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LIFE HISTORY, DISTRIBUTION, AND ABUNDANCE OF BOTTOMFISHES IN THE NORTHWESTERN HAWAIIAN ISLANDS

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ABSTRACT

Relative apparent abundance of the eight most important bottomfish species was examined for the major banks of the Northwestern Hawaiian Islands. Most noteworthy was the dominance of *Pristipomoides filamentosus* at Necker bank, French Frigate Shoals, and Brooks Banks and of *Etelis carbunculus* northwest of Lisianski bank. In general, catch rates and mean sizes increased at the northwestern end of the archipelago. Research on age and growth, length-weight relationships, reproductive biology, feeding habits, and the occurrence of ciguatoxin in bottomfishes was also reviewed.

age and growth
relative apparent abundance
bottomfishes
species composition

INTRODUCTION

The history of the fishery for snappers, grouper, and jacks, commonly referred to as bottomfishes, in the Northwestern Hawaiian Islands (NWHI) is not well documented. This fishery has been in existence in the NWHI at least since the mid-1940s (A.B. Amerson, 1971) and perhaps as early as the 1930s (see paper in this proceedings by Hau). From records maintained by the Division of Aquatic Resources (DAR), Hawaii Department of Land and Natural Resources, summaries of total annual catch, fishing effort (boat trip), and ex-vessel value per year were prepared for the period 1959 through 1977 by Polovina and Moffitt (1980) (Table 1). Annual catch statistics by species were also tabulated. During this period one vessel accounted for 95.5 percent of the catch. Starting in November 1976, a spiny lobster fishery developed in the NWHI; in addition to lobsters, vessels in this fishery landed bottomfishes. When the jig boat albacore fishery expanded to the central North Pacific in 1979, some trolling vessels remained in Hawaii beyond the season for albacore and converted to bottomfishing in the NWHI.

TABLE 1. TOTAL VALUE, WEIGHT OF CATCH, AND NUMBER OF TRIPS IN THE BOTTOM HANDLINE FISHERY IN THE NORTHWESTERN HAWAIIAN ISLANDS

Year	Dollar Value	Kilograms Caught	Number of Trips
1959	26,896	32,164	10
1960	45,779	49,515	16
1961	30,115	34,476	11
1962	25,363	29,244	13
1963	32,653	40,730	18
1964	39,277	47,260	19
1965	20,118	25,154	9
1966	18,213	21,935	9
1967	13,775	14,822	6
1968	14,320	15,172	6
1969	14,812	18,113	4
1970	39,147	33,683	11
1971	50,206	34,180	17
1972	41,992	19,356	17
1973	62,759	28,050	20
1974	48,899	22,313	15
1975	63,873	27,012	14
1976	78,476	26,730	14
1977	95,659	35,576	20

Source: Polovina and Moffitt, 1980

In March 1977 the Magnuson Fishery Conservation and Management Act (FCMA) of 1976 extended federal jurisdiction over fishery resources from 3 to 200 nautical miles (nmi) around the islands in the Hawaiian Archipelago (Figure 1). The FCMA also established eight regional fishery management councils nationally to manage the resources in the fishery conservation zone (FCZ). The Western Pacific Regional Fishery Management Council was established with jurisdiction in the FCZs around Hawaii, Guam, Northern Marianas, and American Samoa and is currently examining the fishery for bottomfishes to determine whether a fishery management plan (FMP) is warranted.

