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BIOLOGY, DISTRIBUTION, POPULATION STRUCTURE, AND PRE-EXPLOITATION ABUNDANCE OF SPINY LOBSTER, *PANULIRUS MARGINATUS* (QUOY AND GAIMARD 1825), IN THE NORTHWESTERN HAWAIIAN ISLANDS

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ABSTRACT

This overview incorporates results of studies conducted on the spiny lobster, *Panulirus marginatus* (Quoy and Gaimard 1825), resource in the Northwestern Hawaiian Islands by the Honolulu Laboratory from October 1976 to September 1981. Of 26 sites surveyed, only Necker Island and Maro reef appeared to have sufficiently large stocks for commercial exploitation. Included also are data on historical catches and fishery development, and results of analyses on geographic and depth distributions, pre-exploitation abundance, size composition, sex ratio, size at maturity, reproduction, behavior, and morphometry. Extrapolation of results from the assessment of the stock at Necker Island provided estimates of the maximum sustainable yield of spiny lobster for the entire Northwestern Hawaiian Islands.

Discussions on economics, fishery potential, and management guidelines are also presented.

spiny lobster — Northwestern Hawaiian Islands
biology — population structure
abundance — distribution

INTRODUCTION

Before 1976, little was known about the marine resources of the Northwestern Hawaiian Islands (NWHI) (Figure 1) and, except for a few commercial fishermen who used French Frigate Shoals as a fishing base or those who made periodic fishing trips for bottomfish, these resources were virtually untouched by humans.

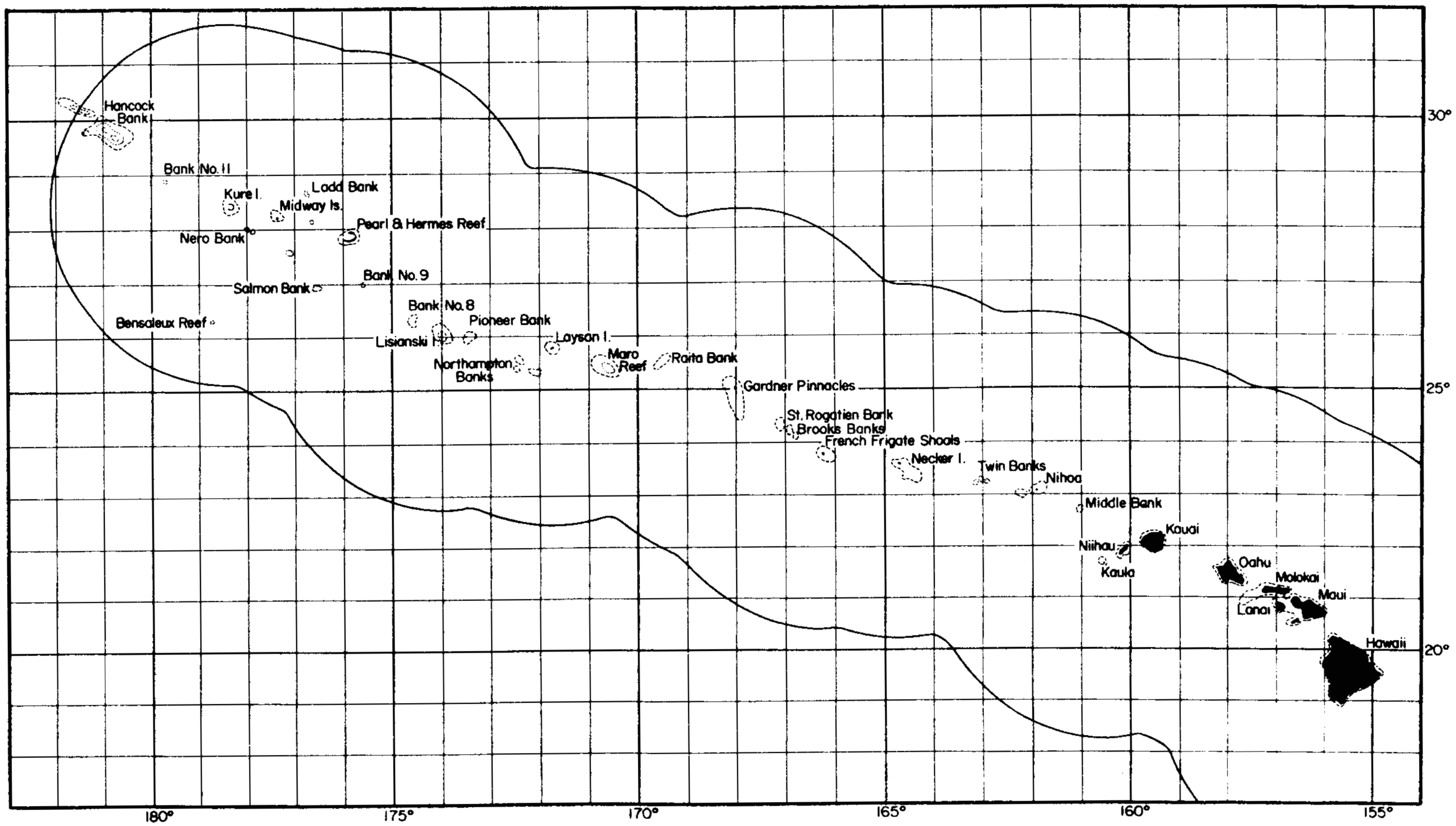

Figure 1. The Hawaiian Archipelago, including the Northwestern Hawaiian Islands

The sequence of events that led to the investigation of the marine and terrestrial resources of these islands is documented in Uchida et al. (1980) and Grigg and Pfund (1980).

From October 1976 to September 1981, the Southwest Fisheries Center Honolulu Laboratory of the National Marine Fisheries Service conducted resource surveys in the NWHI, concentrating on those species of economic significance and high development potential. The objectives of these surveys were to investigate the unfished waters of the NWHI to determine the species that were available, to define their distribution and abundance, to make a first estimate of their potential yield, and to provide preliminary estimates of the likely catch rates. Among the species that showed excellent potential for development was the spiny lobster, *Panulirus marginatus*.

Thus studies were undertaken to determine the geographic and depth distribution, fecundity and spawning, growth and movement, behavior, population structure, and population dynamics of the spiny lobster. Also studied were predation on spiny lobsters, gear competition, and ghost fishing. The results of these surveys form the basis of this overview report. Results of many of the experiments and individual studies are included in published and unpublished reports of the Honolulu Laboratory.

MATERIALS AND METHODS

The data for this study were obtained from trapping operations of research and charter cruises. The standard gear used was the California two-chambered lobster pot. Because fish traps were also used during the surveys, and because lobsters were also taken by these traps, data from fish trapping stations are also included. Both the pot and trap had identical entrances; however, several pots and traps with modified entrances were used for special studies. The lobster pot and fish trap are described in detail in a forthcoming fishery atlas of the NWHI by R.N. Uchida and J.H. Uchiyama.

On our first cruise (TC-76-06), lobster pots and fish traps were alternated on a string. Each lobster pot was separated from the fish trap by 5 m; each pair of trap-pot combination was spaced 18 m apart. Only two pairs of trap-pot combination were used per string with six strings making up the set at each station.

On subsequent cruises, usually eight lobster pots, spaced 35 m apart, were attached to one string and up to five strings were set at varying depths between 20 and 91 m (10 and 50 fathoms); the pots were occasionally set as shallow as 4 m (2 fathoms). For fish traps, usually four traps were placed on a string and up to five strings set at each station. Depths varied from 9 to 337 m (5 to 75 fathoms).

Occasionally, special large-entrance lobster pots were set as deep as 183 m (100 fathoms) to determine whether large lobsters (>140-mm carapace length, CL) were in deeper water and also to examine the spiny lobster's depth distribution. At some stations, fish traps were set singly to depths of 329 m (180 fathoms) to evaluate the catchability of fishes of the snapper-grouper complex; the data obtained from these stations were used to define the spiny lobster's depth limits.

Trapping stations were occupied from about 1800 to 0800 thereby allowing the pots and traps to soak for about 14 hours.

Because almost nothing was known about the distribution of spiny lobsters in time and space (various habitats), preliminary surveys were conducted to identify the most promising sites within the NWHI. A search for suitable depth and bottom conditions was required to make the most efficient use of gear and fishing time. Stations were selected by using existing navigational and bottom contour charts; where information was lacking, bathymetric profiles were first obtained with the echo sounder.

The sampling scheme was modified, after analysis of data from the preliminary surveys, to increase the efficiency of later surveys. The area around each island, bank, and atoll was subdivided into smaller grids or equal-area sampling units 0.1° of latitude and longitude, and within each grid, fishing stations were stratified, whenever possible, by depth. Although some sets were made in waters less than 18 m, sampling was usually confined to the inner shelf (18 to 36 m), outer shelf (36 to 45 m), and shelf edge (45 to 90 m). Some sets were also made in the slope zone (90 to 360 m).

Records were usually kept of the number of legal, sublegal, male, female, and ovigerous female lobsters caught. For most of the lobsters, missing appendages, carapace length, weights, and whether or not the female bore spermatophores (mated) were also recorded. When catches were large or when time was limited, only the total number and weight caught were recorded and the catch was subsampled for lenghts and weights.

For this study, effort is defined as a pot-night for the lobster pot and a trap-night for the fish trap, that is, one pot or one trap fishing overnight, usually for 14 or more hours.

RESULTS

Taxonomy

The spiny lobsters, a clearly defined group in the order Decapoda, can be distinguished from the true lobsters by the lack of claws and the presence of a subcylindrical spiny carapace. In Hawaiian waters, two species of spiny lobsters are found around the major islands -- *P. marginatus* and *P. penicillatus*. Although the species may sometimes be confused with one another, there are distinguishing features that easily separate the two. In *P. marginatus*, the anterior border of the carapace is armed with a pair of strong prominent frontal horns above the eyes, whereas in *P. penicillatus*, there are two pairs of strong anterior spines on the antennal plate (McGinnis, 1972).

Panulirus marginatus is endemic to the Hawaiian islands (George and Holthuis, 1965) and Johnston Atoll (Brock, 1973). *Panulirus penicillatus*, the most widely distributed Indo-Pacific *Panulirus* species, is found from the Galapagos Islands in the east to the Red Sea in the west (Holthuis, 1947).

Historical Catch and Fishery Development

Before the fishery expanded to the NWHI, spiny lobsters were mostly caught around the major Hawaiian islands. The catches were small and constituted only an insignificant part of the total marine fish and shellfish landings in the state. In 1961-75, the mean annual catch reported to the Division of Aquatic Resources, Hawaii Department of Land and Natural Resources, was 3 metric tons (MT) or less than 1 percent of the state's total marine production; however, it is believed that large numbers of lobsters are also taken by recreational fishermen, who are not required to report their catches. The magnitude of the recreational catch has never been determined.

The principal gears used in the commercial fishery around the major Hawaiian islands are tangle nets which are set primarily for spiny lobster, and fish traps (lobsters caught in these traps are considered incidental). About 82 percent of the lobster catch was made in waters around Oahu (Morris, 1968).

The spiny lobster fishery in the NWHI began in November 1976 when one vessel began fishing commercially at Necker Island. In 1977, four other vessels participated in the fishery. The vessels fished primarily at Nihoa and Necker Island but effort was also expended at French Frigate Shoals and as far north as Maro Reef. The principal gear used in this fishery was the California two-chambered lobster pot, a small (0.9 m x 0.6 m x 0.4 m), easy-to-handle, rectangular pot, which occupies about a third as much space as a conventional Hawaiian fish trap.

By 1977, the spiny lobster catch in Hawaii had risen from less than 3 MT in 1976 to slightly more than 37.5 MT (Figure 2). Annual landings in subsequent years fluctuated widely as vessels entered and left the fishery. Because there was no management plan for lobsters during the early years of the fishery, many catches went unreported. Therefore, the catches shown in Figure 2 for 1977-82 were estimated from data collected by NMFS and DAR observers on vessels or from the weight of frozen tails landed (Skillman and Ito, 1981).

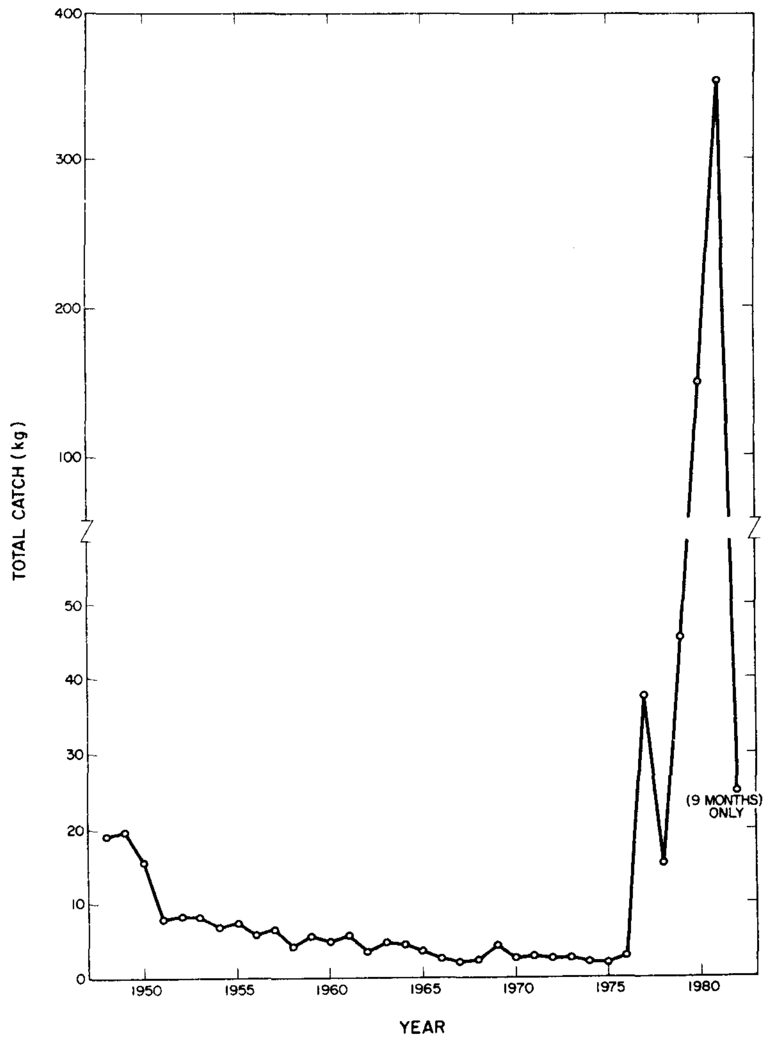

Figure 2. Catch of spiny lobsters in the Hawaiian Archipelago. Data for 1948-78 are from Skillman and Ito (1981); data for 1979-82 are from R.A. Skillman, Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, (1983: personal communication).

