Predation on Released Spiny Lobster, *Panulirus marginatus*, During Tests in the Northwestern Hawaiian Islands

REGINALD M. GOODING

ABSTRACT—In the Northwestern Hawaiian Islands fishery for spiny lobster, Panulirus marginatus, *undersized and berried lobsters must be released. Such lobsters released in the conventional way, are very vulnerable to predation by large carnivores. Field tests showed that the white ulua,* Caranx ignobilis, *was an efficient and aggressive predator on released lobsters. Another suspected predator, the galapagos shark,* Carcharhinus galapagensis, *did not prey on released lobsters. Procedures are suggested for use by commercial fishermen that should preclude serious predation on released lobsters.*

Introduction

During 1976-82, biologists of the NMFS Southwest Fisheries Center's Honolulu Laboratory engaged in an extensive survey of the fishery resources of the Northwestern Hawaiian Islands (NWHI) (Fig. 1). In the early exploratory phase of the survey, substantial populations of spiny lobster, *Panulirus marginatus*, were discovered on several of the NWHI banks (Uchida et al., 1980). Shortly thereafter, this resource became the target of a Honolulu-based trap fishery.

Recent research has been directed toward the accumulation of knowledge which will enable sound management of the spiny lobster resource in the NWHI. Data relative to seasonal and spatial distribution and abundance, population structure, growth rate, sexual maturation, and fecundity provide the basis of a Fishery Management Plan (FMP) for the lobster fishery. The FMP prohibits the retention of egg-bearing (berried) lobsters and those <7.7 cm carapace length (CL). The regulations, which went into effect in January 1983, require that such illegal lobsters caught in the U.S. Fishery Conservation Zone around the NWHI be sorted from the catch and released alive.

On lobster fishing vessels in the NWHI, the usual procedure is to

Reginald M. Gooding is with the Honolulu Laboratory, Southwest Fisheries Center, National Marine Fisheries Service, NOAA, P.O. Box 3830, Honolulu, HI 96812.

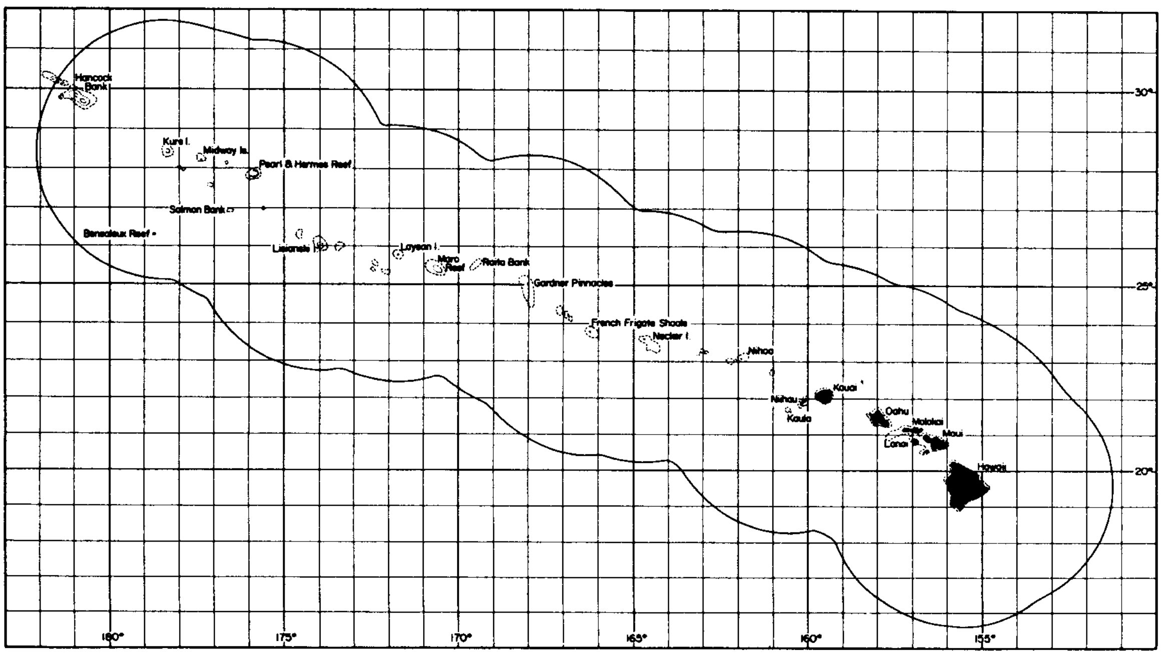

Figure 1.—The Hawaiian Archipelago including the Northwestern Hawaiian Islands.

release illegal lobsters overboard immediately after traps are hauled. Concurrently, old bait remaining in the traps is also discarded. During the period the fishery was unregulated, no estimate was available of the number of lobsters which were caught and released by commercial fishermen. However, the logbook data furnished NMFS by vessels in the NWHI fishery show that for 1983, 23.2 percent of all lobsters trapped were <7.7 cm CL (legally undersized) and 4.4 percent were berried. On grounds that are intensively fished, such as those surrounding Necker Island and Maro Reef in the NWHI, it is likely that many animals are trapped and released more than once.