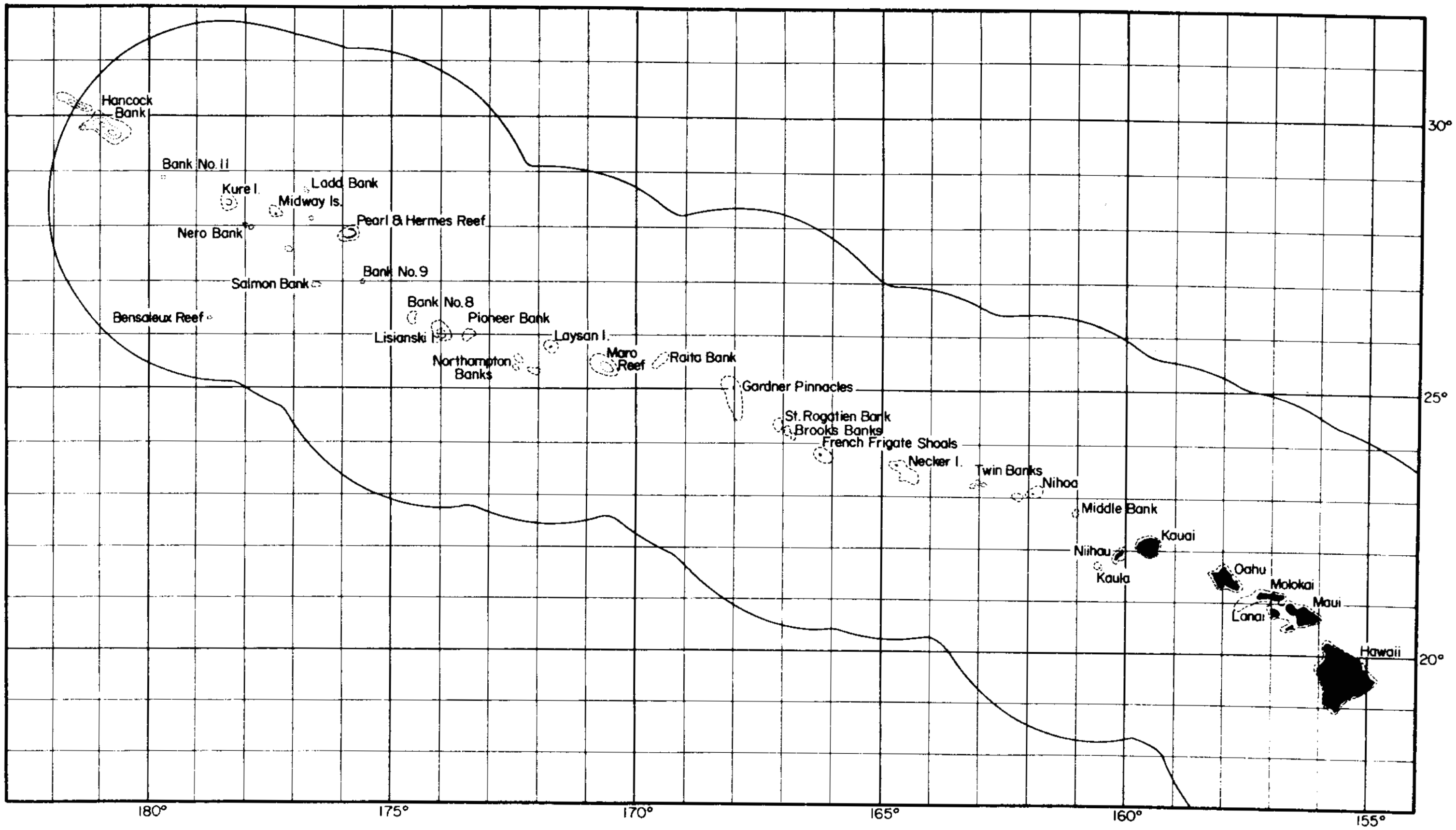

Figure 1. The U.S. Fishery Conservation Zone around the Hawaiian Archipelago

Because very little was known about the biotic resources in the NWHI, a cooperative research agreement was signed by the Division of Aquatic Resources; the Fish and Wildlife Service (FWS), U.S. Department of Interior; and the Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service (NMFS) in 1977 to survey the resources. A year after the formation of the cooperative tripartite agreement, a fourth agency, the University of Hawaii Sea Grant College Program, became an active participant in the resource investigations. In the agreement, FWS was given the responsibility to survey and assess the terrestrial resources such as sea and land birds, DAR was assigned the assessment of inshore fishery resources, and NMFS was assigned the assessment of offshore fishery resources. Later, NMFS also assumed the responsibility for research on the Hawaiian monk seal, Monachus schauinslandi, and the Hawaiian green turtle, Chelonia mydas.

Among the offshore fishery resources are the bottomfishes. Various studies were conducted by NMFS to determine their distribution and relative abundance in the NWHI. Studies on age and growth, reproduction, feeding habits, and the occurrence of ciguatoxin in bottomfishes were also conducted. This paper is a review of the results of these studies conducted by the Honolulu Labortory since 1976.

SPECIES OF THE SNAPPER-GROUPER-JACK COMPLEX

The scientific names of bottomfish species commonly caught in the NWHI are listed in Table 2 along with synonyms and Hawaiian or local names which have remained in use for many decades. The fishes in the snapper-grouper-jack complex are also called deepsea handline fishes, but are referred to as bottomfish in this paper.

DISTRIBUTION AND APPARENT ABUNDANCE

A primary objective of the NMFS NWHI study was to conduct assessments of the resources in the area. Catch data at 283 handline stations were collected from the R/V Townsend Cromwell from October 1976 to September 1982. Effort was recorded as line-hour and catch as either the number or weight of fish.

Bottomfishes were widely distributed throughout the NWHI (Table 3). To determine their vertical distribution, traps, trawls, and handlines were used to sample various depths. The depth range of the various species was tabulated for each bank (Table 3) by Uchida and Uchiyama (in preparation). The true depth range for these species is probably wider than that estimated by the catch data.

