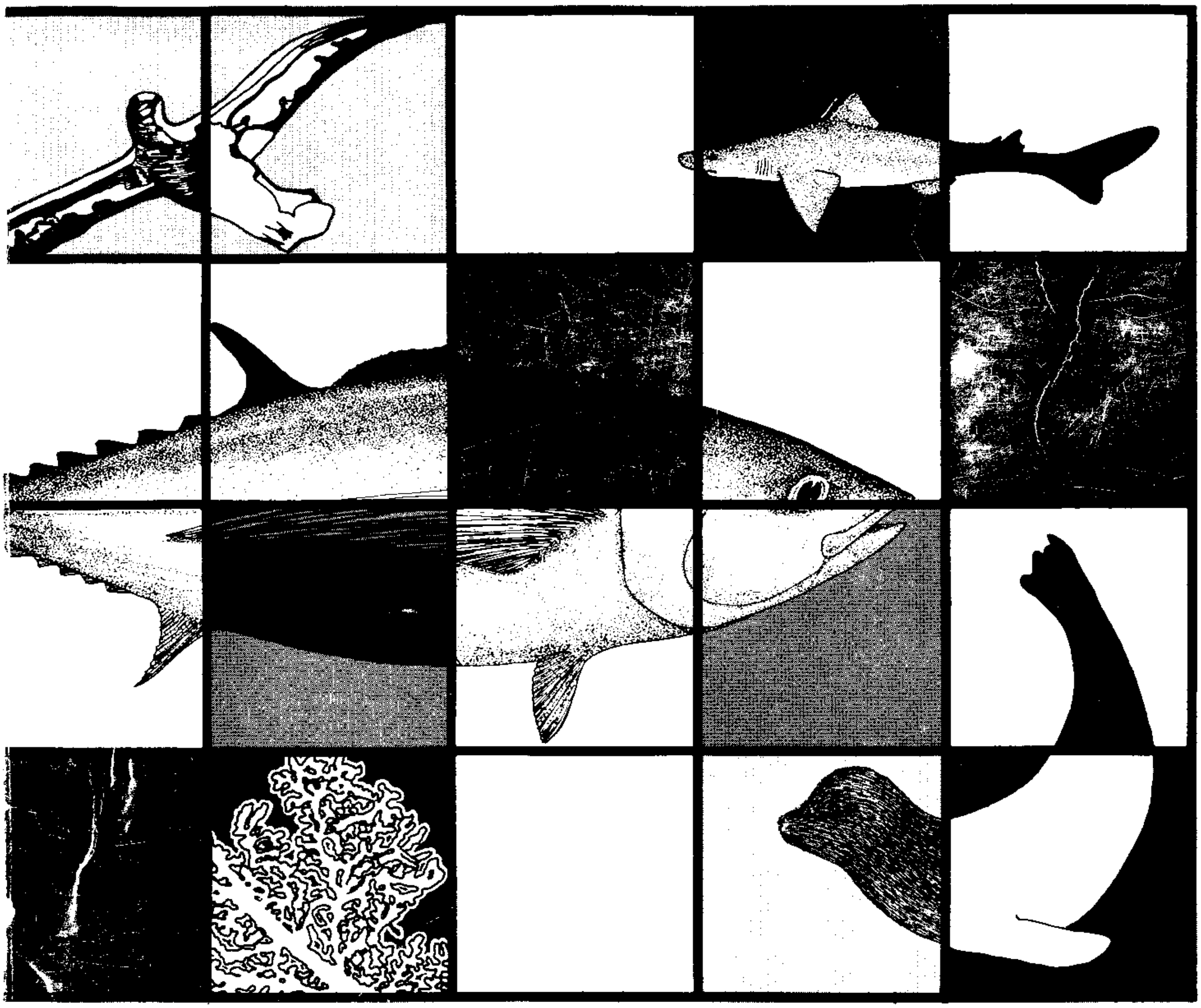
Proceedings of the Second Symposium on Resource Investigations in the Northwestern Hawaiian Islands

