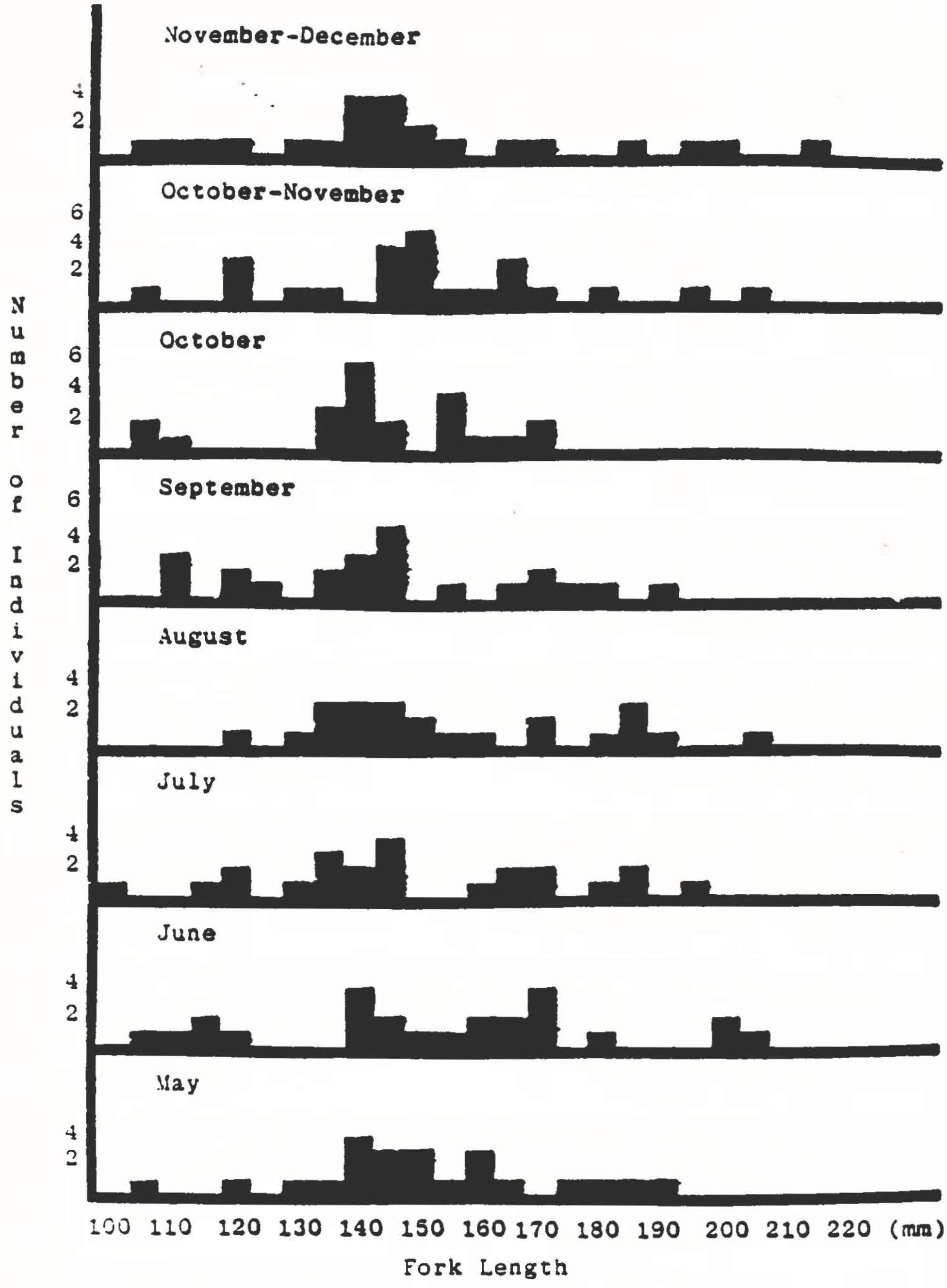

Figure 8. Size-class distribution for *Acanthurus lineatus*.