TABLE 2. SCIENTIFIC NAME, SYNONYM, AND LOCAL NAME OF NORTHWESTERN HAWAIIAN ISLANDS BOTTOMFISHES

Scientific Name	Synonym	Local Name
Serranidae		
Epinephelus quernus		Hapuupuu
Carangidae		
Carangoides orthogramus[1]	*C. ferdau*	Ulua
Caranx ignoblis		Ulua
C. lugubris		Ulua
C. melampygus		Omilu
Pseudocaranx dentex[2]	*C. cheilio*	Pig ulua
Seriola dumerili		Kahala
S. lalandii		Kahala opio
Lutjanidae		
Aprion virescens		Uku
Etelis carbunculus[3]	*E. marshi*	Ehu
E. coruscans[3]	*E. carbunculus*	Onaga
Pristipomodies filamentosus[4]	*P. microlepis*	Opakapaka
P. sieboldii		Kalekale
P. zonatus[5]	*Rooseveltia brighami*	Gindai
Scorpaenidae		
Pontinus macrocephalus[6]	*Merinthe macrocephala*	Nohu

[1]Misidentification corrected by F.W. Smith-Vaniz (Randall, 1980)
[2]Revised by F.W. Smith-Vaniz, The Academy of Natural Sciences, Philadelphia, PA 19103, personal communication, 1981
[3]Revised by Anderson (1981)
[4]Revised by Kami (1973)
[5]Change proposed by W.D. Anderson, College of Charleston, Charleston, SC 29412, personal communication, 1981
[6]Revised by Eschmeyer and Randall (1975)

TABLE 3. DEPTH DISTRIBUTION (IN METERS) BY BANK OF BOTTOM FISHES IN THE NORTHWESTERN HAWAIIAN ISLANDS DURING RESOURCE SURVEYS FROM OCTOBER 1976 TO AUGUST 1981

Bank	*Epinephelus quernus*		*Pseudocaranx dentex*		*Seriola dumerili*		*Etelis carbunculus*		*E. coruscans*		*Pristipomoides filamentosus*		*P. sieboldii*		*P. zonatus*	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Middle Bank	146	146	—	—	44	146	—	—	—	—	36	73	—	—	—	—
Nihoa	44	183	*	*	51	73	128	201	—	—	*	*	137	137	—	—
Twin Banks	183	183	27	46	29	91	183	183	256	256	—	—	91	91	—	—
Necker Island	27	229	66	174	2	229	139	229	*	*	31	328	110	120	183	183
French Frigate Shoals	58	194	110	165	26	186	113	152	—	—	46	186	113	201	128	128
Brooks Banks	183	183	—	—	51	201	—	—	—	—	36	161	—	—	201	201
St. Rogatien Bank	—	—	*	*	*	*	*	*	*	*	*	*	—	—	—	—
Gardner Pinnacles	110	347	16	183	16	128	128	183	*	*	27	183	128	128	—	—
Raita Bank	31	172	183	183	146	146	—	—	—	—	40	40	172	183	—	—
Maro Reef	38	201	102	201	2	201	102	201	—	—	31	183	102	102	102	201
Laysan Island	90	183	146	174	2	183	174	201	256	256	64	174	*	*	201	201
Northampton Seamounts	164	219	201	201	—	—	110	219	—	—	110	201	146	201	164	201
Lisianski Island and Pioneer	110	238	27	194	110	247	179	238	194	194	91	179	194	194	183	238
Bank No. 8	146	183	—	—	146	165	219	238	—	—	71	71	—	—	183	183
Pearl and Hermes Atoll	33	238	48	238	35	238	121	271	183	229	57	164	164	198	146	183
Salmon Bank	119	119	—	—	—	—	119	219	—	—	—	—	219	219	—	—
Ladd Island	66	216	*	*	—	—	146	216	—	—	—	—	146	216	—	—
Midway Islands	26	219	0	183	2	128	192	219	—	—	—	—	—	—	—	—
Nero and Pogy	146	146	183	183	111	111	183	183	—	—	108	108	—	—	—	—
Kure Atoll	18	218	2	183	9	9	219	219	183	183	—	—	*	*	—	—

Note: Information abstracted from Table 2 of Uchida and Uchiyama (in preparation)
* Depth uncertain

The catch rates varied among banks (Table 4). The catch rate of hapuupuu generally increased with distance away from the high islands. For pig ulua, the catch rate was high around Raita Bank, Maro bank, and Laysan bank, whereas for kahala, it was high from Gardner Pinnacles to Pearl and Hermes Atoll. West of Lisianski bank, the relative abundance of ehu increased greatly. Opakapaka were abundant at Necker bank and French Frigate Shoals but were not caught west of Nero Seamount. Although this species was not recorded at Midway bank, it is known to occur there (S. Ralston, 1983: personal communication). Furthermore, opakapaka were caught in lobster pots at bank no. 8, although none were caught on handlines. The relative abundance figures for onaga, kalekale, and gindai were too low to analyze by locality.