The survival rate of undersized lobsters after they have been released may be of considerable significance to the long-term productivity of the NWHI lobster fishery. Thus, it is of some importance to have an understanding of the factors which affect this animal's ability to survive, grow, and reproduce normally after it has been trapped and returned to the sea. With such an understanding, it can be determined whether further regulations governing the way berried and undersized lobsters are handled by commercial fishermen are needed.

Lobsters caught in traps and subsequently released are subject to factors which may cause stress or injury and result in high mortality. These broadly include: Length of time out of the water and subsequent exposure to air, sunlight, and heat; injury resulting from handling; release on an unsuitable substrate; release in an area outside its home range; general disorientation which may make the animal more vulnerable to predation; and presence of lobster predators in the vicinity of the vessel at the time of release. Davis (1981) found that fishery-related injuries inflicted on *P. argus* resulted in a significant decrease in growth rate. Lyons and Kennedy (1981) found considerable evidence indicating that fishery handling techniques in the Florida *P. argus* fishery had a heavy impact on the stocks of sublegal lobsters, delaying or prohibiting their entry into the legal fishery.

Meyer-Rochow (1975) studied the eye of the western rock lobster, *P. cygnus*. Based on that work, Meyer-Rochow and Tiang (1981) concluded that exposure to bright light such as sunlight affects the rock lobster in several ways, all detrimental to survival, including an inability to see predators, even at moderately bright ambient light levels, inability to adjust to differing ambient light intensities, and difficulty in behaving according to a normal diurnal rhythm of activities. A study of fishery-related mortality in undersized and berried rock lobster, *P. cygnus*, showed that poor handling of lobsters before release caused high mortality (Anonymous, 1979, 1981; Brown and Caputi, 1983).

Gooding[1] reported on observations made on surface-released spiny lobsters and potential predators near Necker and Nihoa Islands in the NWHI. The objective of that preliminary study was to determine which fishes might be potential predators on surface-released lobsters. A number of previous casual observations of apparent predation on lobsters by jack crevally, *Caranx ignobilis*, or white ulua, as it is called in Hawaii, and galapagos shark, *Carcharhinus galapagensis*, had been reported by fishermen and scientists on fishing and research vessels. Thus, those two species were of particular interest. Tests were conducted in the presence of blue crevally, *Caranx melampygus*, single white ulua (no schools were seen), galapagos shark, reef whitetip shark, *Triaenodon obesus*, and gray reef shark, *Carcharhinus amblyrhynchos*. With the exception of a galapagos shark, which was observed to briefly mouth a lobster in midwater before releasing it, none of the fishes seen during those preliminary observations showed any inclination to prey on lobsters.

Sudekum[2] found that 1.5 percent of the white ulua he examined had *P. marginatus* and 1.5 percent had *P. penicillatus* remains in their guts. No lobster remains were in the *Caranx melampygus* he examined. Okamoto and Kawamoto (1980) also reported lobster remains in white ulua guts and, while conducting surveys at Pearl and Hermes Reef, they observed white ulua preying on *P. marginatus* which had fled from shelter when disturbed by divers[3]. De Crosta et al. (1984) found that guts of 65 *Carcharhinus galapagensis* he examined did not contain any lobster remains; however, 2 percent of *C. amblyrhynchos* and 11.1 percent of tiger shark, *Galeocerdo cuvier*, had *P. marginatus* remains in the gut contents.

The grouper, *Epinephelus quernus*, which is abundant in the NWHI, was considered a possible predator on released lobsters. However, although *E. quernus* are numerous in waters as shallow as 5 m at Kure Atoll and Midway (Hobson, 1980), they have not been reported in shallow waters in the southeastern part of the NWHI where the principal lobster grounds are located. In Hawaii, they are caught at bank drop-offs in depths >80 m. Seki (1984), in a study of the feeding habits of *E. quernus* caught with deep-sea handlines, did not find any lobster remains in the 67 specimens he examined. No *E. quernus* were seen during this study.

This report describes lobster release tests conducted during cruise 81-04 of the NOAA ship *Townsend Cromwell*. The cruise plan called for fishery survey operations throughout the NWHI which provided an opportunity to conduct tests incidentally when suitable conditions were encountered. Principal goals were to determine 1) under what conditions large schools of large white ulua prey on lobsters, 2) what other fishes are potential predators on released lobsters, 3) the

[1]Gooding, R. M. 1979. Observations on surface-released, sublegal spiny lobsters, and potential spiny lobster predators near Necker and Nihoa. Honolulu Lab., Southwest Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96812, Admin. Rep. H-79-16, 8 p.