Geographical Distribution and Pre-exploitation Abundance

Although two species of spiny lobsters occur in waters of the NWHI, they are distinctly separated by depth, unlike their distribution in waters of the main islands where they are found together. *P. penicillatus*, being a shallow-water inhabitant in the NWHI, were never caught in the area of operation, which included all offshore waters from about 18 m and deeper (except at Maro Reef and those islands northward where it was possible to occupy stations in waters less than 18 m deep).

In the NWHI, sampling for *P. marginatus* began at Nihoa, where lobster trapping surveys produced maximum catches of 2.7 individuals/pot-night and 1.84 individuals/trap-night along the southeastern part of the bank (grid 230617) (Table 1 and Figure 3). Nihoa, because of its close proximity to Honolulu, was one of the first lobster grounds in the early years when commercial fishing began in 1976. *P. marginatus* was also found on an isolated bank (henceforth referred to as Nihoa West Bank) near Nihoa, but the catches here were relatively small. Bank 3, a small bank located between Nihoa and Necker, was also visited but no evidence of lobster was found.

Moving northwestward to Necker Island, dense aggregations of *P. marginatus* were found over much of the northern and southern parts of the bank. Catch rates of lobsters in some of the areas reached as high as 13.25 individuals/pot-night (grid 236646) and 25.83 individuals/trap-night (grid 236647). Commercial operations in late 1976 and 1977 produced catches averaging 5-7 individuals/pot-night. The catch rate reached 6.62 individuals/pot-night in 1976 but dropped to 4.83 individuals/pot-night by 1977 and continued a downward trend to 3.32 in 1978, 1.88 in 1979, 1.70 in 1980, and 1.09 in 1981. The fish trap catch rate was 6.18 individuals/trap-night in 1976, 3.32 in 1977, 3.97 in 1978, 5.09 in 1979, 1.82 in 1980, and 5.62 in 1981. The rise in the fish trap catch rate in 1979 and 1981 was due primarily to sublegal lobsters ($<$77.0 mm CL), which made up 70 to 80 percent of the catch. Because commercial operations significantly reduced the abundance at Necker by the end of 1979, when total catch reached an estimated 45,372 kg, data only for 1976-78 were regarded as indicative of pre-exploitation abundance.

Northwest of Necker Island, *P. marginatus* was also found at French Frigate Shoals, Brooks Banks, St. Rogatien Bank, Gardner Pinnacles, and Raita Bank; however, nowhere was it as abundant as at Necker. The pre-exploitation abundance of *P. marginatus* was extremely low at French Frigate Shoals, Brook Banks, and St. Rogatien Bank, and the species was not caught in fish traps set at Bank 7. Abundance varied at Gardner Pinnacles; some areas (grids 245680, 246681, and 251682) along the southwest and northwest edges of the bank produced relatively good catches. Because the bank at Gardner Pinnacles is extremely large (about 50 nmi in the north-south direction and 24 nmi at the widest point in the east-west direction), about half of it remains unsurveyed. Only one grid at Raita Bank showed relatively high catches.

TABLE 1. CATCH OF LOBSTERS (LEGAL-SIZED, SUBLEGAL-SIZED, AND BERRIED) IN LOBSTER POTS AND FISH TRAPS DURING RESEARCH AND CHARTER CRUISES TO THE NORTHWESTERN HAWAIIAN ISLANDS, OCTOBER 1976 TO SEPTEMBER 1981

Location	Grid		Lobster Pot Catches						Total	Catch/ Pot Night
			1976	1977	1978	1979	1980	1981		
Middle Bank	227	610	--	0(40)	--	--	--	--	0(40)	0.00
(22° 42'N, 161° 02'W)										
Nihoa	230	617	--	--	108(40)	--	--	--	108(40)	2.70
(23° 03'N, 161° 55'W)	230	619	--	40(40)	--	--	--	--	40(40)	1.00
	231	619	--	107(98)	--	--	--	--	107(98)	1.09
	232	618	--	--	--	--	--	0(32)	0(32)	0.00
		Total	--	147(138)	108(40)	--	--	0(32)	255(210)	1.21
Nihoa West Bank	229	621	--	--	15(40)	--	--	--	15(40)	0.38
(22° 58'N, 162° 14'W)	229	622	--	48(80)	--	--	--	--	48(80)	0.60
	229	623	--	--	--	--	--	0(26)	0(26)	0.00
	230	621	--	98(98)	--	--	--	--	98(98)	1.00
		Total	--	146(178)	15(40)	--	--	0(26)	161(244)	0.66
Bank 3	231	631	--	--	--	--	--	0(7)	0(7)	0.00
(23° 13'N, 163° 09'W)	232	631	--	--	--	--	--	0(24)	0(24)	0.00
		Total	--	--	--	--	--	0(31)	0(31)	0.00
Necker Island	232	642	--	--	308(80)	--	--	--	308(80)	3.85
(23° 34'N, 164° 42'W)	232	643	--	246(40)	--	--	--	27(28)	273(68)	4.01
	233	644	--	21(40)	--	--	--	--	21(40)	0.52
	233	645	--	4(40)	--	--	--	--	4(40)	0.10
	233	646	--	142(100)	--	--	--	--	142(100)	1.42
	234	643	--	--	--	--	--	--	--	--
	234	644	--	--	--	--	34(24)	--	34(24)	1.42
	234	645	--	220(101)	--	--	--	9(8)	229(109)	2.10
	234	646	--	319(102)	--	--	--	--	319(102)	3.13
	235	645	--	--	186(48)	--	--	--	186(48)	3.88
	235	646	--	395(100)	--	--	15(30)	--	410(130)	3.15
	235	647	1(12)	1,892(337)	--	0(1)	--	--	1,893(350)	5.41
	235	648	96(20)	593(70)	--	--	--	34(23)	723(113)	6.40
	236	645	157(22)	796(98)	--	--	--	151(135)	1,104(255)	4.33
	236	646	160(8)	687(133)	183(40)	301(143)	518(279)	17(25)	1,812(628)	2.88
	236	647	93(6)	710(138)	13(40)	--	--	--	816(184)	4.43
	236	648	24(4)	738(101)	--	86(62)	--	--	848(167)	5.08
		Total	477(72)	6,763(1,400)	690(208)	387(206)	567(333)	238(219)	9,122(2,438)	3.74
French Frigate Shoals	236	660	--	12(40)	--	--	--	--	12(40)	0.30
(23° 46'N, 166° 18'W)	236	662	--	1(40)	--	--	--	--	1(40)	0.02
	236	663	--	--	--	--	--	--	--	--
	237	662	--	7(60)	--	--	--	--	7(60)	0.12
	237	663	--	--	97(80)	0(22)	--	--	97(102)	0.95
	238	662	--	--	--	--	--	8(48)	8(48)	0.17
	238	663	--	16(99)	7(40)	3(23)	--	--	26(162)	0.16
	238	664	--	--	--	--	--	--	--	--
	239	662	--	--	--	--	--	--	--	--
	239	663	--	--	--	--	--	--	--	--
		Total	--	36(239)	104(120)	3(45)	--	8(48)	151(452)	0.33
Brooks Banks	240	668	--	--	--	3(8)	13(48)	--	16(56)	0.28
(24° 05'N, 166° 50'W)	241	667	--	--	--	--	--	--	--	--
	241	668	--	--	--	6(32)	3(32)	--	9(64)	0.14
	241	669	--	--	--	25(32)	--	--	25(32)	0.78
	242	669	--	--	--	5(8)	2(40)	--	7(48)	0.14
		Total	--	--	--	39(80)	18(120)	--	57(200)	0.28
St. Rogatien Bank	242	670	--	--	--	--	--	--	--	--
(24° 25'N, 167° 15'W)	242	671	--	41(59)	--	--	--	--	41(59)	0.70
	243	670	--	--	--	--	5(24)	--	5(24)	0.21
	243	671	--	--	--	--	10(55)	--	10(55)	0.18
	244	671	--	--	--	--	7(39)	--	7(39)	0.18
		Total	--	41(59)	--	--	22(118)	--	63(177)	0.36
Bank 7	246	672	--	--	--	--	--	--	--	--
(24° 36'N, 167° 18'W)										
Gardner Pinnacles	244	679	--	--	26(16)	--	--	--	26(16)	1.62
(25° 01'N,167° 59'W)	245	680	--	--	--	--	--	74(32)	74(32)	2.31
	246	681	--	--	37(16)	--	--	--	37(16)	2.31
	247	681	--	--	--	--	--	--	--	--
	248	681	--	--	23(29)	--	--	--	23(29)	0.79
	249	682	--	--	--	--	42(24)	54(32)	96(56)	1.71
	250	679	--	28(58)	--	--	--	--	28(58)	0.48
	250	680	--	--	--	--	--	0(7)	0(7)	0.00
	250	682	--	--	--	--	53(24)	38(24)	91(48)	1.90
	250	683	--	--	--	--	--	--	--	--
	251	681	--	--	--	--	19(23)	--	19(23)	0.83
	251	682	--	--	152(30)	--	--	--	152(30)	5.07
	252	680	--	--	--	--	--	--	--	--
	252	681	--	--	--	--	12(8)	--	12(8)	1.50
		Total	--	28(58)	238(91)	--	126(79)	166(95)	558(323)	1.73

Note: (N) = trap-nights

TABLE 1. CATCH OF LOBSTERS (LEGAL-SIZED, SUBLEGAL-SIZED AND BERRIED) IN LOBSTER POTS AND FISH TRAPS DURING RESEARCH AND CHARTER CRUISES TO THE NORTHWESTERN HAWAIIAN ISLANDS, OCTOBER 1976 TO SEPTEMBER 1981 (continued)

Location	Grid		Lobster Pot Catches						Total	Catch/ Pot Night
			1976	*1977*	*1978*	*1979*	*1980*	*1981*		
Raita Bank	254	694	--	--	--	--	16(40)	--	16(40)	0.40
(25°35'N, 169°35'W)	254	696	--	5(22)	--	--	--	--	5(22)	0.23
	255	693	--	137(40)	--	--	--	--	137(40)	3.42
	255	694	--	--	21(24)	--	--	--	21(24)	0.88
	255	695	--	--	--	--	37(32)	--	37(32)	1.16
	256	693	--	--	--	--	40(47)	--	40(47)	0.85
	256	694	--	--	6(6)	--	17(31)	16(32)	39(69)	0.56
	256	695	--	--	--	--	35(23)	--	35(23)	1.52
		Total	--	142(62)	27(30)	--	145(173)	16(32)	330(297)	1.11
Maro Reef	252	704	--	825(151)	--	--	--	--	825(151)	5.46
(25°29'N, 170°35'W)	252	706	--	613(99)	96(48)	--	--	--	709(147)	4.82
	253	704	--	50(16)	--	--	--	--	50(16)	3.12
	253	707	--	--	--	--	--	12(24)	12(24)	0.50
	253	708	--	409(142)	--	--	--	--	409(142)	2.88
	254	706	--	69(18)	--	--	65(12)	--	134(30)	4.47
	254	707	--	166(52)	151(48)	--	--	188(64)	505(164)	3.08
	254	708	--	--	--	--	131(48)	59(23)	190(71)	2.68
	254	709	--	--	--	25(16)	--	--	25(16)	1.56
	255	705	--	--	--	--	49(26)	--	49(26)	1.88
	255	706	--	161(47)	--	--	--	--	161(47)	3.42
	255	707	--	--	--	--	145(32)	--	145(32)	4.53
	255	708	--	--	--	90(16)	123(32)	--	213(48)	4.44
	255	709	--	--	--	--	--	--	--	--
	256	706	--	--	--	--	--	--	--	--
	256	707	--	144(40)	--	--	--	--	144(40)	3.60
		Total	--	2,437(565)	247(96)	115(32)	513(150)	259(111)	3,571(954)	3.74
Northampton Seamounts (25°18'N, 172°04'W)	254	724	--	--	--	--	3(40)	--	3(40)	0.08
Laysan Island	256	717	--	40(24)	--	--	--	--	40(24)	1.67
(25°42'N, 171°44'W)	257	716	--	41(24)	--	--	--	--	41(24)	1.71
	257	717	--	91(81)	--	--	--	--	91(81)	1.12
	257	718	--	97(24)	--	--	--	--	97(24)	4.04
	258	715	--	1(10)	--	--	--	--	1(10)	0.10
	258	716	--	120(56)	--	4(40)	0(24)	--	124(120)	1.03
	258	717	--	42(24)	--	--	--	--	42(24)	1.75
	258	718	--	116(64)	27(40)	9(23)	--	--	152(127)	1.20
		Total	--	548(307)	27(40)	13(63)	0(24)	--	588(434)	1.35
Pioneer Bank (26°00'N, 173°25'W)	259	735	--	--	0(24)	--	--	--	0(24)	0.00
Lisianski Island	258	738	--	--	--	0(16)	--	--	0(16)	0.00
(26°02'N, 174°00'W)	259	737	--	--	--	0(40)	--	--	0(40)	0.00
	259	738	--	--	--	--	--	--	--	--
	259	739	--	0(24)	--	--	--	--	0(24)	0.00
	259	741	--	3(24)	--	--	--	--	3(24)	0.12
	260	738	--	4(64)	--	--	--	--	4(64)	0.06
	260	739	--	--	--	--	0(4)	--	0(4)	0.00
	260	740	--	2(4)	--	--	0(4)	--	2(8)	0.25
	261	739	--	0(23)	--	--	--	--	0(23)	0.00
	262	741	--	0(40)	--	--	--	--	0(40)	0.00
		Total	--	9(179)	--	0(56)	0(8)	--	9(243)	0.04
Bank 8	262	745	--	--	0(24)	--	--	--	0(24)	0.00
(26°17'N, 174°34'W)	263	745	--	--	--	0(32)	--	--	0(32)	0.00
		Total	--	--	0(24)	0(32)	--	--	0(56)	0.00
Salmon Bank	269	763	--	--	--	--	--	--	--	--
(26°56'N, 176°28'W)	269	764	--	2(47)	--	--	0(40)	--	2(87)	0.02
		Total	--	2(47)	--	--	0(40)	--	2(87)	0.02
Pearl and Hermes	277	757	--	25(40)	--	--	--	2(24)	27(64)	0.42
Atoll	277	758	8(12)	3(24)	--	--	--	0(24)	11(60)	0.18
(27°48'N, 175°51'W)	277	759	--	25(24)	--	--	7(64)	2(24)	34(112)	0.30
	277	760	--	--	--	--	--	0(22)	0(22)	0.00
	278	757	--	29(24)	--	9(23)	--	2(16)	40(63)	0.63
	278	759	--	16(11)	--	--	6(4)	--	22(15)	1.47
	278	760	--	120(64)	--	119(62)	2(4)	--	241(130)	1.85
	279	757	--	9(24)	--	--	--	4(32)	13(56)	0.23
	279	758	--	6(22)	--	--	--	--	6(22)	0.27
	279	759	--	--	--	8(23)	--	--	8(23)	0.35
		Total	8(12)	233(233)	--	136(108)	15(72)	10(142)	402(567)	0.71
Nero Seamount (27°57'N, 177°58'W)	279	779	--	--	--	--	0(24)	--	0(24)	0.00