Species composition at each bank is presented in Table 5. Miscellaneous species listed previously by Moffitt (1980) were not included. A noticeable feature of species composition in the NWHI was the dominance of ehu west of Lisianski bank and opakapaka at Necker bank, French Frigate Shoals, and Brooks Banks. Catches west of Lisianski bank were composed of 45.6 to 86.5 percent ehu, excluding data from Midway Islands and Kure Atoll. Opakapaka represented 44.4 percent of the catch at Necker bank, 52.5 percent at French Frigate Shoals, and 40.0 percent at Brooks Banks. No gindai were caught west of Ladd Seamount. This pattern of species composition by banks was similar to that reported by Moffitt (1980).

For each species the fork or total lengths from all banks were pooled and compared by one-way analysis of variance. Mean sizes for seven species at the various banks varied significantly (Table 6). In general, significant differences in fish size existed between banks that were heavily fished and those that were pristine (NMFS, unpublished data). Because the fishes were larger on the northwestern end of the archipelago (except for pig ulua), it was not surprising that catch rates (kilograms per line-hour) also increased at that end of the NWHI (Table 7).

Catch and effort data to estimate sustainable yield from production analysis were unavailable for the NWHI. Annual maximum sustainable yields (MSY) of 111,300 kg for Oahu and 288,320 kg for Maui, Molokai, and Lanai have been estimated (Ralston, 1980; Ralston and Polovina, 1982; Polovina and Moffitt, 1980). These original estimates have since been revised. Assuming that abundance and population dynamics of these species are similar in the NWHI and the main Hawaiian islands, the MSY was estimated for these species in the NWHI (see paper in this proceedings by Ralston).

LIFE HISTORY STUDIES

Otoliths were collected for age and growth studies, gonads for reproductive studies, stomach contents and spew samples for feeding habit studies, and various tissue samples for ciguatoxin studies.

TABLE 4. SUMMARY OF CATCH RATES (NUMBER PER LINE-HOUR) FOR BOTTOMFISHES IN THE NORTHWESTERN HAWAIIAN ISLANDS

Bank	Total Effort (Line-Hours)	*Epinephelus quernus*	*Pseudocaranx dentex*	*Seriola dumerili*	*Etelis carbunculus*	*E. coruscans*	*Pristipomoides filamentosus*	*P. sieboldii*	*P. zonatus*
Middle Bank	9.73	0.21	—	0.10	—	—	—	—	—
Nihoa	168.75	0.12	0.10	0.04	0.50	0.01	0.06	0.19	0.02
Twin Banks	29.47	0.10	—	0.14	0.07	0.03	0.07	0.07	—
Necker Island	363.85	0.14	0.08	0.11	0.33	0.00	0.63	0.08	0.04
French Frigate Shoals	297.17	0.33	0.18	0.12	0.11	0.00	1.05	0.10	0.10
Brooks Banks	61.27	0.05	—	0.03	—	—	0.07	—	0.02
St. Rogatien Bank	49.07	0.43	0.29	0.08	0.35	0.20	0.37	0.06	0.04
Gardner Pinnacles	117.62	0.16	0.15	0.16	0.16	0.03	0.14	0.03	0.04
Raita Bank	94.35	0.49	0.24	0.17	0.25	0.17	0.18	0.17	0.08
Maro Reef	101.47	0.55	0.40	0.22	0.24	—	0.45	0.02	0.10
Laysan Island	175.40	0.42	0.31	0.18	0.36	0.02	0.19	0.05	0.08
Northampton Seamounts	16.60	0.12	0.06	—	0.42	—	0.12	0.18	0.54
Lisianski Island and Pioneer	93.57	0.50	0.07	0.14	0.27	0.06	0.10	—	0.04
Bank No. 8	39.27	0.38	—	0.15	1.17	—	—	—	0.33
Pearl and Hermes Atoll	229.93	0.74	0.22	0.16	1.72	0.12	0.03	0.10	0.03
Salmon Bank	41.60	0.05	—	—	0.75	—	—	0.17	0.02
Ladd Island	52.80	0.15	—	—	1.04	0.04	—	0.09	—
Midway Islands	26.83	0.82	0.45	0.04	0.75	—	—	—	—
Nero and Pogy	18.80	0.53	0.05	—	4.10	—	—	0.05	—
Kure Atoll	75.33	0.42	0.20	0.01	0.20	0.03	—	0.01	—