[2]Sudekum, A. E. 1982. Notes on the biology and feeding habits of *Caranx ignobilis* and *Caranx melampygus* in the Northwestern Hawaiian Islands. Seventh Albert L. Tester Memorial Symposium, Univ. Hawaii, Honolulu, April 1982. Abstr.

[3]Henry Okamoto, Hawaii Division of Aquatic Resources, 1151 Punchbowl Street, Honolulu, HI 96813. Pers. commun., December 1981.

probability of lobsters surviving predation when they are released at the surface and descend to the bottom in the presence of potential predators, particularly large white ulua, and 4) if lobsters contained in a bag from which they can be released at the bottom are less vulnerable to predation than when they are released at the surface and fall to the bottom.

Procedures

Tests were conducted at Maro Reef, Pearl and Hermes Reef, and Midway (Table 1). The lobsters used in most of the tests had been trapped at either Necker Island, Gardner Pinnacles, or Maro Reef during lobster resource surveys which were concurrently being conducted. The trapped lobsters were held in the vessel's baitwell. Lobsters maintained under these conditions and fed cut fish remain in apparent good condition for several weeks. The animals were removed from the tank just before a test release. At Midway four tests were conducted with lobsters which had been hand captured in the immediate area shortly before testing. The smallest lobsters available were used. However, many of the animals, especially for the tests at Pearl and Hermes Reef, were considerably larger than the minimum legal retainable size. Three scuba-equipped observers carried a 16 mm movie camera and a 35 mm still camera.

At Maro Reef and Pearl and Hermes Reef, diving operations were conducted from the *Townsend Cromwell* while the ship was anchored. A standby diver-observer in an inflatable boat maintained position over the underwater observers. A system of hand signals was used by the divers to communicate with the surface observer who monitored the underwater operation through a lookbox or dive mask and relayed instructions to personnel on the vessel to lower the bag or release lobsters. The release bag consisted of a 1.85 × 1.85 m piece of loosely woven plastic mesh material with a grommet in the center. The line to lower the bag was tied to the grommet. The lobsters were placed on the material, and the four corners drawn up forming a bag and tied together with a slipknot using the line leading from the grommet which passed inside of the bag. A 2.3 kg lead weight was attached to the grommet and hung outside and below the bag. When the suspending line was jerked by a diver from a position 5-6 m above the bag (Fig. 2), it opened and released the lobsters. The combination of plastic mesh material, which did not trap air, and the weight permitted the bag to be lowered quickly. For some tests, the lobsters were dropped in batches from the deck of the vessel, similar to the manner in which they would be released from commercial fishing vessels. However, when animals were released in this way, they usually became so widely scattered as they descended, that it was difficult or impossible to observe and photograph subsequent events. If the bag was hung about half way to the bottom and opened by a diver from a position 5-6 m above it, the lobsters were not as widely dispersed, thus permitting far better control of the tests, and more opportunities to observe and photograph predator-prey interactions. Bottom releases using the bag were not actually on the bottom because the process of jerking the line to open the bag invariably resulted in the lobsters being released about 1 m above the bottom. A bag load consisted of 10-15 lobsters.

At Midway, tests were conducted from a small boat. Lobsters were carried in a net bag by one of the diver-observers and single animals were released in midwater while the two other divers observed.

Table 1.—Predation observations.

Date 1981	Local time	Dive no.	Depth (m)	Potential predators in the area: Ulua	Galapagos shark	Gray shark	Type of lobster release
Maro Reef							
7/29	1230	1	32	30-50	3		Free at surface
7/29	1345	2	32	25-40	4-5		Bag in midwater
7/30	0930	3	32	30-40	5		Bag, 5 feet from bottom
7/31	1015	4	30	15-20			Bag, 6 feet from bottom
Midway							
8/3	1330	1	15	2			Hand released from midwater
8/4	1000	2	17	2			Hand released from midwater
8/4	1030	3	17	2			Hand released from midwater
8/5	1400	4	15	1		5	Hand released from midwater
8/6	1430	5	12	2			Hand released from midwater
Pearl and Hermes Reef							
8/8	0915	1	18	75-100	3-5		Free at surface
8/8	0925	1	18	75-100	3-5		Bag in midwater
8/8	0935	1	18	75-100	3-5		Bag on bottom
8/8	1015	2	18	75-100	Several		Bag in midwater
8/8	1025	2	18	75-100	Several		Bag on bottom
8/8	1055	3	18	75-100	Several		Bag in midwater
8/8	1110	3	18	75-100	several		Bag on bottom
8/9	0900	4	18	75-100	Several		Bag in midwater
8/9	0915	4	18	75-100	Several		Bag on bottom
8/9	0955	5	18	75-100	Several		Bag in midwater
8/9	1005	5	18	75-100	Several		Bag on bottom

Results

Maro Reef

The tests were conducted on the western side of Maro Reef in an area characterized by numerous 5-11 m pinnacles rising from depths of 30-34 m. The ship was anchored between the shallower areas in about 30 m. On the evening before the first predation tests, a 37 kg white ulua was caught by trolling in a school of large ulua in this area. It had a spiny lobster (8.6 cm CL) in its stomach.

