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# PREDATION ON SURFACE AND BOTTOM RELEASED SPINY LOBSTER, *PANULIRUS MARGINATUS*, IN THE NORTHWESTERN HAWAIIAN ISLANDS

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# INTRODUCTION

During the period 1976-81 biologists of the Insular Ecosystem Study Task of the Southwest Fisheries Center, Honolulu Laboratory, have been engaged in an extensive survey of the fishery resources of the Northwestern Hawaiian Islands (NWHI). During the early exploratory phase of the survey substantial populations of spiny lobster, *Panulirus marginatus*, were discovered on several of the NWHI banks. Shortly thereafter this resource became the target of a Honolulu-based trap fishery which has since experienced a more or less steady growth.

Recent research has been directed towards the accumulation of a fund of knowledge which will enable the 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 will be the basis of a Fishery Management Plan (FMP) for the lobster fishery. The draft FMP prohibits the retention of egg-bearing (berried) lobsters and those less than a specified minimum size. The regulations based on the draft FMP will require that such illegal lobsters caught in the U.S. Fishery Conservation Zone (FCZ) around the NWHI be sorted from the catch, and released alive.

On lobster fishing vessels in the NWHI it is the usual procedure, as the traps are being retrieved, to sort the undersized and berried lobsters from the catch and throw them overboard. Concurrently, the old bait is removed from the traps and also discarded. However, no estimates of the number of lobsters which are caught and released by commercial fishermen in the presently unregulated fishery are available. On grounds that are being intensively fished, such as those surrounding Necker Island and Maro Reef in the NWHI, it is quite likely that many animals are trapped and released more than once.

What happens to lobsters after they have been released may be of considerable significance to the long-term productivity of the lobster fishery. Thus it is of some importance that we have an understanding of the factors which may have an effect on an animal's ability not only to survive, but also to grow and reproduce normally after it has been trapped and returned to the sea. With such an understanding it can be determined if regulations governing the way berried and undersized lobsters are treated by commercial fishermen should be included in the FMP.

Lobsters caught in traps and subsequently released are subject to factors which may cause stress, injury, or mortality. These broadly include: length of time out of the water; handling; exposure to air, sunlight, and heat; release on an unsuitable substrate; release in an area outside its home territory; general disorientation which may make the animal more vulnerable to predation; and release when lobster predators are actually around the vessel. An Australian study of fishery related mortality in undersized and berried western rock lobster, *P. cygnus*, shows that poor handling of lobsters prior to release causes high lobster mortality (Anonymous 1979, 1981; Rhys S. Brown, Western Australian Marine Research Laboratories, Perth, pers. commun., December 1981).

Gooding[1] reported on observations made on surface released spiny lobsters and potential predators during *Townsend Cromwell* cruise 79-02 near

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

Necker and Nihoa Islands in the NWHI chain. The objective of that preliminary study was to determine what fish may be potential predators on surface released lobsters. Based on a number of previously made casual observations of apparent predation on lobsters by white ulua, Caranx ignobilis, and galapagos shark, Carcharhinus galapagensis, which had been reported by fishermen and scientists on fishing vessels and on the Townsend Cromwell on earlier cruises, those two species were of particular interest to us.

On Townsend Cromwell 79-02 experiments were conducted in the presence of small schools of omilu, Caranx melampygus, two white ulua, galapagos shark, reef whitetip shark, Triaenodon obesus, and gray reef shark, Carcharhinus amblyrhynchos. There were no opportunities to run experiments in the presence of uluas either singly or in schools. With the exception of a galapagos shark, which was observed to briefly mouth a lobster in midwater before spitting it out. None of the fishes seen during that cruise showed any inclination to prey on lobsters. Parrish et al. (1980), in their trophic study of fish communities in the NWHI, found that 3.6% of the white uluas they examined had P. marginatus and 1.8% had P. penicillatus remains in their guts. Hawaii Division of Aquatic Resources (HDAR) biologists also reported lobster remains in ulua guts (Okamoto and Kawamoto 1980). While making fish surveys at Pearl and Hermes Reef they have also seen lobster antennae protruding from the mouths of white uluas, and white uluas preying on spiny lobsters which had fled from shelter when disturbed by the divers (Henry Okamoto, HDAR, Honolulu, pers. commun., December 1981).