TABLE 1. CATCH OF LOBSTERS (LEGAL-SIZED, SUBLEGAL-SIZED AND BERRIED) IN LOBSTER POTS AND FISH TRAPS DURING RESEARCH AND CHARTER CRUISES TO THE NORTHWESTERN HAWAIIAN ISLANDS, OCTOBER 1976 TO SEPTEMBER 1981 (continued)

Location	Grid		Lobster Pot Catches						Total	Catch/ Pot Night
			1976	1977	1978	1979	1980	1981		
Midway Islands	281	774	--	16(30)	--	--	--	--	16(30)	0.53
(28°12'N, 177°22'W)	282	772	--	1(8)	--	--	--	--	1(8)	0.12
	282	773	--	158(88)	166(40)	52(16)	--	--	376(144)	2.61
	282	774	--	111(61)	124(39)	34(23)	--	--	269(123)	2.19
	283	773	--	--	--	--	--	--	--	--
	283	774	--	0(15)	--	--	--	--	0(15)	0.00
		Total	--	286(202)	290(79)	86(39)	--	--	662(320)	2.07
Kure Atoll	283	782	--	--	--	--	0(4)	--	0(4)	0.00
(28°25'N, 178°25'W)	283	783	--	26(96)	20(40)	--	0(4)	--	46(140)	0.33
	284	782	--	101(81)	--	--	--	--	101(81)	1.25
	284	783	--	11(23)	--	--	31(8)	--	42(31)	1.35
	285	783	--	--	--	--	--	--	--	--
		Total	--	138(200)	20(40)	--	31(16)	--	189(256)	0.74
Ladd Seamount	284	766	--	--	--	--	--	--	--	--
(28°32'N, 176°40'W)	285	766	--	--	--	--	0(40)	0(48)	0(88)	0.00
		Total	--	--	--	--	0(40)	0(48)	0(88)	0.00
Bank 11	288	795	--	--	--	--	--	--	--	--
(28°53'N, 179°38'W)	289	795	--	--	--	--	--	--	--	--
		Total	--	--	--	--	--	--	--	--
SE Hancock Seamount (29°47'N, 179°04'E)	298	790	--	--	--	--	--	--	--	--
NW Hancock Seamount (30°16'N, 178°43'W)	302	787	--	--	--	--	--	--	--	--

Location	Grid		Fish Trap Catches						Total	Catch/ Trap Night
			1976	1977	1978	1979	1980	1981		
Middle Bank (22°42'N, 161°02'W)	227	610	--	0(16)	--	--	--	--	0(16)	0.00
Nihoa	230	617	--	--	35(19)	--	--	--	35(19)	1.84
(23°03'N, 161°55'W)	230	619	--	5(16)	--	--	--	--	5(16)	0.31
	231	619	--	--	--	--	--	--	--	--
	232	618	--	--	--	--	--	--	--	--
		Total	--	5(16)	35(19)	--	--	--	40(35)	1.14
Nihoa West Bank	229	621	--	1(16)	--	--	--	--	1(16)	0.06
(22°58'N, 162°14'W)	229	622	--	2(20)	--	--	--	--	2(20)	0.10
	229	623	--	--	--	--	--	--	--	--
	230	621	--	--	--	--	0(1)	--	0(1)	0.00
		Total	--	3(36)	--	--	0(1)	--	3(37)	0.08
Bank 3	231	631	--	--	--	--	--	0(1)	0(1)	0.00
(23°13'N, 163°09'W)	232	631	--	--	--	--	--	0(4)	0(4)	0.00
		Total	--	--	--	--	--	0(5)	0(5)	0.00
Necker Island	232	642	--	--	121(23)	--	--	--	121(23)	5.26
(23°34'N, 164°42'W)	232	643	--	168(20)	40(8)	--	--	34(4)	242(32)	7.56
	233	644	--	--	--	--	--	--	--	--
	233	645	--	39(20)	--	--	--	--	39(20)	1.95
	233	646	--	8(20)	--	--	--	--	8(20)	0.40
	234	643	--	43(20)	--	--	--	--	43(20)	2.15
	234	644	--	--	--	--	39(8)	--	39(8)	4.88
	234	645	--	--	--	--	--	--	--	--
	234	646	--	--	--	--	--	--	--	--
	235	645	--	--	72(8)	--	--	--	72(8)	9.00
	235	646	--	--	--	--	--	--	--	--
	235	647	4(12)	20(17)	--	119(27)	--	--	143(56)	2.55
	235	648	50(20)	--	--	--	--	69(12)	119(32)	3.72
	236	645	159(22)	--	--	--	1(5)	350(64)	510(91)	5.60
	236	646	74(8)	--	20(12)	512(92)	0(9)	30(6)	636(127)	5.01
	236	647	155(6)	97(16)	21(18)	33(10)	--	--	306(50)	6.12
	236	648	3(4)	--	--	99(21)	--	--	102(25)	4.08
		Total	455(72)	375(113)	274(69)	763(150)	40(22)	483(86)	2,380(512)	4.65
French Frigate Shoals	236	660	--	9(20)	--	--	0(2)	--	9(22)	0.41
(23°46'N, 166°18'W)	236	662	--	1(20)	--	--	--	--	1(20)	0.05
	236	663	--	--	--	0(11)	--	--	0(11)	0.00
	237	662	--	0(20)	--	--	--	--	0(20)	0.00
	237	663	--	--	73(35)	--	0(5)	--	73(40)	1.82
	238	662	--	--	--	--	--	2(8)	2(8)	0.25
	238	663	--	0(20)	1(10)	1(7)	--	0(8)	2(45)	0.04
	238	664	--	--	--	0(4)	--	--	0(4)	0.00
	239	662	--	--	--	--	--	0(4)	0(4)	0.00
	239	663	--	--	--	--	--	0(2)	0(2)	0.00
		Total	--	10(80)	74(45)	1(22)	0(7)	2(22)	87(176)	0.49

TABLE 1. CATCH OF LOBSTERS (LEGAL-SIZED, SUBLEGAL-SIZED AND BERRIED) IN LOBSTER POTS AND FISH TRAPS DURING RESEARCH AND CHARTER CRUISES TO THE NORTHWESTERN HAWAIIAN ISLANDS, OCTOBER 1976 TO SEPTEMBER 1981 (continued)

Location	Grid		Fish Trap Catches						Total	Catch/ Trap Night
			1976	1977	1978	1979	1980	1981		
Brooks Banks	240	668	--	--	--	1(8)	--	--	1(8)	0.12
(24°05'N, 166°50'W)	241	667	--	--	--	--	0(2)	--	0(2)	0.00
	241	668	--	--	--	4(7)	0(3)	--	4(10)	0.40
	241	669	--	--	--	0(2)	--	--	0(2)	0.00
	242	669	--	--	--	1(4)	--	--	1(4)	0.25
		Total	--	--	--	6(21)	0(5)	--	6(26)	0.23
St. Rogatien Bank	242	670	--	--	--	1(9)	--	--	1(9)	0.11
(24°25'N, 167°15'W)	242	671	--	--	--	--	--	--	--	--
	243	670	--	--	--	--	0(3)	--	0(3)	0.00
	243	671	--	--	--	--	--	--	--	--
	244	671	--	--	--	--	--	--	--	--
		Total	--	--	--	1(9)	0(3)	--	1(12)	0.08
Bank 7 (24°36'N, 167°18'W)	246	672	--	--	--	--	0(6)	--	0(6)	0.00
Gardner Pinnacles	244	679	--	--	--	--	--	--	--	--
(25°01'N, 167°59'W)	245	680	--	--	--	--	--	0(6)	0(6)	0.00
	246	681	--	--	--	--	--	--	--	--
	247	681	--	--	0(1)	--	--	--	0(1)	0.00
	248	681	--	--	2(9)	--	--	--	2(9)	0.22
	249	682	--	--	--	--	--	5(6)	5(6)	0.83
	250	679	--	--	--	--	--	--	--	--
	250	680	--	--	--	--	--	0(1)	0(1)	0.00
	250	682	--	--	--	--	3(2)	4(4)	7(6)	1.17
	250	683	--	--	--	--	0(3)	0(2)	0(5)	0.00
	251	681	--	--	--	--	5(8)	--	5(8)	0.62
	251	682	--	--	2(9)	--	0(6)	--	2(15)	0.13
	252	680	--	--	--	1(8)	--	--	1(8)	0.12
	252	681	--	--	--	--	17(14)	--	17(14)	1.21
		Total	--	--	4(19)	1(8)	25(33)	9(19)	39(79)	0.49
Raita Bank	254	694	--	--	--	--	--	--	--	--
(25°35'N, 169°35'W)	254	696	--	4(12)	--	--	--	--	4(12)	0.33
	255	693	--	52(20)	--	--	--	--	52(20)	2.60
	255	694	--	--	5(8)	--	--	--	5(8)	0.62
	255	695	--	--	--	--	--	--	--	--
	256	693	--	--	--	--	0(2)	--	0(2)	0.00
	256	694	--	--	0(1)	--	0(2)	0(6)	0(9)	0.00
	256	695	--	--	--	--	--	--	--	--
		Total	--	56(32)	5(9)	--	0(4)	0(6)	61(51)	1.20
Maro Reef	252	704	--	137(20)	--	--	--	--	137(20)	6.85
(25°29'N, 170°35'W)	252	706	--	--	0(6)	--	--	--	0(6)	0.00
	253	704	--	33(4)	--	--	--	--	33(4)	8.25
	253	707	--	--	--	--	--	1(8)	1(8)	0.12
	253	708	--	365(60)	0(4)	--	--	--	365(64)	5.70
	254	706	--	0(4)	--	--	--	--	0(4)	0.00
	254	707	--	170(24)	27(8)	--	--	43(12)	240(44)	5.45
	254	708	--	--	0(1)	--	17(7)	32(8)	49(16)	3.06
	254	709	--	--	--	0(11)	0(6)	--	0(17)	0.00
	255	705	--	--	--	--	--	--	--	--
	255	706	--	79(24)	--	--	--	--	79(24)	3.29
	255	707	--	--	--	--	--	--	--	--
	255	708	--	--	--	75(11)	--	--	75(11)	6.82
	255	709	--	--	--	--	0(3)	--	0(3)	0.00
	256	706	--	--	--	--	1(3)	--	1(3)	0.33
	256	707	--	82(20)	--	--	--	--	82(20)	4.10
		Total	--	866(156)	27(19)	75(22)	18(19)	76(28)	1,062(244)	4.35
Northhampton Seamounts (25°18'N, 172°04'W)	254	724	--	--	--	--	0(4)	--	0(4)	0.00
Laysan Island	256	717	--	12(8)	--	--	--	--	12(8)	1.50
(25°42'N, 171°44'W)	257	716	--	34(12)	--	--	--	--	34(12)	2.83
	257	717	--	31(40)	--	--	--	--	31(40)	0.78
	257	718	--	45(14)	--	--	0(1)	--	45(15)	3.00
	258	715	--	1(4)	--	--	--	--	1(4)	0.25
	258	716	--	120(28)	--	6(20)	0(6)	--	126(54)	2.33
	258	717	--	27(12)	--	--	--	--	27(12)	2.25
	258	718	--	126(32)	--	0(11)	--	--	126(43)	2.93
		Total	--	396(150)	--	6(31)	0(7)	--	402(188)	2.14
Pioneer Bank (26°00'N, 173°25'W)	259	735	--	--	0(24)	--	--	--	0(24)	0.00