Volume 2

May 25-27, 1983



PROCEEDINGS OF THE SECOND SYMPOSIUM ON RESOURCE INVESTIGATIONS IN THE NORTHWESTERN HAWAIIAN ISLANDS

VOLUME 2

May 25-27, 1983
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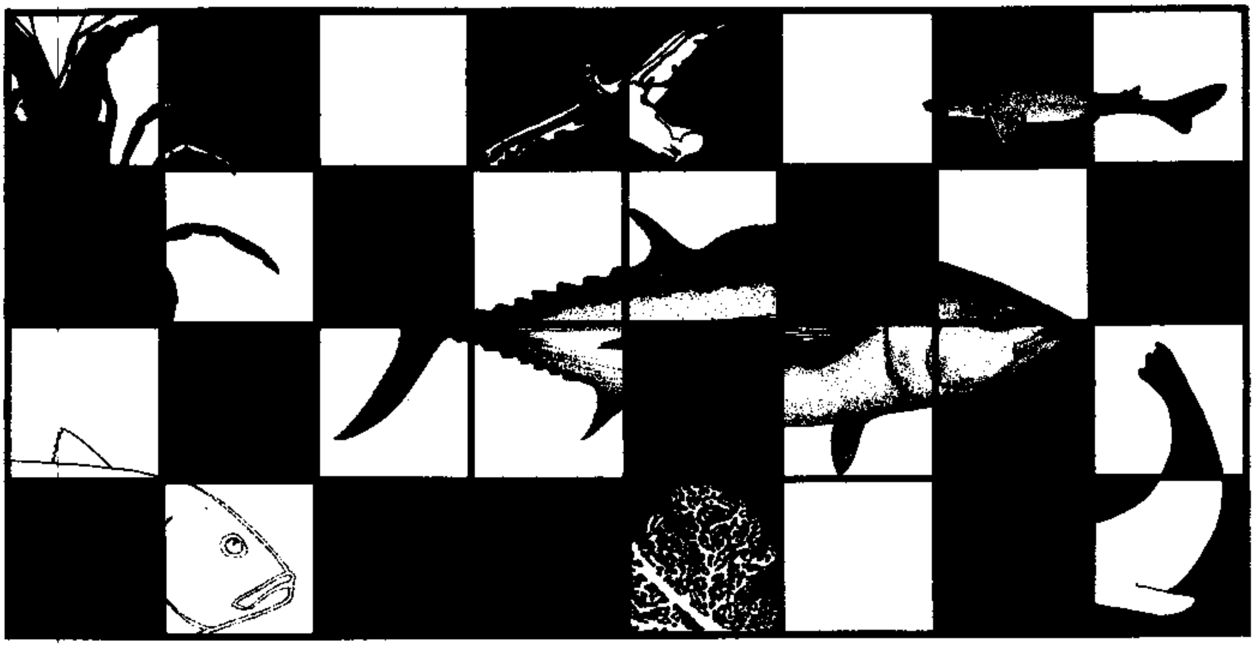


LUNCHEON ADDRESS

May 25, 1983

John V. Byrne

Administrator, National Oceanic and Atmospheric Administration,
Main Commerce Building, Washington, D.C. 20230

Byrne: Thank you Richard. I stand here with some trepidation now that I know Davidson is down there with his pencil in hand. It is always a pleasure to come here. I don't know whether or not you folks who live here appreciate what a pleasure it is to visit Hawaii but let me assure you that the pleasure is increased by an order of magnitude if you come from Washington, D.C. And a few of my colleagues here know exactly what I'm talking about. They came earlier than I did. In any case it is a special pleasure to be here for this particular symposium. We knew it was going to be a good one, because the last one you had was very good. The papers I heard this morning demonstrate very well the excellent research that has been going on here for the last 5 years.