This report describes experiments conducted during Townsend Cromwell cruise 81-04 (17 July-27 August 1981). The cruise plans called for fishing operations throughout the length of the NWHI chain which gave us the opportunity to look for suitable experimental situations while fishing in a variety of locations. The objectives of the experiments were essentially to supplement the rather spotty data collected on previous cruises. We particularly wanted to (1) work with large schools of large white uluas to determine under what conditions they preyed on lobsters, (2) determine what other fishes are potential predators on released lobsters, (3) determine the 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 uluas, (4) determine 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 allowed to descend through the water column.

## Procedure

Experiments were conducted at Maro Reef, Midway Islands, and Pearl and Hermes Reef (Table 1). At Maro Reef and Pearl and Hermes Reef diving operations were conducted from the Townsend Cromwell while the ship was anchored. Procedures in general were similar to those followed during cruise 79-02.

A cage to protect the observers from sharks was suspended from the vessel's boom, either hanging in midwater or resting on the bottom. If sharks were a threat, the diver-observers stayed in the general vicinity of the cage. During this cruise shark behavior did not necessitate the use of the cage. The two or three underwater observers carried a 16-mm movie camera and a Nikonos 35-mm camera. A standby diver-observer in a Zodiac maintained position over the underwater observers. A system of hand

Table 1.--Predation observations.

| Date 1981 | Dive No. | Depth (ft) | Potential predators in the area | Type of lobster release |
|---|---|---|---|---|
| Maro Reef | | | | |
| 7/29 | 1 | 105 | 30-50 uluas, 3 galapagos sharks | Free at surface |
| 7/29 | 2 | 105 | 25-40 uluas, 4-5 galapagos sharks | Midwater from bag |
| 7/30 | 3 | 105 | 30-40 uluas, 5 galapagos sharks | 5 ft from bottom, bag |
| 7/31 | 4 | 100 | 15-20 uluas | 6 ft from bottom, bag |
| Midway | | | | |
| 8/3 | 1 | 50 | 2 uluas | One at a time |
| 8/4 | 2 | 55 | 2 uluas | Do. |
| 8/4 | 3 | 55 | 2 uluas | Do. |
| 8/5 | 4 | 50 | 1 uluas, 5 gray sharks | Do. |
| 8/6 | 5 | 40 | 2 uluas | |
| Pearl and Hermes Reef | | | | |
| 8/8 | 1 | 60 | 75-100 uluas, 3-5 galapagos sharks | Free at surface |
| 8/8 | 1 | 60 | 75-100 uluas, 3-5 galapagos sharks | Midwater from bag |
| 8/8 | 1 | 60 | 75-100 uluas, 3-5 galapagos sharks | Bottom from bag |
| 8/8 | 2 | 60 | 75-100 uluas, several galapagos sharks | Bag in midwater |
| 8/8 | 2 | 60 | 75-100 uluas, several galapagos sharks | Bag on bottom |
| 8/8 | 3 | 60 | 75-100 uluas, several galapagos sharks | Bag in midwater |
| 8/8 | 3 | 60 | 75-100 uluas, several galapagos sharks | Bag on bottom |
| 8/9 | 4 | 60 | 75-100 uluas, several galapagos sharks | Bag in midwater |
| 8/9 | 4 | 60 | 75-100 uluas, several galapagos sharks | Bag on bottom |
| 8/9 | 5 | 60 | 75-100 uluas, several galapagos sharks | Bag in midwater |
| 8/9 | 5 | 60 | 75-100 uluas, several galapagos sharks | Bag on bottom |

signals was used by the divers to communicate with the observer in the Zodiac, who monitored the underwater operation through a look-box or dive mask, and relayed messages to personnel on the vessel, e.g., when to release lobsters, lower the bag, or raise the cage. The release bag consisted of a 1.85 m x 1.85 m (6 ft x 6 ft) piece of Saran material with a grommet in the center. The line to lower the bag was tied to the grommet. In practice, the lobsters were placed on the material, and the four corners drawn up into 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 (5-lb) lead weight was attached to the grommet and hung outside and below the bag. When the suspending line was jerked the bag opened to release the lobsters. The combination of loosely woven Saran material, which did not trap air, and the weight permitted the bag to be lowered quickly. We had originally intended to signal the surface observer to open the bag but found that once it had been lowered from the vessel to the required position either in midwater or at the bottom, we had better control of the experiment if one of the divers jerked the line and opened the bag from a position 5-6 m (15-20 ft) above it. On some experiments to test the behavior of potential predators towards lobsters sinking through the water column, the lobsters were dropped in batches from the deck of the vessel, similar to the manner they are discarded from commercial fishing vessels. However, we found that when animals were released in this way, they usually became so widely scattered, as they descended, that it was difficult or sometimes impossible to observe and photograph subsequent events. If the bag was hung about half way to the bottom and opened by a diver, the lobsters were not as widely dispersed, thus permitting far better visual observations of predator-prey interactions, and more opportunities to take movies. 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. To simulate conditions on commercial vessels, which discard old trap bait concurrently as they release illegal lobsters, chum consisting of either chopped fish or whole anchovies was sometimes released from the bag along with the lobsters.