Dive 1

The cage was suspended about 6 m

Figure 2.—Lobsters being released close to the bottom.

below the surface, and the diver-observers maintained about the same depth. There were 30-50 ulua estimated at 14-36 kg milling about in the immediate vicinity of the divers, and three 1.2-2 m galapagos sharks were circling well outside. On this dive, as on all subsequent dives during the cruise, the ulua did not show any signs of fear of the divers. Frequently they would swim within a few inches of an observer, or even touch him as they passed. Such was not the behavior of galapagos sharks, particularly the smaller ones, which usually stayed well away from human activity. Most of the lobsters released during the experiments at Maro Reef were <7.8 cm CL. Three lots of five lobsters each were released at the surface. As on previous experiments (Gooding, footnote 1), the lobsters did not swim (tail-flip) toward the bottom as is characteristic of spiny lobsters, but descended limply with tail slightly curled and legs spread. The ulua milled about among the sinking lobsters, and followed them to the bottom. Of the 15 lobsters released, we saw only 1 eaten by a fish. The lobster was taken in midwater and eaten tail first. Because of the wide scatter of the falling lobsters and reduced visibility due to turbid water during the dive, we were not able to make satisfactory observations in midwater nor were we able to see what became of the lobsters when they reached bottom.

Dive 2

Observations were made from the bottom. Water clarity had improved and because of the reflection from the sandy substrate, light conditions were better than in midwater. The bag containing 15 lobsters was opened about 5 m from the bottom. About 30 large uluas surrounded the bag as it was lowered from the ship. When the bag was opened, the fish immediately swam among the falling lobsters and nosed the lobsters as they were descending. No lobsters were eaten in midwater. About 8-10 lobsters landed in a group on the sandy bottom and quickly formed a close circular phalanx with their heads and antennae facing out, similar to the pod formations described by Kanciruk and Herrnkind (1978), but on a smaller scale. The remaining lobsters landed singly and assumed a more or less upright defensive posture, folded the tail beneath them, and moved the antennae in all directions (Fig. 3). The bottom was coral rubble or sand and afforded no shelter in the immediate vicinity. The lobsters did not attempt to leave the area. During the 10 minutes of bottom time which remained for the observers, the ulua showed relatively mild interest toward the lobsters. When a fish came close, the lobsters that landed singly would rear up and extend their antennae in the typical defense posture, always keeping their tails curled tightly in a protected position. Those forming a phalanx offered what appeared to be an effective defense, their vulnerable tails protected from attack. During the time available for observation, no lobsters were taken by the fish.

Dive 3

The next morning when about 30-40 large ulua were present, the bag containing fifteen <7.8 cm CL lobsters was opened about 1.5 m from the bottom. The fish showed strong interest in the bag as it was lowered, and when the lobsters were released, the fish immediately swam among them. When the lobsters reached the bottom, groups of two to three lobsters formed several small defensive groups and several single animals took on the characteristic defensive posture and behavior. The fish showed much more interest in the lobsters than on the previous test. Individual lobsters and members of a group were frequently flicked around or nosed by the fish. Several times we took lobsters from the bottom and re-released them by hand about 6 m from the bottom. Several ulua would immediately follow the falling lobsters; however, no lobsters in mid-water were ingested by the fish. After about 15 minutes and just before the observers had to ascend, two lobsters on the bottom were eaten in rapid succession by two different fish. This was the first time we were able to clearly observe predation and the associated behavior. It became clear that the frequent nosing and flicking about of the lobsters were attempts by the fish to place the lobster in a position where it could either be grabbed sideways and afterwards mouthed into a tail-first position and swallowed, or initially taken tail first and swallowed whole (Fig. 4). After being swallowed, the lobsters' antennae remained protruding from the two fishes' mouths for some time.

Dive 4

The next morning, the ship was anchored in the same general area and 15 bagged lobsters were released 1.5 m from the bottom at a depth of 32 m near 15-20 medium-sized (14-18 kg) ulua. The lobsters, singly or in groups, displayed the characteristic defensive behavior. The ulua showed considerable interest in the lobsters. The flicking and nosing action was successful in breaking up two small groups of lobsters; however, during the time we were able to remain on the bottom, no lobsters were eaten or taken into a fish's mouth.

Midway

The tests were conducted from a small boat outside the barrier reef to the south of Sand Island in water 12-18 m deep. The procedure was for one diver-observer to hand-release a single lobster at a time in the presence of the potential predators. There were never more than two ulua present at once during the tests.

Dive 1

Two 18-28 kg ulua were in the area. The two lobsters which were released had been hand-caught a short time before in the same area. The first (about 8.0 cm CL) was released about 9 m from the bottom. It flipped its tail rapidly moving towards the bottom, pursued by both fish, and was caught sideways and swallowed tail first, just before it reached the bottom. Shortly afterward, a second lobster (about 6.0 cm CL) was released 6 m from the bottom. Just as it reached bottom, the same fish caught it and swallowed it tail first. The ulua continued to swim around in the area with two antennae protruding from its mouth until the observers surfaced.