One of the things that I'd like to share with you are some of my thoughts with respect to research, and what I call linkages. One of the advantages that I have in my present position as Administrator of NOAA is, although I don't have the opportunity to get involved in research, I do have the opportunity to see the results of research from a variety of subject areas. The thing that is most intriguing to me is the kind of linkages that can exist among areas of research that appear to be disparate, that appear to be isolated, and separate. And when you do discover these linkages, it really is exciting. Just think of it in your own field. We are at a time where, as you look around, you can see all sorts of clues, tools, techniques, new ideas coming out of other fields that can be very useful to you in terms of solving problems which heretofore have been unsolvable. To mention several examples; for the biologists, certainly advances are being made by geneticists on mitochondrial DNA which is a new tool to determine stock identity in marine populations. Some of you involved with fisheries may have found the occasion to use some of the new satellite imagery. Satellite imagery coming from Nimbus-7 includes both infrared and ocean color, surface colors that show all sorts of patterns that we haven't seen before. Thinking back to SEASAT which lasted only a short time, we find that geodesists can make better identification and interpretation of the sea floor from the surface measurements made by SEASAT's altimeter than we've ever been able to do on a synoptic basis with echo sounders. Statistics and the advent of computers of course make it possible to do all sorts of things in modeling, and in fisheries population dynamic's that were impossible just a few years ago. Traditional fisheries biologists would say that even ecologists are beginning to recognize the importance of recruitment and recruitment models for studies of population density and community structure.

There are a lot of ways at looking at the linkages. I think the film this morning showed several. One of the things that was intriguing in the film was the linkages between the study of coral reefs and the geological history of the archipelago. You recall the film opened up with a shot of how the Hawaiian Archipelago was formed with the plate moving over the hot spot. How the islands developed from undersea volcanos, rose up forming majestic high islands only to subside, erode, and gradually move off the hot spot to the northwest where they eventually drowned at a latitude called the Darwin Point where coral growth ceases to keep pace with island subsidence. If we looked at one area of the earth where it was most appropriate to do these kinds of interdisciplinary studies, I think it would clearly be the Pacific.

And if there was any question of that in the past, there certainly shouldn't be any question about it this year. In 1982-83, we have been going through an event, called the El Nino event or southern oscillation event . . . some oceanographers are even calling it the thermal event of 1982-83 -- which because of its extreme nature makes it easier for us to see the linkages that exist between the atmosphere and the ocean in terms of physical oceanography and some biological activities.

The Pacific is certainly the largest ocean -- and the most active in terms of volcanic activity and in terms of the weather patterns. Again from a geological perspective I would like to mention several studies going back to Charles Darwin. One of the early books that Darwin wrote was called "Coral Reefs" in which he did a masterful job of describing coral reefs, identifying them, putting them into categories, and so on, and then attempting to describe why the different categories of coral reefs should exist. And those of you who are familiar with Darwin's hypotheses, recognize that he very accurately perceived the role of subsidence, and the upward growth of coral in the development of atolls. This was long before there was any idea of plate tectonics, of movement and subsidence of plates away from spreading centers, and I suspect Darwin would be delighted with what we have learned in recent years. That for example the Pacific plate on which the Hawaiian chain rides got its start 190 million years ago and is constantly growing and constantly moving to the northwest carrying atolls to a watery grave is a remarkable prophecy of Darwin's atoll theory. Another aspect of plate tectonics which has biological connections is contained in a recent publication by Victor Springer of the Smithsonian. Springer has looked at plate tectonics to explain the process of species distribution and endemism of fishes in the Pacific. And I think it's intriguing that a systematic biologist would turn to plate tectonics, which is a relatively new concept in geology, to help explain some of the things that he is concerned with. I recall