TABLE 5. SPECIES COMPOSITION (PERCENTAGE) OF BOTTOMFISHES IN THE NORTHWESTERN HAWAIIAN ISLANDS

Bank	*Epinephelus quernus*	*Pseudocaranx dentex*	*Seriola dumerili*	*Etelis carbunculus*	*E. coruscans*	*Pristipomodies filamentosus*	*P. sieboldii*	*P. zonatus*
Middle Bank	66.7	—	33.3	—	—	—	—	—
Nihoa	11.5	9.8	3.4	48.3	0.6	5.7	18.3	2.2
Twin Banks	21.4	—	28.6	14.3	7.2	14.3	14.3	—
Necker Island	10.2	5.7	7.7	23.5	0.2	44.4	5.5	2.8
French Frigate Shoals	16.5	8.9	5.9	5.7	0.2	52.5	5.2	5.0
Brooks Banks	30.0	—	20.0	—	—	40.0	—	10.0
St. Rogatien Bank	23.6	15.7	4.5	19.1	11.2	20.2	3.4	2.2
Gardner Pinnacles	18.1	17.1	18.1	18.1	3.8	16.2	3.8	4.8
Raita Bank	27.7	13.8	9.6	14.4	9.6	10.2	9.6	4.8
Maro Reef	27.9	20.4	10.9	11.9	—	22.9	1.0	5.0
Laysan Island	26.1	19.4	11.0	22.6	1.4	11.7	2.8	4.9
Northampton Seamounts	8.3	4.2	—	29.2	—	8.3	12.5	37.5
Lisianski Island and Pioneer	35.3	5.3	9.8	18.8	4.5	6.8	0.8	3.0
Bank No. 8	18.8	—	7.5	57.5	—	—	—	16.2
Bank No. 9	27.8	3.3	11.1	45.6	1.1	1.1	6.6	3.3
Pearl and Hermes Atoll	23.6	6.9	5.0	54.5	3.8	1.0	3.3	1.0
Salmon Bank	4.9	—	—	75.6	—	—	17.0	2.4
Ladd Island	11.4	—	—	78.6	2.8	—	7.1	—
Midway Islands	31.4	17.1	1.4	28.6	—	—	—	—
Nero and Pogy	11.2	1.1	—	86.5	—	—	1.1	—
Kure Atoll	48.5	22.7	1.5	22.7	3.0	—	1.5	—

TABLE 6. ONE-WAY ANALYSIS OF VARIANCE COMPARING MEAN LENGTHS OF SEVEN SPECIES OF BOTTOMFISHES

Species	Degrees of Freedom	F Value	Probability
Epinephelus quernus	18, 521	6.3347	0.0186
Pseudocaranx dentex	10, 252	6.8400	0.0
Seriola dumerili	13, 163	3.4110	0.0001
Etelis carbunculus	17, 734	6.6013	0.0
Pristipomoides filamentosus	9, 450	26.6070	0.0
P. sieboldii	10, 108	2.2649	0.0191
P. zonatus	10, 70	2.3507	0.0186

TABLE 7. SUMMARY OF CATCH RATES (KILOGRAMS PER LINE-HOUR) FOR BOTTOMFISHES IN THE NORTHWESTERN HAWAIIAN ISLANDS

Bank	*Epinephelus quernus*	*Pseudocaranx dentex*	*Seriola dumerili*	*Etelis carbunculus*	*E. coruscans*	*Pristipomoides filamentosus*	*P. sieboldii*	*P. zonatus*	Total
Middle Bank	0.92	—	0.42	—	—	—	—	—	1.34
Nihoa	0.52	0.52	0.26	0.77	0.04	0.25	0.13	0.03	2.52
Twin Banks	1.20	—	1.79	0.15	0.21	—	0.08	—	3.43
Necker Island	0.72	0.38	0.59	0.43	0.01	1.69	0.06	0.05	3.93
French Frigate Shoals	2.02	1.11	0.64	0.17	0.01	2.71	0.07	0.15	6.88
Brooks Banks	0.30	—	0.24	—	—	0.18	—	0.02	0.74
St. Rogatien Bank	3.11	1.93	0.79	0.52	0.65	1.37	0.04	0.06	8.47
Gardner Pinnacles	0.87	0.87	1.02	0.29	0.15	0.63	0.02	0.06	3.91
Raita Bank	3.81	1.61	1.33	0.54	0.90	0.80	0.12	0.16	9.27
Maro Reef	3.07	1.74	1.39	0.50	—	1.87	0.06	0.18	8.81
Laysan Island	3.67	2.05	1.40	0.69	0.10	1.10	0.02	0.14	9.17
Northampton Seamounts	1.25	0.54	0.10	0.84	—	0.55	—	1.02	4.30
Lisianski and Pioneer	3.49	0.62	1.31	0.64	0.30	0.45	0.00	0.08	6.89
Bank No. 8	3.95	—	1.41	2.58	—	—	—	0.51	8.45
Bank No. 9	11.85	0.70	4.37	3.29	0.28	0.16	0.17	0.22	21.04
Pearl and Hermes Atoll	4.07	1.20	1.45	2.97	0.65	0.15	0.07	0.07	10.63
Salmon Bank	0.58	—	—	1.63	—	—	0.10	0.03	2.34
Ladd Island	1.75	—	—	2.39	0.32	—	0.10	—	4.56
Midway Islands	3.94	1.79	0.41	1.53	—	—	—	—	7.67
Nero and Pogy	3.91	0.28	—	8.19	—	—	0.04	—	12.42
Kure Atoll	2.90	1.05	0.10	0.51	0.10	—	0.01	—	4.67