At Midway diving was conducted from a small boat. Lobsters were carried in a bag by one of the diver-observers and single animals were released in midwater while the two other divers observed. The lobsters used in all of the experiments, except a few at Midway, were trapped at either Necker, Gardner Pinnacles, or Maro Reef during the lobster surveys which concurrently were being conducted during the cruise. After removal from the traps they were put in the vessel's baitwell. We have found that lobsters maintained under these conditions and fed cut fish remain in apparent good condition for several weeks. They were removed from the tank just prior to release during an experiment. During some of the experiments at Midway lobsters were used which had been hand caught shortly before in the immediate area. We used the smallest lobsters available, however, many of the animals, especially during the work at Pearl and Hermes Reef, were considerably larger than the minimum size (carapace length (CL) of 7.7 cm) specified by the latest draft of the FMP.

## Results

### Maro Reef

The experiments were conducted on the western side of Maro Reef, about 5 km (3 mi) southeast of the charted anchorage ground. The area is 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. This area was chosen because on the evening before the first predation experiments were conducted, a 37-kg white ulua was caught by trolling in this area. It had a spiny lobster (8.6 cm CL) in its stomach. The fish was part of a school of large uluas.

Dive 1.—The cage was suspended about 6 m (20 ft) below the surface, and the diver-observers stayed at about the same depth. There were 30-50 uluas ranging from 14 to 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 uluas did not manifest any signs of fear of the divers. Frequently they would swim within a few inches of or even touch, an observer, as they passed. Such was not the case with galapagos sharks, particularly the smaller ones, which usually stayed well away from human activity.

Because, earlier in the cruise, trapping at Necker had yielded a large percentage of undersized animals, most of the lobsters released during the experiments at Maro Reef had carapace lengths of less than 7.8 cm.

Three lots of five lobsters each were released at the surface along with cut fish chum. As on experiments conducted during Cromwell cruise 79-02, the lobsters did not swim (tail flip) towards the bottom as is often characteristic of spiny lobsters, but descended limply with tail slightly curled. The uluas milled about among the sinking lobsters, and followed them to the bottom. Of the 20 lobsters released we saw only one 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 unable to make satisfactory observations in midwater nor were we able to see what became of the lobsters when they reached bottom.

Dive 2.—The observers went to the bottom. Water clarity had improved and because of reflection from the sandy substrate, light conditions were better than in midwater. The bag containing 15 lobsters and cut fish chum was opened 5 m (15 ft) from the bottom. About 30 large, 18-36 kg (40-80 lb), uluas surrounded the bag as it was lowered from the ship. When the bag was opened the fish were immediately in amongst the falling lobsters and chum. The fish nosed the lobsters as they were descending and ate the small pieces of fish chum. 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. The remaining lobsters landed singly and assumed a more or less upright position, tail folded beneath them and antennae extended. 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 min of bottom time which remained for the observers, the uluas showed relatively mild interest towards 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 a very effective defense with 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 uluas were around, the bag containing 15 <7.8 CL lobsters was opened about 1.5 m from the bottom in the same area. The fish were quite curious about the bag as it was lowered, and when the lobsters were released the fish were immediately in amongst them. Several small defensive groups consisting of two to three lobsters formed, and several single animals took on the characteristic defensive posture and behavior. The fish showed a lot more interest in the lobsters than on the previous experiment. 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 (20 ft) from the bottom. Uluas would immediately come up and follow the falling lobsters, however, no lobsters in midwater were ingested by the fish. After about 15 min and just before the observers had to ascend, two lobsters were eaten in rapid succession by two different fish. This was the first time we were able to clearly observe ingestions 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 (1) grabbed sideways and afterwards mouthed in a tail first position and swallowed, or (2) initially take tail first and immediately swallowed whole. After being swallowed the lobsters antennae remained protruding from the two fish's mouths for some time.