. . . when I was teaching marine geology at Oregon State just a few years ago, we had some neat concepts as to how the Pacific Ocean was formed. It was either pulled out as a big chunk of material at the time the moon was formed or it was actually the result of a giant meteorite impact and that it was really a crater. As I said, when I first started teaching marine biology we had no idea what formed the Pacific. Another thing that happened about that time which was intriguing was that some people, in fact one of the pioneers of NOAA, had made some magnetic measurements in the northeast Pacific and they came up with some very stange lineations of paleomagnetic measurements which couldn't be explained. The first thing that many geologists did was to get the original data and recontour it because it was very clear that the original contouring was biased since long, straight patterns just couldn't possibly exist. Of course what came out was the key to understanding sea floor spreading and plate tectonics, the magnetic anomalies being evidence of new crust being formed on either side of spreading centers. The point I'm trying to make is that many existing links in our understanding are very new. This is part of the explosion in science that is going on now. I think it's interesting that Springer's incorporation of plate tectonic theory helps to explain the endemism he finds in the distribution of fish and a very strong gradient, a sharp decrease if you will, in the number of fish taxa as one proceeds eastward across the western margin of the Pacific. I should mention that the western Pacific is the oldest portion of the plate and gets progressively younger as you go to the east.

I'd like now to touch on several aspects of fisheries that demonstrate linkages between the earth and atmospheric sciences. For example, since World War II the annual world's fish catch has increased markedly, largely as a result of increased effort. Immediately after World War II the yearly catch was about 25 million metric tons. By the late 1950s and 1960s scientists were projecting catches of upward to 200 million metric tons. Some of you can remember those early papers in which people were claiming it was 150 million and other people were claiming 200 million and so on, but for some reason these estimates were never realized but instead stabilized around 1970 to the present in the vicinity of 75 million metric tons. No matter what we do, we don't seem to be increasing significantly toward the 150 million or 200 million level.

The question is why hasn't the fish catch measured up to past expectations? Probably a number of factors, but I think if you look at the way these totals were derived you find that the estimates in those days were made species by species, and simply adding them all together. And now as we look at what happens in fisheries biology we find that when one species increases another species frequently declines. There is a tendency to say at the expense of the other species but I think in most cases this isn't so. More often we are now seeing that there are linkages, between the species distributions and some very important oceanographic processes. To give you an example, many of you perhaps remember the California sardine which was a major industry before WWII. Steinbeck's book about Cannery Row talks about the sardine industry. This was back in the 1930s and 1940s when at the peak there were about 800,000 tons of sardines landed per year. Then the fishery collapsed. I think the original thought was that it was strictly due to overfishing. Now we know that's probably not the entire explanation, although fishing pressure was undoubtedly a contributing factor. As a result, we begin to see anchovies increasing, and in time they began to replace the sardine. However, in recent years anchovies are declining and sardines are beginning to reappear. And so it's very clear there are other factors at work here.

The same sort of things seem to have happened off Japan. The sardine populations off Japan peaked at about 1.6 million metric tons in the 1930s and then dropped to about 9,000 tons in 1965. In recent years there has been a rather substantial recovery. In 1980 the catch was back up to 2.2 million metric tons. It's hard to know whether or not the increase is due to good management, luck, or whatever. It's very clear to many of us that there are many factors at work.

The Peruvian anchovy is another example. In 1970 about 12 million metric tons were landed. This single fishery constituted about 20 percent of the total world catch in that year. A major, major fishery! And from this peak of 12 million metric tons it has tumbled to a low of 720,000 tons 10 years later. We now know from this year, that the environment has had a significant impact on the fishery. If there's one series of linkages that we're becoming more and more aware of, it's the linkage between the atmosphere and the ocean and its impact on the biology of the ocean. Last June (1982) we began to see that there was a fluctuation appearing in the southern oscillation index. The southern oscillation index is a term that atmospheric scientists use to measure the difference in pressure between Tahiti and Darwin, Australia, i.e., a high pressure cell over Tahiti, and a low pressure cell over Darwin, Australia. And as long as this high pressure cell is maintained over Tahiti it stays low near Darwin, and there is a general movement of water from east to west across the Pacific such that it piles up in the western Pacific. Charles Darwin noticed this. He knew that one of the reasons there were coral reefs in the western Pacific was that the currents along the equator were moving warm water farther to the west and that the warm water actually piled up there. The depth of the thermocline (he didn't call it the thermocline) actually increased as you went towards the west. In any case, the southern oscillation occurs when the high pressure in Tahiti and low pressure in Darwin begins to relax. And when it relaxes, we think now, a wave of water (not a current) moves back across the Pacific from west to east. This results in a current of warm water in the area of Ecuador and Peru that has been called the El Nino for many, many years now. It has only been in recent years that the El Nino has been attributed to the southern oscillation although the southern oscillation has been known since 1926.