Age and Growth

Considerable effort has been expended in estimating age and growth of NWHI bottomfishes (Figure 2). All species were aged by enumerating daily increments on otoliths; two species were aged by counting the annuli. Evidence that increments are deposited daily was obtained only for the pig ulua (Uchiyama et al., in preparation). It is highly improbable that daily increments can be validated for species such as ehu, gindai, kalekale, and onaga that live at great depths. Thus, age and growth estimates are considered tentative for species in which daily increments were not validated.

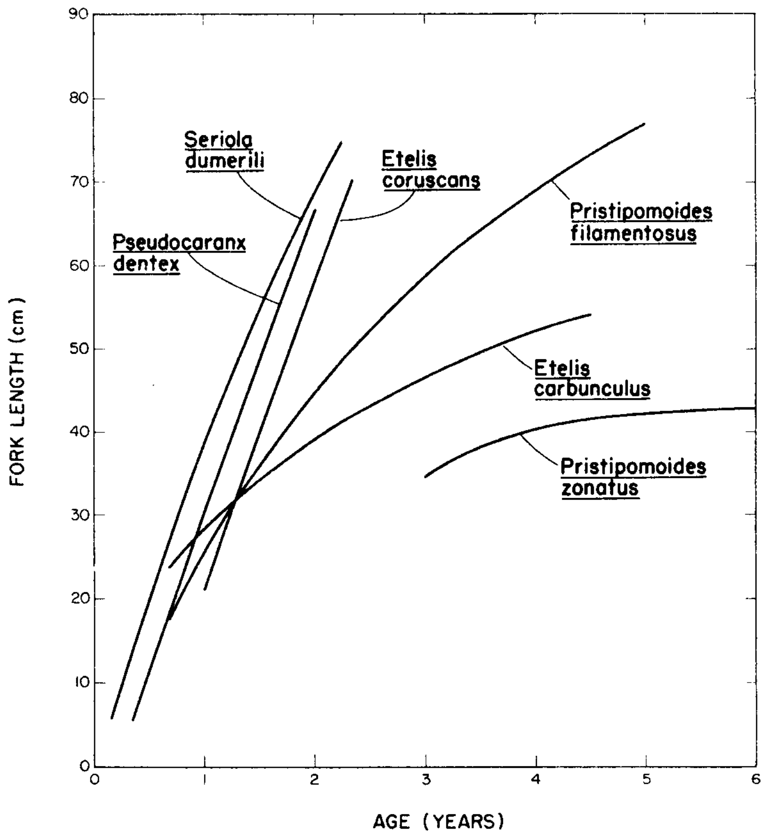

Figure 2. Estimated growth curves ot tne bottom-fishes in the Northwestern Hawaiian Islands

Von Bertalanffy growth parameters (L_∞ = 97.1 cm, k = 0.31, t_0 = 0.02 yr) and a growth curve for opakapaka (Figure 2) were determined from age data (Uchiyama et al., in preparation). Annuli were validated by showing that they were formed at the same time (early summer) each year. The method was validated by comparing back calculated length at age with length at age of the von Bertalanffy growth curve. Annual marks make it possible to age more fish in less time and to age older fish. It was difficult to age opakapaka beyond 3 years with daily increment counts. Age determination by enumeration of daily increments agreed well with the growth curve based on annuli (Uchiyama et al., in preparation).

In need of a faster way to age fish using daily increments, Ralston and Miyamoto (in press) analytically integrated otolith growth rate to estimate age-length relationships. Their estimates of opakapaka age-length relationship suggested growth at 33 to 50 percent of the estimated rate determined by Uchiyama et al. (in preparation). R.L. Radtke (unpublished manuscript) enumerated daily increments on opakapaka otoliths with scanning electron microscopy. His estimates of the age-length relationship were similar to those of Uchiyama et al. (in preparation) for fish of 20 to 56-cm fork length (FL). His age estimates for fish greater than 60-cm FL were higher than those of Uchiyama et al. (in preparation), but lower than those estimated by Ralston and Miyamoto (in press).

Preliminary von Bertalanffy parameters (L_∞ = 43.1 cm, k = 1.09, t_0 = 1.51 yr) and a growth curve (Figure 2) were also estimated for gindai using annual marks (J.H. Uchiyama, unpublished data). However, due to a small sample size the annual marks were not validated. Only three age determinations were made using daily increment counts. These points were within the length ranges of estimated year classes.