Dive 4.—The next morning with the ship anchored in the same general area, we released 15 lobsters from the bag 1.5 m from the bottom at a depth of 32 m (100 ft) where 15-20 medium sized, 14-18 kg (30-40 lb) uluas were around. No galapagos sharks were visible. The lobsters displayed the characteristic defensive behavior in groups or singly. The uluas 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 Islands

All experiments were conducted from a small boat to the south of Sand Island, 1.5-2 nmi west of the channel entrance, in depths of 12-18 m (40-60 ft). The procedure simply was for one observer to hand release a single lobster at a time in the presence of the potential predators. We never had more than two uluas around during the experiments.

Dive 1.—Two 18-28 kg (40-60 lb) uluas 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 (30 ft) from the bottom. It descended rapidly towards the bottom pursued by both of the fish and was caught sideways and swallowed tail first, just before it reached bottom. Shortly afterwards a second lobster (about 6.0 cm CL) was released 6 m (20 ft) from the bottom. The same fish caught it just as it reached bottom 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 (40-60 lb) uluas started circling as soon as we entered the water. One observer carried two lobsters (7.5-8.0 cm CL) which had been held in the Cromwell's baitwell. The first lobster was released about 8 m (25 ft) 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 and took the lobster from the diver's hand, and swallowed it, slightly biting his hand in the process.

Dive 3.—In the same area as the previous dive about 30 min later, the ulua that had taken the lobster from the diver's hand was still around. 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) that had been caught in the area a short time before, when released 8 m (25 ft) from the bottom, 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 on this lobster, the third eaten within 45 min. When a fourth lobster of about the same size was released a few minutes later, the ulua, with the antennae of the lobster eaten earlier still protruding from its mouth, followed the rapidly swimming lobster to the bottom, gave it a nudge and swam away showing no more interest. Quite evidently three lobsters were all it could handle during that period.

Dive 4.—The following day in the same general area (15 m (50 ft) depth) with five gray sharks and one 18-23 kg (40-50 lb) ulua present, a slightly undersized lobster which had been held in the ship's baitwell, was released, then retrieved and re-released five times. Each time it fell to the bottom the lobster elicited very little interest from either the ulua or the sharks. The sharks left the area after a few minutes.

Dive 5.—Shortly afterwards, two uluas approximately 18 kg (40 lb) were located in 12 m (40 ft) of water several hundred yards to the west. A 7-8 cm lobster from the *Cromwell*'s baitwell was released 6 m (20 ft) from the bottom. Both fish attacked the lobster as it descended. 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 min 7-8 cm CL lobsters were individually released in midwater about a dozen times. The same two uluas continued to show interest, following the lobsters to the bottom each time but no more lobsters were eaten. Afterwards a speared fish about 20 cm (8 in.) long was released. Both fish pursued it and one ate it.

Pearl and Hermes Reef

The *Cromwell* was anchored southwest of the small boat channel in about 19 m (60 ft) during the experiments. Conditions were excellent with calm sea and good water clarity.

*Dive 1*.—There were an estimated 75-100 uluas, ranging in size from about 11 to 45 kg (25 to 100 lb). The fish were very 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.

During the dive three experiments were run. Ten lobsters each were released (1) from the ship at the surface, (2) from the bag in midwater about 8 m (25 ft) from the bottom, and (3) from the bag close to the bottom. On these experiments and all subsequent experiments nearly all the lobsters released were larger than 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 techniques. Of those animals that were released at the surface and in midwater, many were taken before they attained bottom. Those that reached bottom would immediately be surrounded by many fish endeavoring 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 very audible crunch when an animal was taken sideways. The uluas followed the bag down to the bottom, and many fish were immediately in amongst the lobsters as they were released. Most of the lobsters were taken before they could group into a defensive circle. Those animals that did survive the initial attack, immediately had a gang of fish surrounding them and within a few seconds were eaten. None of the 30 lobsters survived for more than a few minutes after release.