TABLE 1. CATCH OF LOBSTERS (LEGAL-SIZED, SUBLEGAL-SIZED AND BERRIED) IN LOBSTER POTS AND FISH TRAPS DURING RESEARCH AND CHARTER CRUISES TO THE NORTHWESTERN HAWAIIAN ISLANDS, OCTOBER 1976 TO SEPTEMBER 1981 (continued)

Location	Grid		Fish Trap Catches						Total	Catch/ Trap Night
			1976	1977	1978	1979	1980	1981		
Lisianski Island	258	738	--	--	--	0(8)	--	--	0(8)	0.00
(26°02'N, 174°00'W)	259	737	--	--	--	1(20)	--	--	1(20)	0.05
	259	738	--	--	--	0(3)	--	--	0(3)	0.00
	259	739	--	2(12)	--	--	--	--	2(12)	0.17
	259	741	--	2(12)	--	--	--	--	2(12)	0.17
	260	738	--	6(32)	--	--	--	--	6(32)	0.19
	260	739	--	--	--	--	--	--	--	--
	260	740	--	--	--	--	--	--	--	--
	261	739	--	0(12)	--	--	--	--	0(12)	0.00
	262	741	--	0(20)	--	--	--	--	0(20)	0.00
		Total	--	10(88)	--	1(31)	--	--	11(119)	0.09
Bank 8	262	745	--	--	0(8)	--	--	--	0(8)	0.00
(26°17'N, 174°34'W)	263	745	--	--	--	0(8)	--	--	0(8)	0.00
		Total	--	--	0(8)	0(8)	--	--	0(16)	0.00
Salmon Bank	269	763	--	--	--	--	0(5)	--	0(5)	0.00
(26°56'N, 176°28'W)	269	764	--	0(26)	--	--	--	--	0(26)	0.00
		Total	--	0(26)	--	--	0(5)	--	0(31)	0.00
Pearl and Hermes	277	757	--	0(20)	--	--	0(2)	1(5)	1(27)	0.04
Atoll	277	758	7(12)	13(12)	--	--	0(7)	0(4)	20(35)	0.57
(27°48'N, 175°51'W)	277	759	--	14(12)	--	--	0(7)	2(8)	16(27)	0.59
	277	760	--	--	--	--	--	0(13)	0(13)	0.00
	278	757	--	28(13)	--	0(11)	--	0(2)	28(26)	1.08
	278	759	--	--	--	--	--	--	--	--
	278	760	--	41(32)	--	40(34)	--	--	81(66)	1.23
	279	757	--	15(12)	--	--	--	0(6)	15(18)	0.83
	279	758	--	5(12)	--	--	--	--	5(12)	0.42
	279	759	--	--	--	4(11)	--	--	4(11)	0.36
		Total	7(12)	116(113)	--	44(56)	0(16)	3(38)	170(235)	0.72
Nero Seamount (27°57'N, 177°58'W)	279	779	--	--	--	--	0(6)	--	0(6)	0.00
Midway Islands	281	774	--	48(21)	--	--	--	--	48(21)	2.28
(28°12'N, 177°22'W)	282	772	--	--	--	--	--	--	--	--
	282	773	--	124(44)	62(20)	--	--	--	186(64)	2.91
	282	774	--	34(28)	62(20)	13(4)	--	--	109(52)	2.10
	283	773	--	0(4)	--	--	--	--	0(4)	0.00
	283	774	--	0(8)	--	--	--	--	0(8)	0.00
		Total	--	206(105)	124(40)	13(4)	--	--	343(149)	2.30
Kure Atoll	283	782	--	--	--	--	0(2)	--	0(2)	0.00
(28°25'N, 178°25'W)	283	783	--	7(48)	0(20)	--	--	--	7(68)	0.10
	284	782	--	2(37)	--	--	--	--	2(37)	0.05
	284	783	--	2(16)	--	--	--	--	2(16)	0.12
	285	783	--	--	--	--	0(2)	--	0(2)	0.00
		Total	--	11(101)	0(20)	--	0(4)	--	11(125)	0.09
Ladd Seamount	284	766	--	--	--	--	0(1)	0(6)	0(7)	0.00
(28°32'N, 176°40'W)	285	766	--	--	--	--	0(6)	0(16)	0(22)	0.00
		Total	--	--	--	--	0(7)	0(22)	0(29)	0.00
Bank 11	288	795	--	--	--	--	0(1)	--	0(1)	0.00
(28°53'N, 179°38'W)	289	795	--	--	--	--	0(4)	--	0(4)	0.00
		Total	--	--	--	--	0(5)	--	0(5)	0.00
SE Hancock Seamount (29°47'N, 179°04'E)	298	790	--	--	0(4)	--	0(5)	--	0(9)	0.00
NW Hancock Seamount (30°16'N, 178°43'W)	302	787	--	--	0(4)	0(1)	--	--	0(5)	0.00

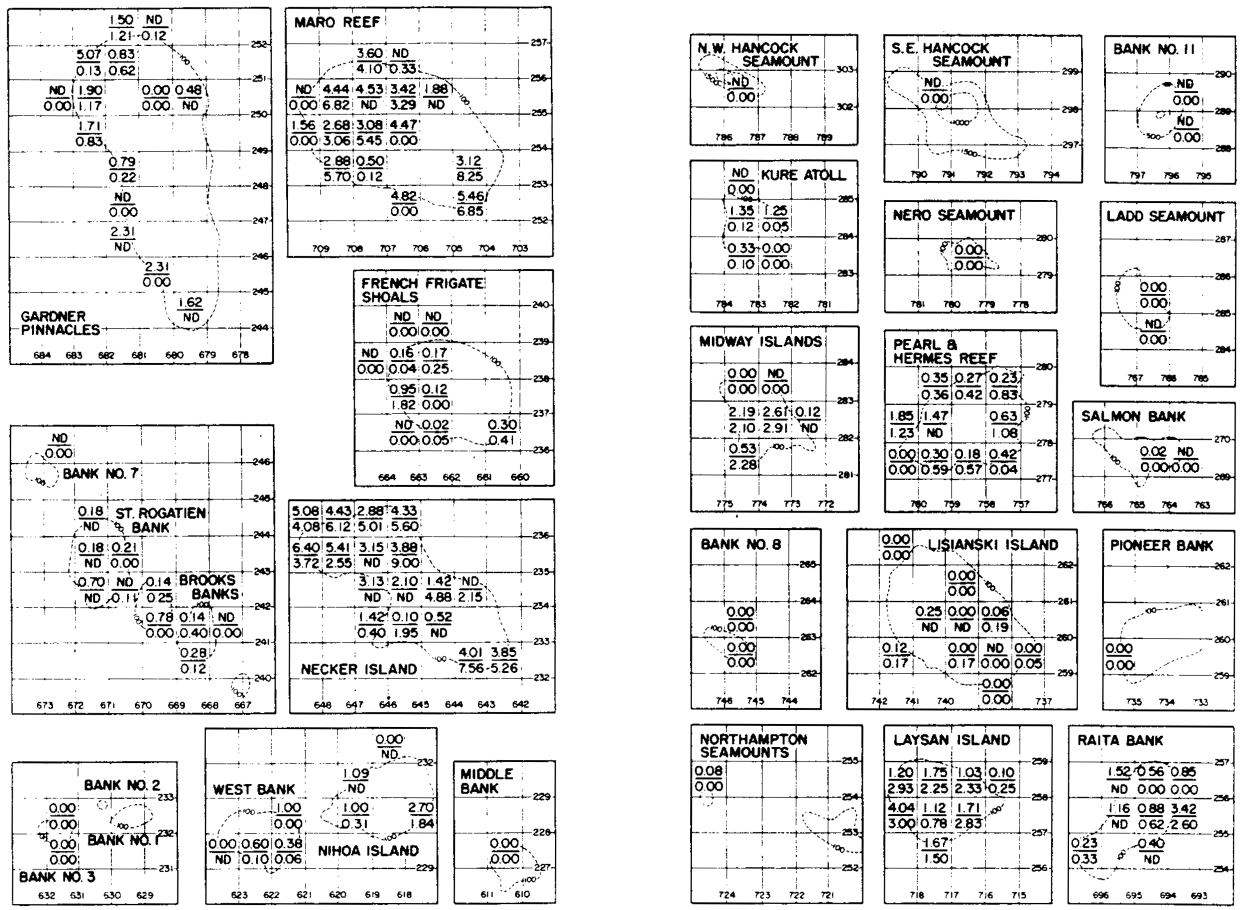

Figure 3. Distribution of spiny lobster catch rates by lobster traps (upper figure) and fish traps (lower figure) for 0.1° squares in the Northwestern Hawaiian Islands, October 1976 to September 1981. (ND = No data)

P. marginatus was also found around the islands and atolls farther up the chain. At Maro Reef, which contrasted sharply with Necker in substratum condition, high catch rates of *P. marginatus* were also obtained. The surveys conducted at Maro Reef in 1977 produced catch rates varying between 2.88 and 6.19 individuals/pot-night, whereas the fish traps produced catches ranging from 0.00 to 8.25 individuals/pot-night. The high abundance at Maro Reef was unexpected because subsurface observations made during a cruise in 1977 revealed a substratum of predominantly sand and sandstone just outside that coral reef; however, subsequent discussions with other investigators who dove at Maro Reef brought out the fact that many areas in the 10 to 55 m depth range have suitable lobster habitat. Due to the high catch rates, Maro Reef was established as the second important area in the spiny lobster fishery.

Beyond Maro Reef, none of the sites surveyed showed commercial concentrations of *P. marginatus*, although several had moderately good catch rates. Whether a commercial fishery can be developed at these sites depends to a large extent on the cost of operating at such distances from the home port. Few lobsters were found at Northampton Seamounts, but relatively good catches were made at several sites (grids 257716, 257718, 258716, 258717, 258718) at Laysan Island. Pioneer Bank near Lisianski Island produced nothing and catches at Lisianski, which has a rather large bank, were extremely low at all the sites surveyed.

Bank 8 and Salmon Bank received very little effort; the former produced nothing and only two lobsters were caught in 87 pot-nights and 31 trap-nights at the latter. At Pearl and Hermes Atoll, the entire area outside the reef was surveyed and good catches were made along the central western edge of the bank (grids 278759 and 278760); other survey sites produced relatively small catches.

At Nero Seamounts, 24 pot-nights and 6 trap-nights of effort produced no spiny lobsters, but at Midway Islands, the catch rates were over 2 individuals/pot-night and trap-night in three grids (281774, 282773, and 282774). At the extreme northwestern end of the Hawaiian Archipelago, *P. marginatus* was found at Kure Atoll but not in the same numbers as at Midway. Kure marks the northern limit of the distribution of *P. marginatus* as none were found at Ladd Seamount, which is located slightly north of Kure, nor at Bank 11 and Hancock Seamounts to the northwest.

Simpson (1976) speculated that for *P. argus*, areas which are conducive to high survival could be associated with bottom topography, that is, there are many suitable hiding places for the young stages to molt safely. This is believed to be a plausible explanation for the high densities of spiny lobster at Necker and Maro Reef.

Catch by Depth

Although *P. marginatus* has been reported at depths ranging from 110 to 183 m in Hawaiian waters (McGinnis, 1972), we believe the species is not found at depths beyond 137 m[1]. The surveys indicated that this species was usually found in water depths of 90 m or less. The relative abundance of spiny lobster taken in lobster pots and fish traps by 9-m strata was calculated for each of the islands and banks (Figure 4). Along the lower portion of the archipelago the relative abundance was highest at the 55 to 64 m depth around Nihoa and Necker and at the 65 to 73 m depth around French Frigate Shoals. Farther northward at Gardner Pinnacles, the relative abundance of spiny lobsters was higher at shallower depths of 19 to 27 m to about 46 to 54 m.

At Raita Bank, the relative abundance was highest between 28 and 36 m. Northwestward at Maro Reef, there was a dramatic shift in relative abundance: the highest values were in the shallowest area. This trend towards higher abundance at shallower depth appeared to be consistent at the remaining islands, banks, and atolls to the northwest of Maro Reef. Uchida et al. (1980b) suggest that the relatively low catch rates observed in waters deeper than 64 m in the northern part of the archipelago may be the result of differences in the temperature regime from north to south in the NWHI.

The proportion of legal-sized, sublegal-sized, and berried female lobsters were also examined by depth for Necker and Maro Reef, because of the importance of these areas for commercial trapping (Figure 5). At Necker, it was found that catches at the 19 to 27 m depth were composed predominantly of sublegal-sized lobsters, but at the 28 to 36 m depth the proportion of legal-sized and sublegal-sized lobsters was nearly 1:1. At depths deeper than 36 m, however, legal sizes predominated by a slight margin. At Maro Reef, legal-sized lobsters predominated at the shallowest depth by a small margin. At the 10 to 18 m depth sublegal-sized lobsters were predominant, comprising 60 percent of the catch. The catches at depths greater than 18 m were composed of legal-sized lobsters by a very wide margin over sublegal-sized lobsters.

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[1]McGinnis (1972) cited cruise report 35 of the *Townsend Cromwell*, prepared by the Bureau of Commercial Fisheries (now NMFS), and which involved shrimp, *Penaeus marginatus*, trawling operations. McGinnis assumed that the by-catch of spiny lobster, *Panulirus marginatus*, was also made at the same depths trawled for shrimp. The original catch records reveal that 22 spiny lobsters were captured on the bank north of Molokai between Kaiehu Point and Paualaia Point during four trawl hauls on April 6, 1968 in waters which averaged 110, 124, 128, and 137 m in depth.