All other species were aged by daily increments only. Von Bertalanffy parameters and growth curves were estimated for ehu (L_∞ = 63.9 cm, k = 0.36, t_0 = -0.60 yr) and kahala (L_∞ = 149.4, k = 0.31, t_0 = 0.04 yr) (Uchiyama et al., in preparation) (Figure 2). The estimated L_∞ of ehu (63.9 cm) was very close to the size of the largest ehu (63.5-cm FL) caught during the survey cruises. Ehu in the NWHI appeared not to grow as large as those from New Caledonia [105 cm, 19.0 kg; (R. Grandperrin, 1982: personal communication)] and the Indian Ocean (Forster et al., 1970). The estimated L_∞ of kahala (149.4 cm) was also very close to the size of the largest kahala (149.0-cm FL) caught during the survey cruises. Kahala are known to grow up to 155 cm off Florida (Burch, 1979).

Only linear growth stanzas were calculated for onaga (J.H. Uchiyama, unpublished data) and pig ulua (Uchiyama et al., in preparation) because the largest fish for either species examined had not reached the asymptotic growth phase (Figure 2). Furthermore, no attempt was made to estimate growth of onaga, kahala, and pig ulua beyond the ages indicated in Figure 2 because the otoliths of older fish were not readable. The nucleus of the sagittae of larger fish became very opaque after age 2 and did not allow an accurate enumeration of daily growth increments.

Length-weight Relationships

Predictive and functional length-weight relationships have been calculated from lengths and weights of hapuupuu, ehu, onaga, opakapaka, kalekale, gindai, pig ulua, and kahala caught in the NWHI (see Table 4 of paper in this proceedings by Uchiyama et al.). For all species except onaga, the data were separated into groups by sex, cruise, and location of capture, and the slopes of the regression for each grouping were compared by ANCOVA. No significant differences in slopes between sexes were found for ehu, opakapaka, kalekale, gindai, pig ulua, and kahala. Slopes between sexes were not tested for hapuupuu. Among cruises, significant differences were found for hapuupuu and opakapaka. Since these two species are the most important in the NWHI handline fishery, changes in size composition may have caused the slopes to differ over a period of time. Unusually large or small opakapaka and hapuupuu caught during several cruises could have caused the significantly different slopes among cruises. Among locations, differences in slopes were not significant, except for hapuupuu. The body of hapuupuu is stout, compared with the elongated or laterally compressed body types of the other bottomfish species, which may result in a greater change in weight per unit of length.

Reproduction

Studies on reproduction of bottomfishes have centered on determining spawning seasons, size at sexual maturity, and fecundity. The spawning season was determined by the seasonal distribution of mean gonadal somatic indices. Kahala was found to spawn at a low level throughout the year, with increased activity between February and July and peaking in March and April (see paper in this proceedings by Kikkawa and Everson). Opakapaka spawning peaked in August (ripe ovaries were collected from June through December) (see paper in this proceedings by Kikkawa). Ehu spawned from May through October, peaking from July through September (see paper in this proceedings by Everson). The spawning season for kalekale was from June through September, peaking in August and September; whereas for onaga it was estimated to be in August and September based on ovaries collected primarily in the summer (A.R. Everson, 1983: personal communication). Ripe ovaries of gindai were collected in August, whereas those of pig ulua were collected in January and July and those of hapuupuu in January and February. There appeared to be a serial succession of spawning peaks by species groups: hapuupuu in the winter months, carangids in spring and early summer, and snappers in late summer.

Size at maturity has been determined for three species. Gonads began to develop when the kahala reached a length of 72 cm, and the smallest female with ripe ovaries was 78 cm long (see paper in this proceedings by Kikkawa and Everson). For opakapaka, the ovaries generally began to develop when the females were about 42.5 cm long. The females generally reached spawning condition at a length of about 48.7 cm, although the smallest female with a ripe ovary was only 38.4 cm long (see paper in this proceedings by Kikkawa). The ehu reached sexual maturity at a length of about 29.8 cm and spawned at about 31.8 cm (see paper in this proceedings by Everson). In terms of age, kahala reached sexual maturity at about 2.1 years and began spawning at about 2.4 years. Opakapaka reached sexual maturity at about 1.8 years and generally spawned at about 2.2 years. The ehu was about 1.1 years when it reached sexual maturity and spawned at about 1.2 years.

Fecundity for the same three species was estimated following the method of Van Dalsen (1977). The smallest examined kahala (83.0 cm long) yielded about 1.3 million eggs at one spawning and the largest (118.6 cm long) about 4.0 million eggs (see paper in this proceedings by Kikkawa and Everson). The relationship between the number of eggs spawned and length was linear. The smallest examined opakapaka (48.7 cm long) yielded about 457,090 eggs, at one spawning and the largest (76.3 cm long) about 1,461,875 eggs (see paper in this proceedings by Kikkawa). The relationship between eggs spawned and length for this species was curvilinear. The smallest examined ehu (38.3 cm long) yielded about 349,500 eggs at one spawning and the largest (50.8 cm long) about 1,325,600 eggs. The relationship between the number of spawned eggs and length was also curvilinear (see paper in this proceedings by Everson). All three species appeared to be partial spawners, but the number of times a fish spawned in a season was not determined (see paper in this proceedings by Kikkawa and Everson).