Dive 2 and 3.—Four releases of ten lobsters each, two in midwater and two near the bottom were made during two dives in the following 1.5 h. The feeding capacity of the school was undiminished throughout the experiments and none of the released lobsters survived.

Dive 4.—The experiments were conducted in approximately the same area as on the previous day and probably with the same school of 75-100 uluas. There were also several galapagos sharks and gray sharks in the outlying area.

On the first experiment, when ten 8-9 cm CL lobsters were released from the bag in midwater about 10 m (30 ft) 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 about 10 sec and none reached the bottom. Shortly afterwards 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. This fish swam around for several minutes with the tail protruding from its mouth, apparently unable to swallow it. When we returned about an hour later on dive No. 5, no protruding tail was observed.

Dive 5.—This was a repeat of the previous experiments. Ten each lobsters were released in midwater 6 m (20 ft) from the bottom, and on the bottom. Most of those released in midwater were eaten before reaching bottom, but the four animals that did get there assumed a defensive posture and lasted a little longer than on previous experiments with this school of fish. Although many fish continuously circled each lobster, the last one was not taken until several minutes later. On the following experiment the last individual of the batch of 10 released on the bottom managed to survive for about 5 min, and our impression was that the rate of serious attempts by the ulua to capture lobster had definitely decreased to a noticeable degree.

On those two experiments where slower action prevailed, it became more evident that in this school only the larger fish were eating or even mouthing lobsters of the size we were releasing. It was, however, difficult to estimate the size of the smallest fish which was able to ingest lobster of the size we were releasing. Our rough guess was about 16 kg (35 lb).

Figures 1-4 show uluas preying on lobsters at Pearl and Hermes Reef. Also during the experiments about 1,000 ft of 16-mm movies were taken at normal speed and in slow motion (48 and 64 frames/sec).

## Experiments With Galapagos Sharks

During the experiments at Maro Reef and Pearl and Hermes Reef there usually were relatively small galapagos sharks (<2 m) in the vicinity. They always stayed well outside the center of activities and never approached a lobster or showed any inclination to do so.

While anchored off Necker Island one afternoon we chummed with cut fish, and soon had several galapagos sharks ranging up to 2 m in length around the vessel. While chumming with fish, live lobsters tied to a light line were hung in the water amongst the chum. Sharks on numerous occasions 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, when the exoskeleton was removed from a tail and only the muscle was hanging in the water a shark took it immediately and swallowed it. The experiments 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 without taking them, except once, when 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.

Tiger shark, Galeocerdo cuvieri, are known lobster predators. Parrish et al. (1980) found that 15% of the tiger shark guts they examined contained remains of P. marginatus, however, no tiger sharks were present during our observations.

## DISCUSSION AND CONCLUSIONS

In any study wherein the natural environment is modified because of the presence of man, the question as to how experimental results are affected must be addressed. We do not think that the presence of divers, even in the immediate vicinity, had a significant effect on the feeding behavior of uluas relative to spiny lobsters. This was not so with galapagos sharks. Usually galapagos sharks will swim very close to a ship, and show no hesitancy to approach any potential foodlike items that are tossed or hung in the water. However, during the diving experiments on this cruise the galapagos sharks stayed well away, even when there presumably was some degree of olfactory stimulation produced by the fish-chum which was released with the lobsters during some of the experiments. It seems likely that the behavior of the relatively small sharks we saw during the experiments was influenced by diver activity, and had no divers been around, the sharks would have come in closer to the release bag and the area in which lobsters were released. However, although the experiments with diver-observers described herein may not have provided reliable data on whether galapagos sharks are predators on released lobsters, other evidence indicates that this species does not prey on spiny lobsters. Parrish et al. (1980) did not find any lobster remains in the gut contents of 42 galapagos sharks they examined, and during Townsend Cromwell cruises 79-02 and 81-04, attempts to induce large surface swimming galapagos sharks to ingest live lobsters or parts of lobsters, except tail muscle, were unsuccessful.

During this cruise we were able to work with large schools of large white uluas at Maro Reef and at Pearl and Hermes Reef, and with pairs and individuals at Midway. The fish at Pearl and Hermes ranging from 14 to 45 kg were very voracious predators on lobsters which were for the most part considerably larger than animals which would be discarded by commercial fishing vessels under the legal minimum prescribed in the draft FMP. Large schools of uluas which were, on the average, somewhat smaller (14-38 kg) at Maro Reef displayed far less interest in smaller lobsters that should presumably be more easily ingestible. At Midway pairs of fish and single fish in the 25 kg range fed avidly on lobsters of up to about 8.5 cm CL.