Dive 2

Two 18-28 kg ulua started circling as soon as we entered the water. One observer carried two lobsters (7.5-8.0

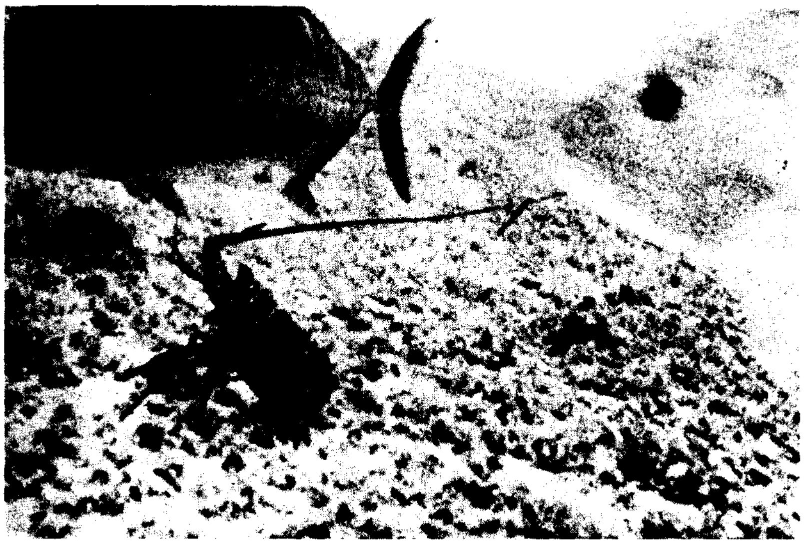

Figure 3.—Lobster in defensive posture.

Figure 4.—An ulua swallowing a lobster tail first.

Figure 5.—An ulua attacking a lobster which has just landed on the bottom and has been unable to assume a defensive posture.

cm CL) which had been held in the *Townsend Cromwell's* baitwell. The first lobster was released about 8 m from the bottom. It started falling limply and was eaten tail first by one of the fish. When the other lobster was removed from the bag, the same ulua rapidly swam over, took the lobster from the diver's hand, and swallowed it.

Dive 3

In the same area as the previous dive and about 30 minutes later, the ulua that had taken the lobster from the diver's hand was still present. The antennae that had been protruding from its mouth were no longer visible. The other fish was not in sight. A lobster (about 8.5 cm CL), caught in the area a short time before, was released 8 m from the bottom and started a rapid tail-flip descent for the bottom. The fish took the lobster tail first and ate it. The swallowing process was noticeably slower with this lobster, the third eaten by the same fish within 45 minutes. When a fourth lobster of about the same size was released a few minutes later, the ulua, with the antennae of the previously eaten lobster still protruding from its mouth, followed the rapidly swimming lobster to the bottom, gave it a nudge, swam away, and showed no more interest. Apparently, three lobsters were all it could handle within that period.

Dive 4

A test was run the following day in the same general area 15 m deep where five gray reef sharks and one 18-23 kg ulua were present. A slightly undersized lobster which had been held in the ship's baitwell was released about 6 m above the bottom, then retrieved and re-released five times. The lobster elicited very little interest from the ulua or the sharks on any of these descents. The sharks left the area after a few minutes.

Dive 5

Shortly afterward, two ulua (of about 18 kg) were located in 12 m of water several hundred meters away. A 7-8 cm lobster which had been held in the *Cromwell*'s baitwell was released about 6 m from the bottom. Both fish attacked the lobster as it fell. One fish mouthed it several times, each time getting it sideways. The other fish, on a single pass, swallowed it tail first. During the following 15 minutes, more 7-8 cm CL lobsters were individually released in midwater about a dozen times. The same two ulua continued to show interest, following the lobsters to the bottom each time, but no more lobsters were eaten. Afterward, a speared wrasse, *Thalassoma* sp., about 20 cm long was released. Both fish pursued it and one ate it.

Pearl and Hermes Reef

The *Cromwell* was anchored in 19 m of water southwest of the small boat channel during the experiments. Conditions were excellent: The sea was calm, and water clarity was good.

Dive 1

An estimated 75-100 ulua, 11-45 kg, were present. The fish were bold and curious, and started milling around the divers as soon as they entered the water. There were also several galapagos sharks in the area, but they stayed well outside the center of activity, and usually were too far away to be visible.