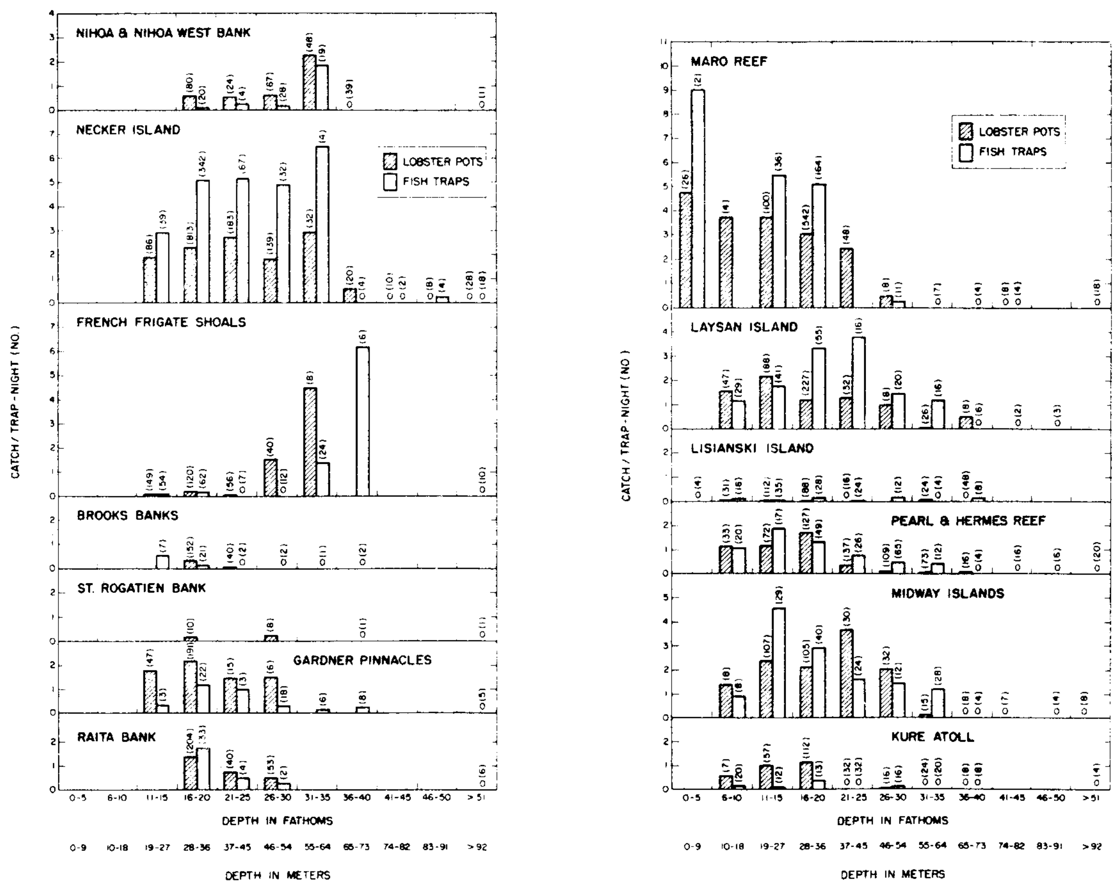

Figure 4. Distribution of spiny lobster catch rates, by depth, in the Northwestern Hawaiian Islands, October 1976 to September 1981. (No.) = effort in pot-night or trap-night

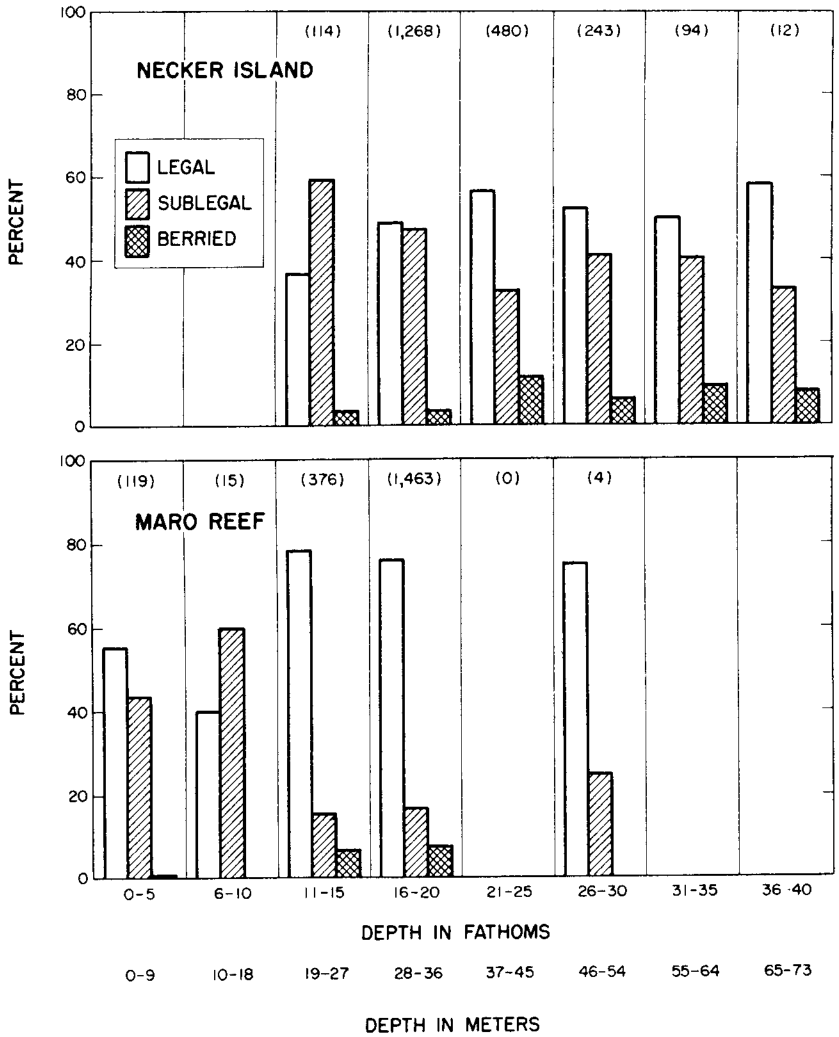

Figure 5. Percentage of legal, sublegal, and berried (ovigerous) female lobsters in catches by depth at Necker Island and Maro Reef, October 1976 to September 1981. (No.) = number of lobsters; zero indicates effort expended at that depth range but no lobsters caught.

Life History

To satisfy the data needs of the Western Pacific Regional Fishery Management Council, and also to fill gaps in the knowledge of the life history of P. marginatus in the NWHI, studies on several aspects of the life history, including fecundity and spawning (Honda, 1980, in preparation), growth and movement (Uchiyama, in preparation), size at maturity (Prescott, in preparation), behavior (reaction to offal) (Gooding, in preparation), and predators (Gooding, 1979, 1982), of P. marginatus were conducted. The results of these studies are reviewed in the following sections.

FECUNDITY AND SPAWNING

Fecundity of P. marginatus from Oahu was estimated by Morris (1968) and McGinnis (1972). Fecundity studies conducted by Honda (1980, in preparation) on NWHI P. marginatus collected between 1978 and 1981 are based on egg counts of 75 samples of egg masses from berried females at Necker and Maro Reef. The slopes of the regression of fecundity on CL for the Maro Reef and Necker samples were not significantly different. Honda also showed that fecundity increased with size. The fecundity-CL relationship (Maro Reef and Necker samples pooled) is described by the equation:

$$Y = 6.5334CL^{2.3706}$$

where

CL = carapace length in millimeters, and
Y = number of eggs carried

When compared with fecundity estimates for Oahu, Honda found that the NWHI estimates were in rather close agreement as far as the smaller females were concerned; however, the discrepancy between Oahu and NWHI estimates became greater for the larger females. For example, at 110-mm CL, an NWHI female was estimated to carry 460,000 eggs whereas an Oahu female had an estimated 575,000 eggs.

The percentage of berried females in the catch was examined by month at Necker and Maro Reef (Table 2). Using only data for reproductively mature females of 60.7-mm CL (see section on "Size at Maturity" below) it was found that between 9 and 23 percent of the female population at Necker was berried in all months of the year except January (no data available) and August, when only 19 male and 5 non-berried female lobsters were captured. Data on berried females from Maro Reef were even sparser; however, it appears evident that spawning occurs at least during the summer. Data for other months are either not available or too sparse to be meaningful.

TABLE 2. PERCENTAGE OF BERRIED FEMALE IN THE CATCH AT NECKER ISLAND AND MARO REEF, BY MONTH, BASED ON DATA COLLECTED DURING FISH AND LOBSTER TRAPPING OPERATIONS, OCTOBER 1976 TO SEPTEMBER 1981

	Necker Island			Maro Reef		
	Total Female	Berried		Total Female	Berried	
		Total	%		Total	%
January	--	--	--	--	--	--
February	44	8	18	--	--	--
March	98	9	9	--	--	--
April	65	12	18	60	10	17
May	254	51	20	165	31	19
June	163	24	15	577	103	18
July	215	42	20	266	51	19
August	5	0	0	39	10	26
September	350	80	23	--	--	--
October	185	34	18	362	23	6
November	191	20	10	--	--	--
December	22	5	23	8	2	25

Of 8,304 females caught on research and charter cruises to the NWHI, information on the presence or absence of the sperm packet or spermatophores was recorded for about a third or 2,716 individuals. The smallest mated female measured 48.3-mm CL and the largest 140.0-mm CL. The percentage of mated females was highest among those between 80.00 and 89.0-mm CL. Of 774 mated sublegal-sized (<77.0-mm CL) females collected during the surveys, 673 individuals or 87 percent were from Necker, indicating that copulation takes place in greater numbers there among sublegal-sized females than at any other site in the NWHI.

Of the 668 berried females measured, nearly 63 percent were between 80.0 and 99.0-mm CL. The smallest berried female, caught at Necker, measured 49.5-mm CL whereas the largest, from Maro Reef, was 132.5-mm CL. The Necker population of females apparently spawned at a smaller size; of 165 berried sublegal-sized females sampled throughout the NWHI, 137 individuals or 83 percent were from Necker.

GROWTH AND MOVEMENT

Lobsters were tagged to collect data on growth, movement, and abundance. Of 5,367 lobsters tagged during the early phases of the investigation, 139 were recaptured, either by commercial vessels or on research cruises. Tagged lobsters ranged from 45.3

to 145.8-mm CL; recaptures were from 68.0 to 100.3-mm CL. Considerable difficulty was experienced with tags; many of the vinyl and polyurethane tags, when recovered, were worn down to small stubs as if chewed on by other lobsters. Also 98 or 70 percent of the recoveries either were not accompanied by any CL measurements or showed no positive growth which would be useful for determing growth rates. As a result, analysis was restricted to modes in the length-frequency data collected from the northern sector of Necker Island on four cruises during 1976-78. Confining the analysis to data from the northern sector of Necker bank reduced variability attributable to differences in habitat, stock density, stages of exploitation, and population structure.

Whereas a progression of modes was evident in the male length-frequency distribution, that for the females was unimodal and the mode appeared to regress with time (Uchiyama, in preparation). Including the lobster puerulus, a von Bertalanffy growth curve was constructed based on modal progression in the length-frequency distribution of males collected at Necker Island (Figure 6).

Based on tagging data published by McGinnis (1972) the growth of male and female lobsters caught around Oahu were estimated and compared with the male growth curve from Necker. The curves are similar for the males. Data on growth rates furnished by C. MacDonald (1983: personal communication) indicated that lobsters at Kure Atoll and French Frigate Shoals grows slightly faster than those around Necker and Oahu.

Although the tag recovery data were not appropriate for calculating the growth curve, sufficient data was obtained on recapture location to determine the movement of lobsters. For tagged lobsters which were recovered by a NMFS research vessel, or by commercial vessels carrying NMFS observers, the recapture locations were determined rather precisely; however, for those recoveries made by commercial vessels with no NMFS observer aboard, reliance was made on data supplied by the captain. Of 94 recoveries with usable data, 85 (90 percent) showed movement of 5 nmi or less. Only 9 (10 percent) had traveled more than 5 nmi, the farthest being 15.6 nmi. No correlation was found between CL and distance traveled ($r = -0.102$; d.f. = 92; $P > 0.05$) or between days at liberty and distance traveled ($r = 0.226$; d.f. = 92; $P > 0.05$). Twenty-one lobsters (22 percent) were at liberty for 30 days or less, 49 (53 percent) for 31 to 60 days, and 11 (12 percent) for 61 to 90 days. The remaining 13 (14 percent) were at liberty for 322 days.

SIZE AT MATURITY

Most of the past studies on size at maturity have been based on females because males lack satisfactory indicators of sexual maturity. Studies by Heydorn (1965, 1969), Berry (1973), and Aiken and Waddy (1980) on size at maturity of male lobsters are

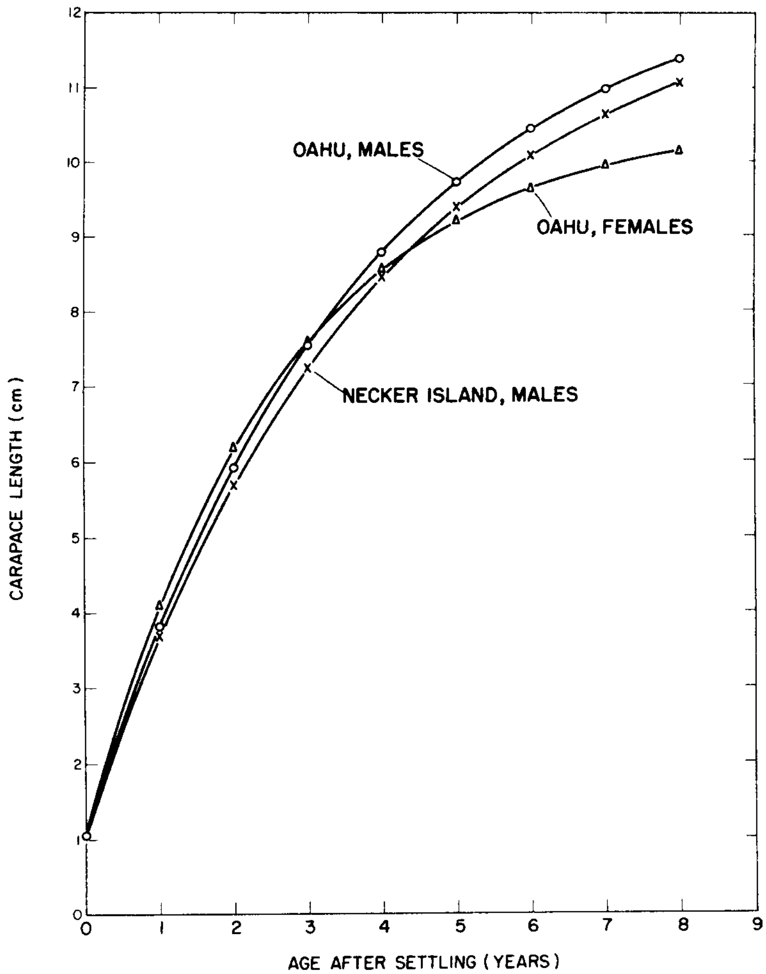

Figure 6. Growth curve of spiny lobsters from Necker Island and Oahu
Oahu male: L = 12.77 cm; K = 0.2698
Oahu female: L = 10.60 cm; K = 0.3857
Necker male: L = 12.46 cm; K = 0.2632

based on either weight or stage of development of the vas deferentia.