Our data are insufficient to permit any analysis of the variability of the feeding behavior of uluas on lobsters which was observed during the experiments. State of satiation must always be a factor, and the potential number of lobsters which can be consumed by a school must be related to fish size and to lobster size as well as size of school. Other factors might include: feeding frenzy of the fish and behavior of the lobsters.

Prior to this study we had hypothesized that the type of substrate over which lobsters were released could significantly affect predator success, as it would affect the ability of the lobster to protect itself and find shelter when it reached the bottom. The latter would be dependent on aspects of its physical condition such as walking leg and antennae condition, and ability to orient rapidly to the new environment. Our observations were mostly made over substrates which afforded little shelter in the immediate vicinity and with lobsters, excepting a few at Midway, that had been held in captivity for periods up to 2 weeks. The markedly different behavior of recently caught lobsters which tail flip to the bottom when released in midwater, as opposed to the behavior of animals held in captivity for some time which fall limply to the bottom, may indicate that lobsters which have experienced prolonged captivity are handicapped in their ability to adjust to a sudden reintroduction into their natural environment. Thus our experiments may have been conducted under conditions which placed the lobster in a less advantageous situation than if a commercial vessel held its undersized and berried animals for only a short time before releasing them. Despite the above-mentioned limitations of our experimental conditions, based on our observations of the ability of large uluas to effectively prey on lobsters, we do not think that lobsters released in the presence of ulua schools, even on a substrate which affords good shelter, can be effectively protected with a bottom release system or any other practical system. Probably the only practical way to safeguard lobsters is to release them from a bag at the bottom when there is reasonable assurance that the substrate offers shelter, and that uluas are not around the vessel. As water depths on the NWHI grounds are too great to make visual checks of the bottom type the release would best be made on known fishing grounds. Ulua schools are not so plentiful on the NWHI banks that, if a vessel has the capacity to hold all or part of the day's catch of illegals in a circulating water tank and the fishermen are willing to handle the lobsters with reasonable care and wait for a suitable time and place before releasing them, this should not be quite practical. Such a procedure will not protect every lobster from predation, but if it is followed we do not think that predation from uluas will be seriously detrimental to the lobster population in the NWHI fishery.

These observations have conclusively verified what had previously been suspected. White ulua do prey on lobsters which have been released at the surface from commercial fishing vessels in the NWHI, and a large school of hungry fish may have the ability to consume several hundred lobsters.

All available information indicates that galapagos sharks are not a significant threat to released lobsters.

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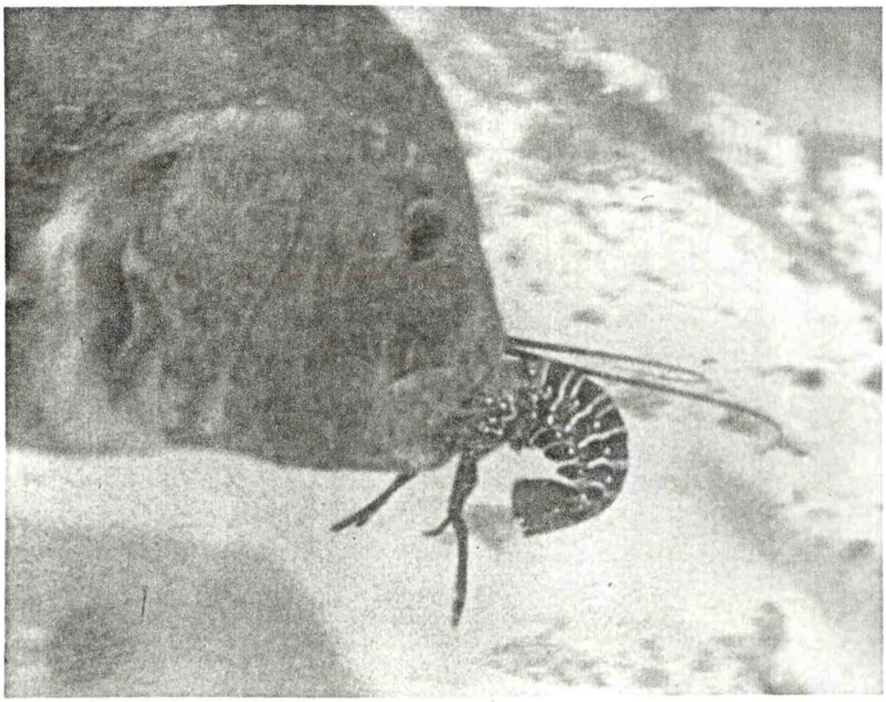

Figure 1.--A rare instance of an ulua attempting to swallow a lobster head first.