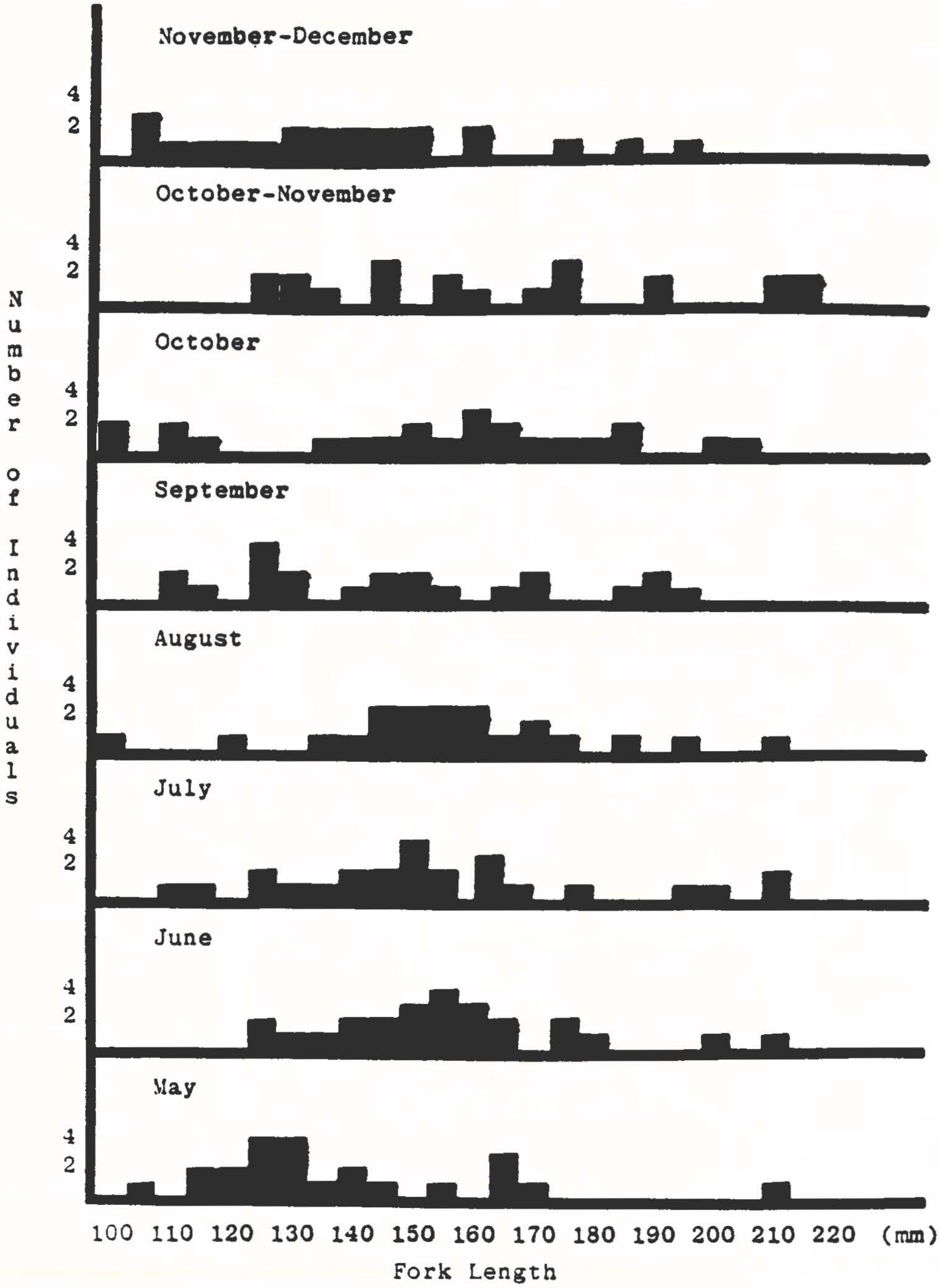

Figure 9. Size class distribution for *Naso lituratus*.