Three tests were run during the dive. Ten lobsters each were released 1) from the ship at the surface, 2) from the bag in midwater about 8 m from the bottom, and 3) from the bag close to the bottom. On these tests and all subsequent tests, nearly all the lobsters released were >7.7 cm CL, ranging up to about 9.0 cm, the largest we had used thus far. The fish voraciously attacked and ate the lobsters as soon as they were released by all three of the release techniques. Of those animals that were released at the surface and in midwater, many were taken before they reached bottom. Those that reached bottom would immediately be surrounded by many fish trying to take a lobster. Occasionally, a fish would not be able to swallow a lobster and would spit it out, at which time many other fish would vie for it. There was often a clearly audible crunch when an animal was taken sideways. The ulua followed the bag down to the bottom, and many fish were immediately in among the lobsters as they were released. Most of the lobsters were taken before they could group into a defensive circle (Fig. 5). Those animals that survived the initial attack were immediately surrounded by a group of fish, and within a few seconds were eaten. None of the 30 lobsters survived for more than a few minutes after release.

Dives 2 and 3

Four more releases of 10 lobsters each in midwater and two near the bottom were made during two dives in the following 1.5 hours. The feeding activity of the school was undiminished throughout the tests and none of the released lobsters survived.

Dive 4

The tests were conducted in about the same area as on the previous day and probably with the same school of 75-100 ulua. There were also several galapagos sharks and gray sharks in the outlying area.

On the first test, when ten 8-9 cm CL lobsters were released from the bag about 10 m from the bottom, dozens of fish were around the bag as it opened. The lobsters were eaten so fast that it was difficult to see or film the action. All the lobsters were gone within 10 seconds and none reached the bottom. Shortly afterward another batch was released at the bottom. Again dozens of fish crowded around, and all 10 lobsters were gone within seconds of release. For the first time we saw a large ulua take a lobster head first into its mouth (Fig. 6). This fish swam around for several minutes with the tail protruding from its mouth, apparently unable to swallow it.

Dive 5

This was a repeat of the previous tests. Ten lobsters each were released 6 m from the bottom, and on the bottom. Most of those released in midwater were eaten before reaching bottom, but the four animals that reached bottom assumed the characteristic defensive posture and survived a little longer than on previous tests with this school of fish. Although many fish continuously circled each lobster, the last one was not eaten until several minutes later. On the following test, the last individual of a batch of 10 lobsters released on the bottom managed to survive for about 5 minutes, and our impression was that the rate of serious attempts by the ulua to capture lobster had decreased noticeably. On these last tests, it was evident that in this school only the larger fish were eating or mouthing the lobsters. It was, however, difficult to estimate accurately the size of the smallest fish which was able to ingest lobster of the size we were releasing, but our rough guess was about 16 kg.

Figure 6.—A rare instance of an ulua attempting to swallow a lobster head first.

Sharks

During the tests at Maro Reef and Pearl and Hermes Reef, there usually were relatively small galapagos sharks (<2 m) in the vicinity. They always stayed well away and showed no inclination to approach released lobsters. While anchored off Necker Island one afternoon, we chummed with cut fish, and soon had several galapagos sharks ranging up to 2 m long around the vessel. While chumming continued, live lobsters tied to a light line were hung in the water among the chum. Sharks often came up to the lobsters with open mouth and turned just before reaching the lobster, or sometimes nosed it. The same thing was tried with lobster tails and heads, with the same results. However, in one test when the exoskeleton was removed from a tail and only the muscle was hung in the water, a shark took it immediately and swallowed it. The tests with a live lobster and complete tail were repeated while pouring fish blood into the water. The sharks went into a frenzy of feeding excitement, continuously nudging the lobster bait without taking them. Once the exoskeleton of a tail, from which the muscle had been removed, was taken into a shark's mouth for a moment and spat out. When fish (*Bodianus* sp.) were hung on a line, the shark bit them off and ate them without hesitation.

We did not have the opportunity to conduct experiments with *G. cuvier*, which are known lobster predators. Parrish et al. (1980) found that 11.1 percent of the tiger shark guts they examined contained remains of *P. marginatus*.

Discussion and Conclusions

Based on our experience, the presence of divers did not influence the feeding behavior of ulua toward spiny lobsters. However, galapagos sharks probably were affected. Usually galapagos sharks will swim very close to a vessel and show no hesitancy to approach anything resembling food that is tossed or hung in the water. During the diving observations in this study, galapagos sharks stayed well away. It seems probable that the behavior of the sharks during the tests was influenced by diver activity. Had no divers been present, the sharks might have come closer to the release bag or to the released lobsters. Thus the tests with diver-observers present may not have provided reliable data on whether galapagos sharks are potential predators on released lobsters. However, other evidence indicates that apparently this species is not a predator on spiny lobsters. De Crosta et al. (1984) did not find any lobster remains in the gut contents of the 65 galapagos sharks they examined, and our attempts to induce large galapagos sharks to ingest live lobsters or parts of lobsters, except peeled tail muscle, were unsuccessful.

Tests were conducted with large schools of large, white ulua at Maro Reef and at Pearl and Hermes Reef, and with pairs and individuals at Midway. There was considerable variation in the intensity of feeding by ulua on lobsters. The 14-45 kg fish at Pearl and Hermes Reef were voracious predators on lobsters, most of which were considerably larger than animals which would be released by commercial fishermen. At Maro Reef, large schools of ulua averaging 14-38 kg showed less interest when tested with smaller lobsters that should be more easily ingested. At Midway, pairs and single fish averaging about 25 kg, fed avidly on actively swimming lobsters up to about 8.5 cm CL.