Among the secondary sexual characteristics in male spiny and clawed lobsters, length of the walking legs was found to increase significantly in some species as the lobster grew. George and Morgan (1979) for P. versicolor and Grey (1979) for P. cygnus estimated the size at maturity using linear growth phases of the walking legs.

Estimates of the size at maturity of *P. marginatus* were obtained from populations around Oahu and Necker Island (Prescott, in preparation). Using regression analysis, Prescott estimated size at maturity from changes in the allometric growth of pairs of walking legs. For the Oahu population, Prescott found that males mature at 63.6-mm CL and females at 58.6-mm CL, a difference in CL of 5.0 mm. For the Necker Island population, Prescott obtained estimates of 59.2-mm CL for males and 60.7-mm CL for females. No significant differences were found in size at maturity between sexes and between localities. The size at maturity estimated for Necker females is considerably larger than the size of the smallest mated female found there (48.3-mm CL); however, this discrepancy does not invalidate Prescott's results because the presence of spermatophores is not conclusive evidence that the female has mature ovaries (Wilson, 1948).

Population Structure

SIZE COMPOSITION

The percentage frequency distributions of carapace lengths of male and female spiny lobsters caught during our surveys are given by island and bank in Figure 7. Because there are wide temporal and spatial gaps in sampling, only a descriptive summary of size differences among areas and between sexes is provided.

It was shown earlier that the size of lobsters differed with locality (Uchida et al., 1980a). Because catches from both fish traps and lobster pots are included in the samples from almost all of the localities surveyed, differences in size reflect the population and not an artifact of the sampling gear.

Moving from Nihoa northwestward, the lobsters were smallest at Necker and only slightly larger at French Frigate Shoals. At these localities, the average size was much smaller than that from other islands and banks, even during earlier surveys (Uchida et al., 1980a). Therefore, the small sizes, particularly at Necker, do not represent a gradual reduction in size caused by increasing fishing effort and removal of the large adults. Farther north, no apparent trend or cline in the average size of the lobsters was found; the largest lobsters were found at Kure Atoll where the males averaged 116-mm CL followed by those at Brooks Banks where the males averaged 113-mm CL (Table 3).

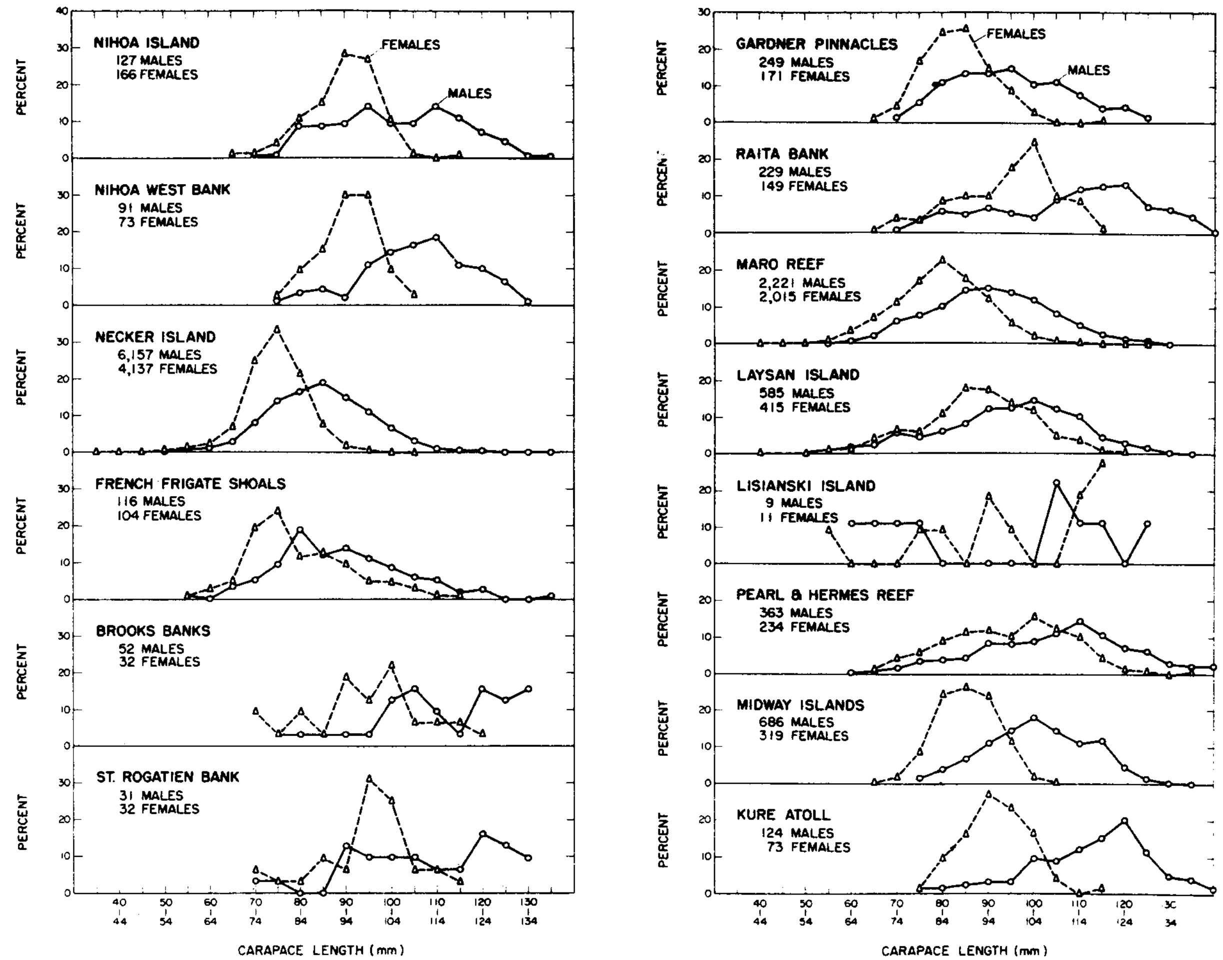

Figure 7. Percentage frequency distribution of carapace lengths of male and female spiny lobsters sampled in the Northwestern Hawaiian Islands, October 1976 to September 1981

TABLE 3. THE SIZE RANGE, MEAN CARAPACE LENGTH, STANDARD DEVIATION, AND VARIANCE OF MALE AND FEMALE SPINY LOBSTERS SAMPLED IN THE NORTHWESTERN HAWAIIAN ISLANDS, OCTOBER 1976 TO SEPTEMBER 1981

Location	Male				Female			
	Size Range (cm)	Mean Carapace Length (cm)	Standard Deviation	Variance	Size Range (cm)	Mean Carapace Length (cm)	Standard Deviation	Variance
Nihoa	7.18 to 13.56	10.41	1.3964	1.9499	6.72 to 11.70	9.21	0.7513	0.5644
Nihoa West Bank	7.66 to 13.15	10.86	1.1677	1.3636	7.60 to 10.61	9.30	0.6317	0.3990
Necker Island	4.28 to 13.70	8.70	1.0895	1.1869	3.37 to 10.52	7.71	0.6739	0.4542
French Frigate Shoals	5.96 to 13.51	9.16	1.3793	1.9024	5.62 to 11.56	8.25	1.1577	1.3402
Brooks Banks	7.59 to 13.50	11.31	1.5870	2.5186	7.36 to 12.01	9.70	1.3102	1.7165
St. Rogatien Bank	7.25 to 13.18	11.06	1.6002	2.5606	7.39 to 11.94	9.73	1.0290	1.0589
Gardner Pinnacles	7.21 to 12.79	9.75	1.2862	1.6543	6.77 to 11.70	8.58	0.7559	0.5713
Raita Bank	7.49 to 14.31	11.06	1.6722	2.7963	6.98 to 11.70	9.67	1.0685	1.1417
Maro Reef	4.74 to 13.67	9.34	1.3190	1.7397	4.38 to 13.25	8.70	0.9906	0.9813
Laysan Island	5.19 to 13.90	9.69	1.5332	2.3508	4.48 to 12.40	9.01	1.2588	1.5847
Lisianski Island	6.15 to 12.94	9.50	2.4550	6.0268	6.00 to 11.88	9.82	1.9997	3.9990
Pearl and Hermes Atoll	6.05 to 14.91	10.84	1.7121	2.9312	6.77 to 14.00	9.74	1.3509	1.8249
Salmon Bank	7.72 to 12.51	10.90	2.7569	7.6004	8.54 to 11.25	9.90	1.9162	3.6720
Midway Islands	7.53 to 13.64	10.34	1.1122	1.2369	6.73 to 10.94	8.78	0.6539	0.4275
Kure Atoll	7.71 to 14.34	11.55	1.3510	1.8253	7.91 to 11.85	9.45	0.7227	0.5223

There is no known explanation for the small size of lobsters at Necker. It has been speculated that there may be a density-dependent effect on growth rate caused by intraspecific competition (Uchida et al., 1980a). Such an effect could occur in a large population over a limited area and may account for the high catch rates at Necker. Also, if most of the food energy available to lobsters at Necker was converted into egg production, then one would expect not only small sizes associated with impaired somatic growth, but also a smaller size at maturity. Data presented earlier on percentage of ovigerous and mated females at Necker provide evidence supporting this conclusion. Chittleborough (1979) also reported that when the density of the breeding stock is high, the mean size at maturity is low and the adults are generally stunted.

The size of the sexes also differed. In every area except Lisianski, where the sample size was too small to be meaningful, males were consistently predominant among the large size classes. The differences in average size between sexes is thought to result from dimorphism related to egg bearing in females (Heydorn, 1969). Simpson (1976) cited a faster growth rate or reduced mortality among males, or both, in accounting for the predominance of males in populations of *P. argus*. MacDonald (in Prescott, in preparation) believes that growth rate per se does not account for the difference in size between the sexes for *P. marginatus*. Rather it is reduced mortality among males that is responsible for their predominance in the population.

RATIO OF LEGAL-SIZED TO SUBLEGAL-SIZED LOBSTERS

The lobster catches based on a legal size of 82.5-mm CL were analyzed in an earlier study (Uchida et al., 1980a). However, because of a new legal minimum size of 77.0-mm CL for the NWHI lobster, the ratio between legal and sublegal sizes was calculated (Table 4). Apparently, the ratios have not changed drastically from those calculated earlier.

The ratio of legal- to sublegal-sized lobster, by locality, for pot catches during October 1976 to September 1981 varied widely between 51:49 at Necker and 97:3 at Kure. For fish trap catches, where the number of sublegal-sized lobsters would be expected to be higher, the ratios varied from 39:61 at Necker to 100:0 at several banks; however, if those banks where less than 25 lobsters were taken by fish traps are not counted, then the ratio is closer to 94:6.