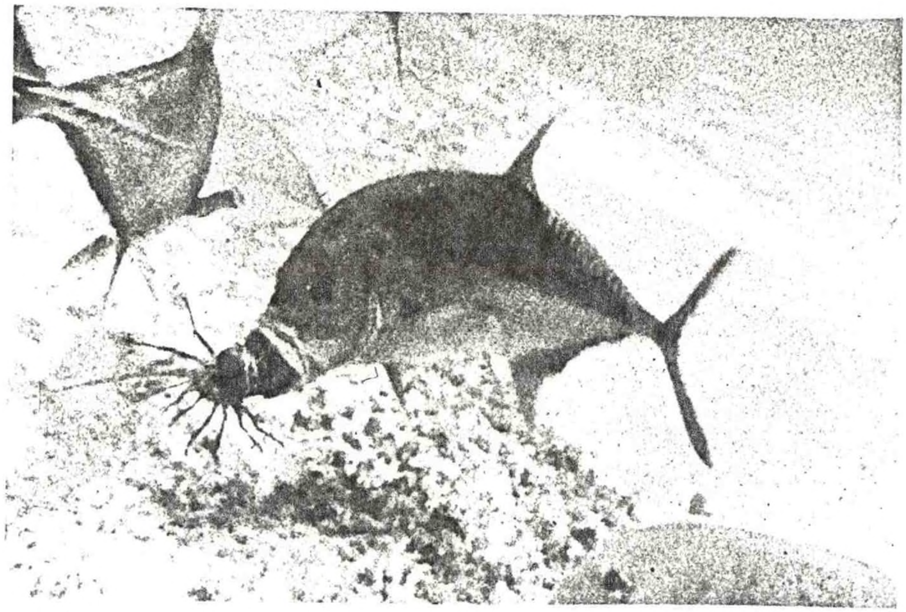

Figure 2.--An ulua swallowing a lobster tail first.

Figure 3.--Fish milling around lobsters on the bottom looking for an opportunity to attack.

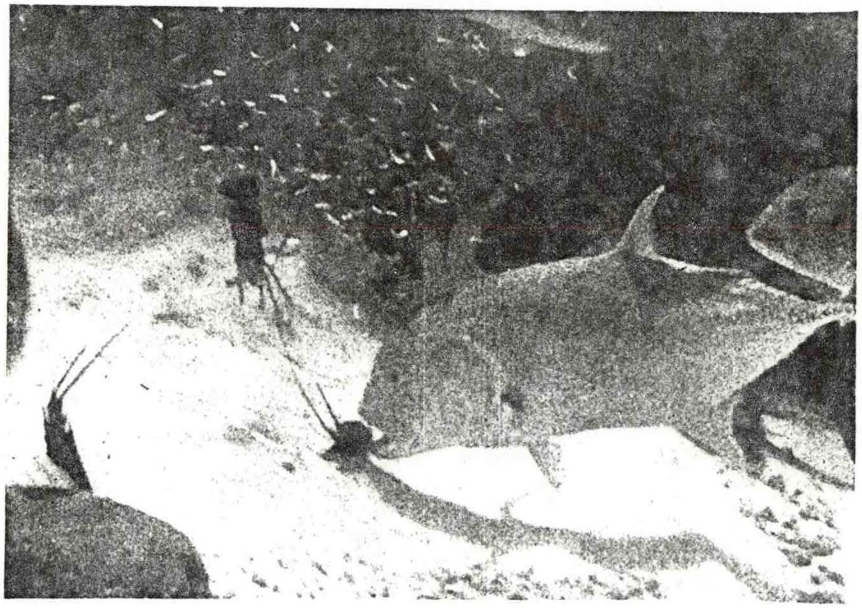

Figure 4.--Uluas attacking a lobster which has just landed on the bottom and has not been able to assume a defense posture.