In addition to state of satiation, a fish school's potential for lobster consumption presumably is related to fish size and size of school as well as lobster size. Other factors might include behavior of the lobsters and the behavioral elements that induce excitation of the fish.

The nature of the bottom over which lobsters are released could significantly influence the degree of predator success. However, the ability of animals to protect themselves on reaching bottom is not only contingent on availability of adequate shelter, but also on the lobsters' physical condition. Impairment to walking legs or antennae, or to an animal's physiological state would be detrimental to locomotion, or ability to adjust rapidly to the different environment.

Our observations were mostly made over bottoms which afforded little shelter. The test lobsters were apparently in good condition. However, except for those animals at Midway which were released shortly after capture, the test lobsters had been held in tanks for periods up to 2 weeks. The recently caught lobsters usually tail flipped to the bottom when released in midwater, whereas animals that had been held in captivity for some time always drifted limply to the bottom.

Brown and Caputi (1983) noted that *P. cygnus,* which had been exposed to air in direct sunlight for more than 30 minutes, drifted to the bottom with legs spread-eagle and tail either curled or extended on being returned to the water. Our test lobsters had not experienced such extreme exposure, but nevertheless, this markedly different behavior may indicate that lobsters which have experienced prolonged captivity are handicapped by an inability to adjust rapidly to a sudden reintroduction into their natural environment. Such animals may have a survival disadvantage compared with lobsters which are released shortly after capture. However, tests at Midway with recently caught lobsters that swam rapidly towards the bottom showed that they were also very vulnerable to ulua predation.

Clearly, white ulua are very effective predators on released lobsters. In the NWHI, a large school of feeding fish probably has the potential to consume a large percentage of the lobsters released freely at the surface from a commercial fishing vessel.

One way to safeguard most lobsters might be to release the animals from a bag near the bottom when there is reasonable assurance that white ulua are not in the vicinity and the substrate affords shelter. Since depths on the NWHI banks are too great to visually check the bottom type, such releases should be over known lobster fishing grounds. If the day's catch of lobsters below the legal minimum size were held in circulating tanks, handled with reasonable care, and a suitable time and place when ulua were not in the vicinity was chosen, this procedure should be effective. If followed, it is unlikely that predation from ulua during trap fishing would be detrimental to lobster populations on the NWHI grounds.

However, such a procedure may not be very practical. It is questionable that fishermen, after a long, hard day of hauling traps would be willing to devote the time and effort necessary to protect the released lobsters effectively. In addition, predation is probably not the principal hazard lobsters are exposed to when they are captured and released in the NWHI fishery. A recently completed study of fishery induced mortality in undersized rock lobster, *P. cygnus*, in the Western Australian fishery (Anonymous, 1979, 1981; Brown and Caputi, 1983) showed that there was a mortality of 15 percent of all undersized lobsters if they were transported more than 100 m away from their home reefs. The Australian work and that of Davis (1981) working with *P. argus*, showed that the more frequently lobsters were handled, the more damage they suffered, i.e., loss of appendages, exposure, etc. Physical damage increased mortality or decreased growth rate which prolongs the undersized period, and increases the toll of natural mortality in the population before the lobsters are recruited into the fishery at legal size. Brown[4] found that for average damage (1.5 appendages lost) and average exposure to the air (8 minutes) the mortality for undersized

[4]Rhys S. Brown, Western Australian Marine Research Laboratories, Perth, Australia. Pers. commun., August 1982.

P. cygnus was approximately 15 percent. If these results can be extrapolated to the NWHI *P. marginatus* fishery, the inevitable handling which trapped and released lobsters undergo may eventually result in far greater mortality from displacement, physical damage, and exposure than the threat posed by white ulua predation.

The problem begins when undersized and berried animals are captured in the traps. In the Western Australia *P. cygnus* fishery, unobstructed escape gaps are required in all traps (Bowen, 1971). They found that with the currently required 5.4 × 30.5 cm escape gap, about 80% of all undersized lobsters (< 7.6 cm CL) escape. Recent research indicates that if the gap widths were increased to 5.5 cm, escapement would increase. Their data show that with escape gaps the catch of legal-sized lobsters is not reduced (footnote 4).

A recent study with *P. marginatus* (Paul, 1984) essentially corroborates the Australian experience on the efficacy of escape gaps. Working with three types of gaps (all 6 cm wide), Paul found the overall average escapement of lobsters < 8.1 cm CL was about 60 percent.

In the NWHI lobster fishery, if the numbers of undersized lobsters landed on fishing vessels were significantly reduced by requiring that traps be provided with escape gaps of specified dimensions, the potential mortality from exposure and handling as well as predation might be so reduced that no measures to directly protect lobsters from predation would be needed.