Feedings Habits

Studies of stomach contents and spew samples of hapuupuu, kahala, and pig ulua have been completed (see papers in this proceedings by Seki on hapuupuu and trevally; see paper in this proceedings by Humphreys and Kramer). Humpreys and Kramer found that the kahala could be separated into two size groups on the basis of their diet: small (<9 kg) and large (>9 kg). They also separated the prey into three general groups: bottom-associated prey, water column-associated prey, and prey that occupied both habitats. For small kahala from the NWHI, 83.8 percent of the stomach contents consisted of bottom-associated prey, 10.7 percent of water column organisms, and 5.5 percent of prey that occupied both habitats. On the other hand, large kahala preyed more heavily on water column organisms (38.1 percent); bottom-associated organisms comprised 58.0 percent of the prey and organisms associated with both the bottom and water column accounted for 3.9 percent. By volume, the content of small kahala stomachs contained 66.3 percent fish, 31.1 percent cephalopods, and 2.6 percent crustaceans. The content of large kahala stomachs differed by containing 96.2 percent fish, 3.1 percent cephalopods, and 0.7 percent crustaceans. Seki (see papers in this proceedings on hapuupuu and trevally) described both hapuupuu and pig ulua as carnivorous, opportunistic bottom feeders. The hapuupuu fed primarily on fish (76.1 percent) and also consumed some crustaceans (14.6 percent) and molluscs (8.3 percent) (by volume). It appeared to prefer pandalid shrimps which accounted for 64.4 percent of the food items by number but only 7.2 percent by volume. The pig ulua's diet was composed of 64.2 percent fish, 9.4 percent molluscs, 4.3 percent crustaceans, and 21.2 percent rubble and unidentified remains. The stomach contents of ehu were also examined, but not analyzed and the ehu has been described as a carnivorous bottom feeder (M.R. Seki, 1983: personal communication). Spew samples of opakapaka were found to consist of fish, crustaceans, molluscs, and chordates (S. Ralston, 1983: personal communications).

Ehu, hapuupuu, kahala, opakapaka, and pig ulua all had a number of bottom-associated diet items in common, but, except for ehu, each also had preference for a unique prey item. Hapuupuu ate a large number of small crustaceans (see paper in this proceedings by Seki on hapuupuu). Large kahala had a preference for Decapterus, a benthopelagic fish (see paper in this proceedings by Humphreys and Kramer). Opakapaka spew samples uniquely consisted of 42.2 percent by volume of Pyrosoma sp. (S. Ralston, 1983: personal communication), pelagic tunicates (Kami, 1973), and other chordates. The pig ulua's diet contained a high proportion of rubble (21.2 percent by volume) (see paper in this proceedings by Seki on trevally). No unique preferred item was noticed for ehu perhaps because of the small number of spew samples available. These five species appeared to compete for food at least part of the time.

Ciguatoxin Studies

Preliminary progress reports on ciguatoxin in fishes from the NWHI have been published (Ito and Uchida, 1980; Uchida et al., 1979, 1981). Toxicity level is believed to be related to fish size. In their preliminary report, Ito and Uchida (1980) reported a low but significant correlation exists between toxicity level and fish size. This relationship, however, is still under review (B.M. Ito, 1983: personal communication).

Humphreys and Kramer (see paper in this proceedings) compared the diets of kahala which had high radioimmunoassay counts indicating possible presence of ciguatoxin with the diets of nontoxic kahala. Overall diets were quite similar. However, differences between diets of small kahala (<9 kg) and large kahala (>9 kg) were found. Humphreys and Kramer hypothesized that small kahala, which feed on benthic organisms, pick up ciguatoxin in their diet and that large kahala, which feed primarily on pelagic *Decapterus*, contain accumulated toxin from an earlier benthic feeding phase.

Kikkawa and Everson (see paper in this proceedings) examined the occurrence of ciguatoxin in kahala in relation to the reproductive cycle and found no correlation.

CONCLUSIONS

The relative abundance and species composition of bottomfishes varied considerably throughout the NWHI. Most noteworthy was the dominance of opakapaka at Necker bank, French Frigate Shoals, and Brooks Banks, and of ehu west of Lisianski bank.

Members of the three families of bottomfishes studied spawn at different times, i.e., the grouper in winter, carangids in spring and early summer, and the snappers in August. Five species whose stomach contents and spews were examined all fed on an assortment of bottom-associated organisms, which suggested some degree of competition for prey. On the other hand, four species also fed on unique items, indicating niche sepration occurs for at least several species.

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