Except at Necker and French Frigate Shoals where the catch of sublegal-sized lobsters was as high as if not higher than legal lobsters, the proportion of sublegal-sized lobsters in the NWHI is expected to be low, because juveniles molt more frequently than adults, tend to remain secluded and, hence, are not subject to capture. They are, however, more susceptible to

TABLE 4. THE LEGAL TO SUBLEGAL SIZE RATIO AND MALE TO FEMALE SEX RATIO OF CATCHES BY LOBSTER POTS AND FISH TRAPS DURING RESEARCH CHARTER CRUISES IN THE NORTHWESTERN HAWAIIAN ISLANDS, OCTOBER 1976 TO SEPTEMBER 1981

Island/Bank	Gear	Legal Size			Male: Female Sex Ratio	Sublegal Size			Male: Female Sex Ratio	Total Male	Total Female[2]	Male: Female Sex Ratio	Legal: Sublegal Size Ratio
		Male No.	Female No.[1]	Total No.		Male No.	Female No.[1]	Total No.					
Nihoa	Lobster	110	83	193	57:43	5	9	14	36:64	115	151	43:57	93:7
	Fish	16	12	28	57:43	3	1	4	75:25	19	21	48:52	88:12
Nihoa West Bank	Lobster	80	44	124	64:36	3	2	5	60:40	83	64	56:44	96:4
	Fish	2	1	3	67:33	0	0	0	0:0	2	1	67:33	100:0
Necker Island	Lobster	3,343	516	3,859	87:13	1,531	2,110	3,641	42:58	4,874	3,307	60:40	51:49
	Fish	649	114	763	85:15	611	594	1,205	51:49	1,260	860	59:41	39:61
French Frigate Shoals	Lobster	56	30	86	65:35	20	32	52	38:62	76	64	54:46	62:38
	Fish	26	13	39	67:33	14	24	38	37:63	40	41	49:51	51:49
Gardner Pinnacles	Lobster	298	144	442	67:33	27	53	80	34:66	325	236	58:42	85:15
	Fish	20	6	26	77:23	4	5	9	44:56	24	11	68:32	76:26
Brooks Banks	Lobster	26	22	48	54:46	1	1	2	50:50	27	30	47:53	96.4
	Fish	5	2	7	71:29	0	0	0	0:0	5	2	71:29	100:0
St. Rogatien Bank	Lobster	30	26	56	54:46	1	3	4	25:75	31	32	49:51	93:7
	Fish	—	—	—	—	—	—	—	—	—	—	—	--
Raita Bank	Lobster	419	258	677	62:38	18	24	42	43:57	437	290	60:40	94:6
	Fish	35	20	55	64:36	2	4	6	33:67	37	24	61:39	90:10
Maro Reef	Lobster	1,405	980	2,385	59:41	313	331	644	49:51	1,718	1,626	51:49	79:21
	Fish	417	246	663	63:37	147	149	296	50:50	564	481	54:46	69:31
Laysan Island	Lobster	306	195	501	61:39	33	32	65	51:49	339	249	58:42	89:11
	Fish	177	92	269	66:34	66	61	127	52:48	243	168	59:41	68:32
Lisianski Island	Lobster	2	5	7	29:71	2	0	2	100:0	4	5	44:56	78:22
	Fish	3	1	4	75:25	2	3	5	40:60	5	6	45:55	44:56
Pearl and Hermes Atoll	Lobster	229	137	366	62:38	11	11	22	50:50	240	161	60:40	94:6
	Fish	92	61	153	60:40	4	5	9	44:56	96	72	57:43	94:6
Midway Islands	Lobster	440	156	596	74:26	17	34	51	33:67	457	215	68:32	92:8
	Fish	222	82	304	73:27	8	25	33	24:76	230	113	67:33	90:10
Kure Atoll	Lobster	117	60	177	66:34	2	4	6	33:67	119	69	63:37	97:3
	Fish	6	3	9	67:33	0	0	0	0:0	6	5	55:45	100.0

[1] Excludes berried females
[2] Includes berried females

predation because of their smaller size. Furthermore, the initial catches at any given locality would tend to include a large proportion of the large older individuals, particularly males, partly because of their aggressive behavior. This display of dominance for shelter and food exists in a natural environment (Chittleborough, 1974). In a fishery, however it is the baited trap that becomes an object of dominant behavior.

That large lobsters were removed from the population early in the fishery was quite evident from changes in the proportion of legal lobsters in the catches at Necker. In November 1976 when trapping operations first began, the ratio of legal- to sublegal-sized lobsters at grid 236646, located north of Necker Island, was 60:40 but dropped to 43:57 by May 1977 and declined to 34:66 by August 1977. The rapid decline in the proportion of legal-sized lobsters is attributable to heavy fishing pressure by the commercial vessels.

SEX RATIO

The study data show that for lobsters taken in the NWHI, some selectivity was evident in that the proportion of females was usually lower among the legal sizes whereas it was higher among sublegal sizes in most areas sampled. Among the areas sampled, several had small sample sizes and it is believed that the ratios calculated are unlikely to be representative of the populations at those locales. For this analysis, samples with less than 10 lobsters were ignored. For the lobster pot catches, the male and female ratio among legal-sized lobsters varied from 87:13 at Necker to 54:46 at Brooks Banks and St. Rogatien Bank. For fish trap catches, the ratios were not dissimilar, ranging from 85:15 at Necker to 57:43 at Nihoa.

Among sublegal-sized lobsters, the male to female ratio was near 50:50 at Maro Reef, Laysan, and Pearl and Hermes Atoll but considerably in favor of the females at Nihoa, Necker, French Frigate Shoals, Gardner Pinnacles, Raita Bank, Midway, and Kure. The fish trap catches reflect a somewhat similar preponderance of females. Whereas it was near 50:50 or very slightly in favor of males at Necker, Maro Reef, and Laysan, the ratios were largely in favor of females at French Frigate Shoals and Midway. Samples from other areas were too small to be representative. Therefore, although male predominance in the catch is evident at almost every bank among legal-sized lobsters, it is not reflected in the catch of sublegal-sized lobsters.

MORPHOMETRIC STUDIES

A study of the relationship between CL and total weight was completed in 1979 (Uchida et al., 1980a). Six hundred five lobster measurements and weights collected from Necker, Maro Reef, and French Frigate Shoals were used. Because there is sexual dimorphism in the growth of spiny lobsters, the exponential model, $W = aCL^b$, was fitted to data for males and females by the least squares method after log transformation. The length-weight relationships for the 408 males and 197 females are:

$$\text{Males:}\quad W = 0.00423CL$$

$$\text{Females:}\quad W = 0.00090CL$$

where

W = weight (g), and
CL = carapace length (mm).

The relationships are shown in Figure 8. For lobsters having a CL of 77.0 mm, the equations predict a total weight of 378.1 g (13.3 oz) for males and 402.4 g (14.2 oz) for females.

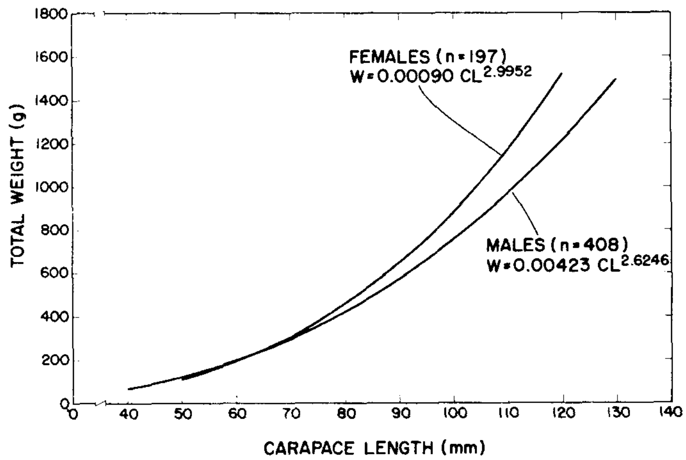

Figure 8. Length-weight relationship of male and female <u>Panulirus</u> <u>marginatus</u> determined from samples collected at Necker Island, French Frigate Shoals, and Maro Reef

For enforcement purposes in situations where a vessel lands only frozen tails, it is useful to know the relationship between tail weight or tail width, provided that either one is used as a criterion for minimum legal size. Uchida et al., (1980a) fitted exponential models to data for male and female CL and frozen tail weight and obtained:

$$\text{Males:}\quad TW = 0.00731CL$$

$$\text{Females:}\quad TW = 0.00094CL$$

where

TW = tail weight (g), and
CL = carapace length (mm).

The equations predict that lobsters with a CL of 77.0 mm would have a tail weight of 130.4 g (4.6 oz) for males and 156.3 g (5.5 oz) for females.

To determine whether a lobster was of legal size when captured, based on frozen tail width, a discriminant analysis procedure to classify them was performed (Polovina and Tagami, 1981). Based on the discriminant analysis, a lobster in which the width of the first tail segment equals or exceeds 49 mm can be classified as legal size.[2] The discriminant analysis correctly classified 94.8 percent of the sublegal-sized and 85.8 percent of the legal-sized lobsters. The tolerance factor adopted was that no more than 15 percent of the total number of tails may be less than the specified tail width limit.

MAXIMUM SUSTAINABLE YIELD (MSY)

In the NWHI, the fishery for spiny lobster is based on a single homogeneous stock within the archipelago (Shaklee and Samollow, 1980). A model developed to assess the fishery for P. marginatus therefore addressed the Hawaiian population as a single stock (Polovina and Tagami, 1980).

Polovina and Tagami assumed that the ratio of natural mortality to recruitment was constant and used changes in catch/pot-night at Necker during November 1976 to April 1979 to make the first preliminary assessment of the fishery. Because the fishery was relatively new and historical catch data were not available, they used data from research cruises as well as available commercial data to estimate population size and catchability. They derived an estimate of the initial population size of 132,400 legal-sized lobsters ($\geq$82.5-mm CL) in Region I, which is the northern, most heavily fished sector of Necker bank. By April 1979, according to their analysis, this population was reduced to 68,571 legal-sized lobsters. Their study concludes that Region I had a sustainable yield of 10,000 to 21,000 legal-sized lobsters which translated to a density estimate of 13.3 to 27.5 legal-sized lobsters/km^2/year.

Considering the possibility that the legal minimum size could be lowered, Polovina and Tagami used a Beverton-Holt equilibrium yield model to estimate yield per recruit at several levels of fishing intensity and minimum CL. They determined that a minimum legal size of 67.5 mm would produce the maximum yield per recruit. A worst-case situation would result in a decrease

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[2]The spiny lobster Fishery Management Plan was approved with a 50-mm requirement.

of 15 percent in yield per recruit at a minimum legal size of 67.5 mm as compared with a 82.5-mm minimum legal size. In the best case, a 167 percent increase in yield per recruit would result. This analysis, however does not consider the effects that a lowered minimum legal size would have on stock reproductive potential.

Extrapolating the region I estimates to the entire population in the NWHI provided possible MSY ranges of 210,000 to 435,000 lobsters/year. Adjusting for differences in the geographic distribution of lobsters within the NWHI and using catch rates obtained during research cruise surveys, Polovina and Tagami also calculated lower ranges of possible MSY values of 200,000 to 378,000 lobsters/year. They also determined that although the precise magnitude of the impact of lowering the legal minimum size cannot be determined conclusively, it appears that a 15 percent increase in yield would be sustainable if the minimum legal size were reduced to 77.0 mm.

The Western Pacific Regional Fishery Management Council has adopted a range of MSY of 200,000 to 435,000 lobsters/year in the NWHI. These estimates were based on a minimum legal size of 82.5 mm, but the yield per recruit analysis suggests that a higher yield is possible at the new minimum legal size of 77.0 mm. The estimates, therefore, are on the conservative side. The accumulation of commercial data will permit future analysis to derive more precise estimates.

Exploitation

GEAR COMPETITION EXPERIMENTS

It may be argued that a decline in catch per pot-night of spiny lobsters may not represent an actual decrease in numbers but may reflect instead the results of competition among the pots for the same lobster. If spacing distances are small, the capturing fields overlap, thus resulting in an apparent decline in catch per pot-night.

Studies conducted in 1977 during research and charter cruises showed that gear competition does exist and that it is density dependent (Polovina, 1980). The highest catch rates were obtained with pot spacing in the range of 35 to 46 m (20 to 25 fathoms). From experiments conducted on the NMFS research vessel, where five spaces of 18, 27, 36, 46, and 55 m (10, 15, 20, 25, and 30 fathoms) per location were tested, spacing effects were significant for medium density areas but not in low-density and high-density areas. For data obtained from a chartered commercial vessel, no significant differences in catch rates between 36 and 55-m (20 and 30 fathoms) spacings at either high-density or very high-density areas were found. Furthermore, the catch rate with pot spacing of 18 m (10 fathoms) was significantly lower than catch rates obtained with 36 and 55-m (20 and 30 fathoms) spacing.

ESCAPE GAP AND GHOST FISHING EXPERIMENTS

In a study to determine whether the use of escape panels or vents would significantly reduce the number of sublegal sizes taken by pots, tank experiments were conducted using different-sized escape gap widths (Paul, in preparation). She found that the overall escape rate of sublegal-sized lobsters was about 60 percent and that escape rate decreased linearly with an increase in CL. No significant differences were found in escape rates of males and females. There were, however, notable differences in escape rate depending on the types of vents used and Paul concluded that vent effectiveness depends more on total vent area than on width of the vent.

In all trials conducted, it was found that unbaited traps in which live lobsters were present attracted other lobsters or ghost fished. To examine the degree of ghost fishing in lost traps, several field trials were conducted. Although lobsters are attracted to and enter unbaited pots that contained live lobsters, there was also evidence that lobsters can easily escape through the pot entrance over a period of up to 1 week. There was also evidence of cannibalism and molting among trapped lobsters.

Longer-term tests over periods of 3 weeks to 1 month indicated that lost pots can and do attract lobsters. In one test, it was observed that of 38 live, marked lobsters left in unbaited traps, 22 individuals or 58 percent remained in the same pots after 4 days. One individual left one pot and entered another. The pots also captured 14 new, unmarked lobsters. The new entries were marked and left with the remaining 22 marked lobsters and the pots were reset. At the end of the experiment, 26 days after it began, only one marked lobster remained together with five new entries, three of which were dead. All other lobsters were missing and presumed to have escaped through the entrance. These results contrast with those of Paul who found ghost fishing to be a big problem; the study data indicate that although ghost fishing does occur, there is also a high escape rate over the long term.

REACTION TO OFFAL

It became apparent soon after the Hawaiian fishery began that the vessels would begin landing a large proportion of the catch as frozen tails for the export market. A question arose of whether the offal (heads) of tailed lobsters discarded on the trapping grounds would affect the distribution and catch rates of lobsters. Declines in catch rates caused by lobster offal have been documented, and discarding offal on lobster grounds has been banned in such places as Africa and Australia (Matthews, 1962; Chittleborough, 1974; Hancock, 1974).

To study the effects of offal on catches in the NWHI, field experiments were conducted by NMFS during Townsend Cromwell cruises TC-81-04 and TC-82-05 (Gooding, in preparation). In the first experiment during cruise TC-81-04 at Maro Reef, catch rates of baited pots with offal tied on the outside were compared with those of controls which were baited only. During this experiment the catch rates were 4.56 individuals/pot-night for the control and 0.13 individuals/pot-night for the experimental traps. At Necker, the catch rate for control traps was 0.97 individuals/pot-night and that for experimental traps was 0.19 individuals/pot-night.