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Literature Cited

Anonymous. 1979. The fate of undersized rock lobsters returned to the sea. Fish. Ind. News Serv. 12(3):10-12.

________. 1981. Handling techniques costing W. A. rock lobster fishermen about $3.2 million a year. Fish. Ind. News Serv. 14(2):3-5.

Bowen, B. K. 1971. Management of the western rock lobster (*Panulirus longpipes cygnus* George). Proc. Indo-Pac. Fish. Counc. 14(Sect. 2):139-153.

Brown, R. S., and N. Caputi. 1983. Factors affecting the recapture of undersize western rock lobster *Panulirus cygnus* George returned by fishermen to the sea. Fish. Res. 2:103-128.

Davis, G. E. 1981. Effects of injuries on spiny lobster, *Panulirus argus*, and implications for fishery management. Fish. Bull., U.S. 78:979-984.

De Crosta, M. H., L. R. Taylor, Jr., and J. D. Parrish. 1984. Age determination, growth, and energetics of three species of carcharhinid sharks in Hawaii. *In* R. W. Grigg and K. Y. Tanoue (editors), Proc. Second Symp. Resour. Invest. Northw. Hawaiian Islands, Vol. 2, May 25-27, 1983, p. 75-95. Univ. Hawaii, Honolulu, UNIHI-SEAGRANT-MR-84-01.

Hobson, E. S. 1980. The structure of reef fish communities in the Hawaiian Archipelago: Interim status report. *In* R. W. Grigg and R. T. Pfund (editors), Proc. Symp. Status Resour. Invest. Northw. Hawaiian Islands, April 24-25, 1980, p. 57-70. Univ. Hawaii, Honolulu, UNIHI-SEAGRANT-MR-80-04.

Kanciruk, P., and W. Herrnkind. 1978. Mass migration of spiny lobster, *Panulirus argus* (Crustacea: Palinuridae): Behavior and environmental correlates. Bull. Mar. Sci. 28:601-623.

Lyons, W. G., and F. S. Kennedy, Jr. 1981. Effects of harvest techniques on sublegal spiny lobsters and on subsequent fishery yield. Proc. Gulf Caribb. Fish. Inst. 33:290-300.

Meyer-Rochow, V. B. 1975. Larval and adult eye of the western rock lobster (*Panulirus longipes*). Cell. Tissue Res. 162:439-457.

________, and K. M. Tiang. 1981. Seeing lobsters are correctly treated. Catch '81, April: 17-21. New Zealand.

Okamoto, H., and P. Kawamoto. 1980. Progress report on the nearshore fishery resource assessment of the Northwestern Hawaiian Islands: 1977 to 1979. *In* R. W. Grigg and R. T. Pfund (editors), Proc. Symp. Status Resour. Invest. Northw. Hawaiian Islands, April 24-25, 1980, p. 121-130. Univ. Hawaii, Honolulu, UNIHI-SEAGRANT-MR-80-04.

Parrish, J., L. Taylor, M. DeCrosta, S. Feldkamp, L. Sanderson, and C. Sorden. 1980. Trophic studies of shallow-water fish communities in the Northwestern Hawaiian Islands. *In* R. W. Grigg and R. T. Pfund (editors), Proc. Symp. Status Resour. Invest. Northw. Hawaiian Islands, April 24-25, 1980, p. 175-188. Univ. Hawaii, Honolulu, UNIHI-SEAGRANT-MR-80-04.

Paul, L. M. B. 1984. Investigations into escape vent effectiveness and ghost fishing in captive populations of the spiny lobster, *Panulirus marginatus*. *In* R. W. Grigg and K. Y. Tanoue (editors), Proc. Second Symp. Resour. Invest. Northw. Hawaiian Islands, Vol. 2, May 25-27, 1983, p. 283-295. Univ. Hawaii, Honolulu, UNIHI-SEAGRANT-MR-84-01.

Seki, M. P. 1984. The food and feeding habits of the grouper, *Epinephelus quernus* Seale 1901, in the Northwestern Hawaiian Islands. *In* R. W. Grigg and K. Y. Tanoue (editors), Proc. Second Symp. Resour. Invest. Northw. Hawaiian Islands, Vol. 2, May 25-27, 1983, p. 179-191. UNIHI-SEAGRANT-MR-84-01.

Uchida, R. N., J. H. Uchiyama, R. L. Humphreys, Jr., and D. T. Tagami. 1980. Biology, distribution, and estimates of apparent abundance of the spiny lobster, *Panulirus marginatus* (Quoy and Gaimard), in waters of the Northwestern Hawaiian Islands: Part I. Distribution in relation to depth and geographical areas and estimates of apparent abundance. *In* R. W. Grigg and R. T. Pfund (editors), Proc. Symp. Resour. Invest. Northw. Hawaiian Islands, April 24-25, 1980, p. 121-130. Univ. Hawaii, Honolulu, UNIHI-SEAGRANT-MR-80-04.