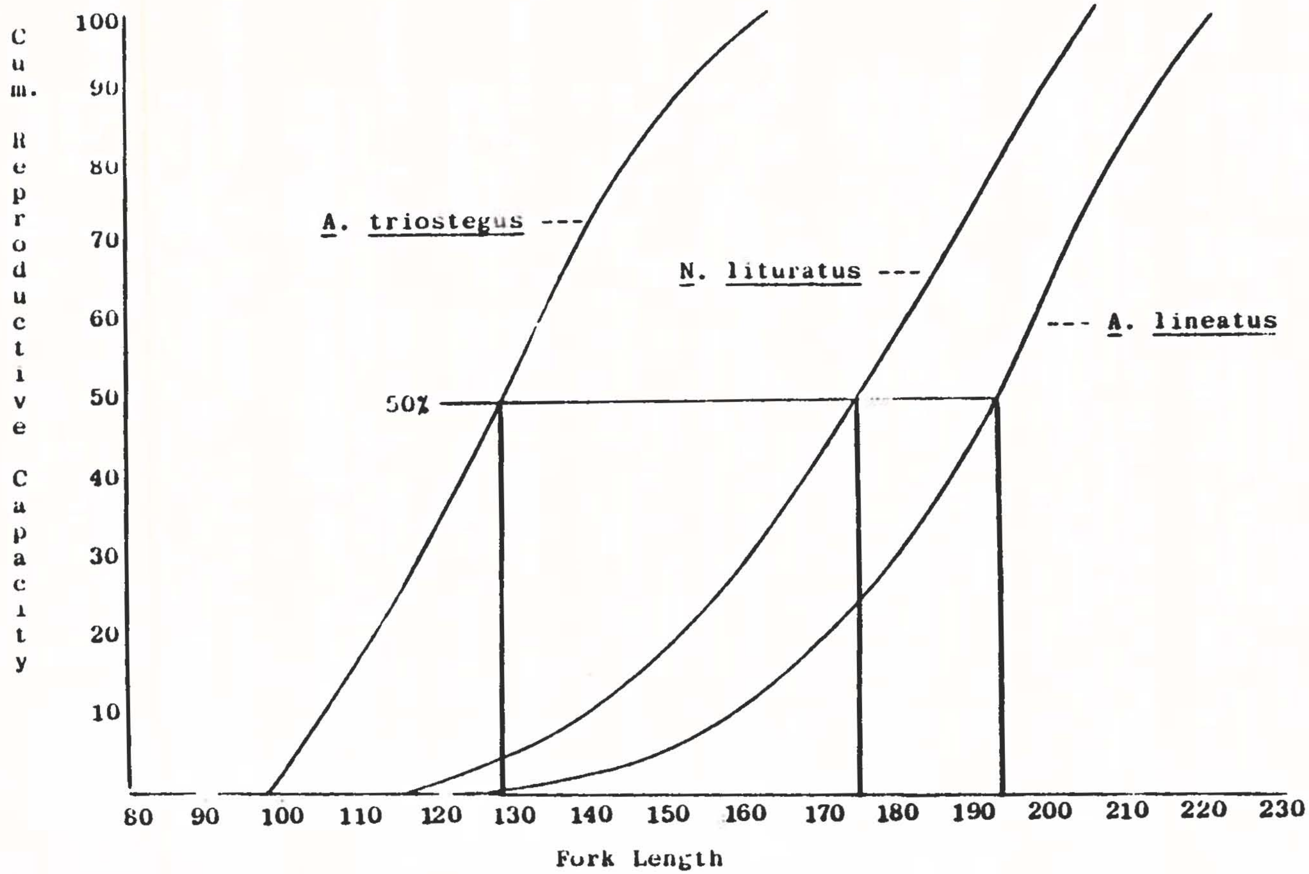

Figure 10. Cumulative reproductive capacity for <u>Acanthurus triostegus</u>, <u>Acanthurus lineatus</u>, and <u>Naso lituratus</u>. The 50 percent retention values are defined for all three species.

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