During the second experiment on cruise TC-82-05, five stations produced catch rates from 0.08 to 2.31 individuals/pot-night for controls whereas those obtained from the experimental traps ranged from 0.00 to 0.06 individuals/pot-night. Data from one station were not used in the analysis due to effects produced by rough seas resulting in heavy gear losses and zero-catch rates.

The experiments demonstrated that the presence of offal in or around the pots substantially decreases catch rates for P. marginatus in the NWHI.

PREDATORS

Among the management measures adopted for the spiny lobster fishery in Hawaii is the prohibition of retaining berried female and sublegal-sized lobsters. The usual practice aboard commercial boats is to sort out the berried female and sublegal-sized lobsters as the traps are retrieved and to return them to the water as quickly as possible. At the same time, the fishermen remove and discard the old bait and replenish the container.

What happens to lobsters that have been caught and released is of considerable importance to the fishery. Gooding (1979, in preparation) noted that when berried and sublegal-sized lobsters were hauled aboard a boat and later released, they are subjected to considerable stress, resulting primarily from long exposure to air and sunlight, rough handling, release over unsuitable or unfamiliar territory, disorientation, and predators.

Because used bait is discarded as a vessel moves along the string of traps, predators are easily attracted to the stern; thus, discarded bait as well as surface-released lobsters are both consumed. To determine the degree of this type of predation and to identify the predators, the Honolulu Laboratory conducted field experiments during cruises TC-79-02 and TC-81-04, as well as during the Easy Rider charter cruise ER-80-01.

Casual observations on several research cruises and those made by commercial fishermen indicated that there were at least two principal predators -- the hon-ulua (Caranx ignobilis) and the galapagos shark (Carcharhinus galapagensis). Gooding (1979) reported that predators such a omilu (Caranx melampygus), hon-ulua, reef whitetip shark (Triaenodon obesus), and gray reef shark (Carcharhinus amblyrhynchos) were seen near the NMFS vessel but none showed any inclination to prey on surface-released lobsters. Likewise, on cruise ER-80-01, potential predators such as hon-ulua, galapagos shark, tiger shark (Galeocerdo cuvieri), and ono (Acanthocybium solandri) were observed around the vessel but underwater observations revealed no predation on surface-released lobsters.

Results obtained during cruise TC-81-04, however, demonstrated conclusively that hon-ulua are voracious predators. Gooding (1982) concluded that the state of satiation is always a factor and that the number of lobsters consumed is directly related to predator size, predator school size, and size of lobsters released. Furthermore, Gooding's observations showed that bottom-release of lobsters, even on substrata that offers good shelter, does not ensure high survival in the presence of voracious predators. The only practical safeguard to ensure high survival was to release lobsters near the bottom in protective bags or containers and only when there was reasonable assurance that large schools of predators were not following the boat.

ECONOMIC STATUS AND POTENTIAL

In early 1977, following the discovery of commercial concentrations of spiny lobsters at Necker, five commercial vessels began full-scale trapping operations and by the end of the year had produced a catch of 31,547 kg from the NWHI, thereby catapulting the statewide landings of spiny lobster to more than 13 times the previous year's landings. This early beginning of the fishery was not without problems. The market structure was unorganized and the boats returning from the NWHI lobstering grounds faced a local market that was chaotic and unable to absorb the sudden heavy influx of live, whole lobsters. Ex-vessel prices averaged $6.39/kg ($2.09/lb) and the year's statewide catch of 37,659 kg was worth about $240,600 to the fishermen.

The fishery experienced other "growing pains." Captains unfamiliar with transporting large numbers of live lobsters in their baitwells over the long distance from the NWHI lobstering grounds to Honolulu sometimes experienced losses of entire loads due to overcrowding and poor water circulation in the baitwells. Those vessels lucky enough to return with a full live load were faced with declining prices and attempted to maintain prices by marketing their catches in small amounts and over a longer period.

The chaotic market forced several marginal producers out of the fishery and by October 1977, only two vessels remained. These vessels continued to fish until October 1978 when they were joined by another entry into the fleet. The result was that landings from the NWHI declined to 12,440 kg, a 60 percent decrease from the previous year. The ex-vessel price, however, rose to $6.60 kg ($3.00/lb) making the 1978 statewide landings of 15,294 kg worth $82,100 to the fishermen.

Also about this time, the industry began looking for other outlets for their products, particularly the frozen lobster tail export market. This new impetus raised the hopes of the industry and landings again rose, reaching 45,372 kg; however, only two vessels participated, and presumably almost all of the catch was from the NWHI. At an ex-vessel price of about $7.05/kg ($3.20/lb), the 1979 catch was worth $319,900. At-sea processing required large vessels not only with freezing capabilities but also with the ability to exert greater fishing pressure.

By 1980, the fleet was composed of three vessels, and among them they had the potential of setting and retrieving 2,500 lobster pots per night. This resulted in a catch of 148,907 kg worth $1.1 million at an ex-vessel price $7.49/kg ($3.40/lb).

Encouraged by the rising prices and continued strong demand for frozen lobster tails, the fishery continued to produce record catches. By 1981, the fleet had increased to 10 vessels, which caught a record 354,200 kg worth $2.7 million at an ex-vessel price of $7.71/kg ($3.50/lb).

Although catch records for 1982 are incomplete, the annual catch, produced by six vessels, is estimated to be 83,711 kg, down considerably from 1981. Ex-vessel prices advanced little to $8.06/kg ($3.60/lb), making the 1982 catch worth an estimated $674,714 to the fishermen.

Annual estimated landings with ranges of MSY are given below. Using the average CL of the males and females at Necker and Maro Reef (Table 3) and converting these to average weight using the length-weight relationships (Figure 8), an average weight of 533 g for both sexes combined was calculated. Based on this average weight, the range in MSY is estimated to be 106,600 to 231,855 kg.

The landings in 1977-79 were far below the lower range MSY. In 1980 and 1982, the estimated landings fell within the range of MSY but in 1981, the upper limit of the MSY was exceeded by about 122,000 kg.

When the fishery first began, some believed that the potential was as good as that of other lobstering grounds throughout the world. Potential production from the NWHI grounds based on extrapolations of initial catch rates seemed encouraging; however, as with many new, developing fisheries, once the initial stock was reduced by heavy fishing and catch rates declined, enthusiasm subsided. By then, our surveys demonstrated that the NWHI catch rates of spiny lobster were nowhere near those of the major lobster fisheries of the world, for example Australia and South Africa. Furthermore, in the NWHI fishery, risks were greater as vessels had to travel 1,700 nmi round trip to fish at Necker and Maro Reef, the only two grounds with commercial concentrations of spiny lobsters.

Even with the most optimistic projection, it is not likely that the NWHI spiny lobster stock could support more than a few full-time vessels. Furthermore, profitability may depend on a multispecies operation. Places such as Nihoa, Pearl and Hermes Atoll, Gardner Pinnacles, and Midway can probably be fished profitably in combination with other types of fishing. Examples are bottomfishing for members of the snapper-grouper complex, trolling for coastal pelagic species such as wahoo (*Acanthocybium solandri*), and trapping for deepwater caridean shrimps. There are also several important species in the by-catches of lobster pots such as slipper lobsters (*Scyllarides squammosus* and *S. haani*) and frog or kona crab (*Ranina ranina*) which could add to a vessel's profitability.

MANAGEMENT GUIDELINES

Management of the spiny lobster fishery in Hawaii is achieved through a series of regulations which apply to two permit areas. Permit Area 1 encompasses the U.S. fishery conservation zone (FCZ) around the NWHI or all islands and banks west of long. 161° 00'W. Permit Area 2 includes the main Hawaiian islands or those islands and banks in the archipelago east of long. 161° 00'W.

Currently the management measures published in the Federal Register[3] include the following:

> Size regulation. Whole lobsters of 77.0-mm CL or greater may be retained. If the CL cannot be determined, only lobsters with tails at least 50 mm wide may be retained, except for an allowance of up to 15 percent of the catch, by number, which may include tail widths between 45 and 49 mm.
>
> Reproductive condition restrictions. Berried females may not be retained or stripped of eggs attached to the pleopods.
>
> Closed areas. Spiny lobster trapping is not allowed within 20 nmi of Laysan and within the FCZ landward of the 10-fathom curve as depicted on National Ocean Survey charts 19022, 19019, 19016.
>
> Gear restrictions. Spiny lobsters may be taken only with lobster pots or by hand. Other gears or chemical agents are prohibited. Furthermore, pot entrance may measure no more than 26.7 cm (10.5 in) at its greatest

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[3]Federal Register 47(126), June 30, 1982, contains the proposed rule; Federal Register 48(26), February 7, 1983, contains the final rule. The final rule contains no substantial changes from the proposed rule except minor revisions.

diagonal or diameter at the larger end and no more than 16.5 cm (6.5 in) at its greatest diagonal or diameter at the smaller end.

Permits. Any U.S. vessel trapping commercially in the NWHI management area (Permit Area 1) must have a permit issued by the director, Southwest Region, NMFS.

Recordkeeping and reporting. The operator of any vessel engaged in lobster trapping operations in Permit Area 1 shall maintain an accurate and complete logbook furnished by NMFS, recording all information as required.

Landing requirements. The operator of a fishing vessel that has fished in Permit Area 1 shall contact by radio or otherwise, an authorized officer at least 24 hours before landing and report to this officer the port, date, and time of unloading. An authorized officer is defined as any commissioned, warrant, or petty officer of the U.S. Coast Guard (USCG); a special agent of the NMFS; any officer designated by the head of any federal, state, or territorial agency which has entered into an agreement with the Secretary of Commerce and the Secretary of Transportation to enforce the provisions of the Magnuson Fishery Conservation and Management Act; and any USCG personnel accompanying and acting under the direction of any USCG commissioned, warrant, or petty officer.

Experimental fishing. The Secretary of Commerce may authorize experimental fishing for spiny lobster which would otherwise be prohibited. A NMFS scientific observer must be aboard the vessel while the vessel is engaged in such activity.

An additional provision of the regulations applies to protective measures established for the Hawaiian monk seal (Monachus schauinslandi) which was designated a depleted species under the Marine Mammal Protection act and listed as an endangered species effective November 23, 1976. Briefly, these measures specify that in the event that a monk seal dies from causes that appear to be related to the spiny lobster fishery, an investigation will be conducted by the director of the Southwest Region. If it is determined that the death is related to the spiny lobster fishery, emergency measures will be instituted, as required, to protect the monk seal population. In addition to the regulations established under the Spiny Lobster Fishery Management Plan, there are state laws and rules which are applicable to fishing for and landing of spiny lobsters and other crustaceans. State laws establish a seasonal closure, prohibit taking of ovigerous females, establish a minimum size, and prohibit the landing of lobsters from which the carapace and tail have been separated; however, the state law also provides that such measures shall not apply if the catch was made outside of state waters and the possession or sale has been licensed (import permit) by the Hawaii Department of Land and Natural Resources.

SUMMARY

The investigation conducted by NMFS has elucidated several aspects of the spiny lobster resource in the NWHI. Particularly striking is the fact that P. marginatus is unevenly distributed and the only stocks which are of commercial potential are those at Necker and Maro Reef. The survey showed that the relative abundance of lobsters is highest at the 55 to 73 m depth in localities near the lower end of the NWHI chain and at the 19 to 54 m depth in those localities toward the northern end of the chain. Whereas a small female lobster from the NWHI may spawn just as many eggs as one in waters off Oahu, at larger sizes the NWHI female apparently spawns fewer eggs. The spawning season for NWHI populations is estimated to be all year at the lower end of the chain, peaking in summer. However, among the more northern localities, the spawning period is shorter and confined primarily to the summer months.

Studies on growth rate showed that a male lobster from Necker grows at about the same rate as one in waters around Oahu. For the Oahu stock, males mature at 63.6-mm CL whereas the females mature at 58.6-mm CL. For the stock at Necker, males mature at 59.2-mm CL and females at 60.7-mm CL. The difference between localities is not significant.

Lobsters tend to avoid baited traps in the presence of offal. Large schools of predators can inflict serious losses among surface-released berried and sublegal-sized lobsters.

The lobsters at Necker and French Frigate Shoals are, on the average, smaller than those found elsewhere in the chain. The legal to sublegal size ratio of the catch showed wide variation with no particular trend. The sex ratio of the stocks, however, showed that among the legal-sized lobsters in the catch, males predominated. Among sublegal-sized lobsters, however, there was a preponderence of females at most localities.

A legal-sized lobster of 77.0-mm CL weighs about 378.1 g, whereas a legal-sized female is heavier, weighing 402.4 g. There is sexual dimorphism in the growth pattern.

The relationship between CL and tail weight predicts a legal-sized male would have a tail weight of 130 g and a female 156 g.

Discriminant analysis based on tail width correctly classifies 94.8 percent of the sublegal-sized and 85.8 percent of the legal-sized lobsters. The tolerance factor adopted for the fishery management plan is that no more than 15 percent of the total

number of tails landed may be less than the specified tail width limit of 50 mm.

Studies on population dynamics provided a range of possible MSY of from 200,000 to 435,000 lobsters/year.

Experiments on gear competition showed that pot spacings of between 35 and 46 m produced the highest catch rates. Tests with escape gaps revealed that the overall escape rate of sublegal-sized animals was about 60 percent. Studies on ghost fishing of lost traps demonstrated that they continue to attract lobsters and, over the short term, continue to fish; however, over the long term, lobsters appear to escape through trap entrances.

Finally, the investigation showed that even with the most optimistic projections, it is not likely that the NWHI lobster fishery will expand significantly over the next few years. The upper limit of the MSY was exceeded in 1981. With reduced catch rates at this time, it is not likely that the present scale of production can support more than a few vessels. The future of the fishery will depend to a large extent on the operation of multispecies fishing boats that can participate in other fisheries being developed in the NWHI.

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