In any case, last June we began to see a shift in the southern oscillation and as a result there was a great deal of attention paid to watching what happened with respect to the El Nino. This was fortunate because what we saw was an event which we have never measured before. The extremes that have taken place in 1982 and 1983 are far greater than any that we have ever seen with respect to the ocean in the tropics and particularly the eastern Pacific. The El Nino effect has been known a long time . . . you can go back to the classic text by Swerdrup, Johnson, and Fleming in 1940 and read about the kill-off of the anchovies around Ecuador and Peru, the death of the shorebirds, the high incidence of decaying fish, the production of hydrogen sulfide, and so on. What we're now beginning to see are the linkages that take place between the southern oscillation and the fishery. The warm water moving into an area where there is normally cold upwelled water either kills them off, or as is frequently the case, causes them to migrate to some other area. In the Peruvian case, we find that as the sardines and the anchovies begin to decrease, they may actually increase in the waters further to the south. That suggests there has been a movement of these fish.

Let me explore the linkages a little bit more about El Nino. With the major shift of warm water from the western Pacific to the eastern Pacific during this year, we've also experienced a shift in atmospheric conditions, causing terrible droughts in Australia and torrential rains in California, Peru, and Chile. The atmosphere patterns shifted in the form of something like an echelon, that is, to the east and caused extremes in weather which we have never experienced before. All our records don't show anything that measures up to this El Nino event.

There are other linkages. In continuing to look for oceanographic linkages, we see that the tidal level as far north as Vancouver Island off Canada is 6 to 8 inches higher than normal during this period. Temperature anomalies -- warm water where it normally is not that warm -- extended all the way around the Pacific during December 1982 and January 1983. They occurred all the way up the west coast into the Gulf of Alaska. They also occurred in the waters off Japan and in the area west of Japan. The temperatures in the central Pacific are anomalously low. These, we think, will certainly have an impact on fisheries and on the biota in these areas. In southern California where sport fishing is a big industry, they're advertising that this is the time to catch fish that are normally caught off southern Mexico.

There are other things that we don't quite fully understand. We find, for example, that storms in the Atlantic, particularly hurricanes, have an almost mystical correlation with respect to the southern oscillation index. When the southern oscillation index is low, that's when an El Nino event occurs and the number of Atlantic hurricanes is very low. It doesn't mean that the hurricanes that do form are any less severe but there are fewer of them. Another thing is that in the year following an El Nino there appears to be frequently higher than normal hurricanes in the Atlantic. Thus, not only is El Nino an ocean-atmosphere coupling affecting the oceanography in the Pacific but it also appears to be affecting the atmospheric conditions in the Atlantic and other parts of the tropical world.

Another thing we have suspected for some time is that El Nino also has an impact on the jet stream as it occurs in the high latitudes. You perhaps recall that the weather on the mainland during the winter is frequently a result of where the atmospheric waves in the jet stream impinge on North America. If the wave comes down over Canada, mainland weather is very cold. Last year in November because of the volcano that erupted in Mexico a lot of predictions were made that it was going to be the severest weather that the United States had ever experienced. And there were a number of meteorologists who made that prediction. The people in the long term forecasting unit of the Weather Service at the National Meteorological Center sort of held off, and said that we'll give you our prediction in mid-November. And they did. And the prediction was that the eastern United States would have the mildest winter of the century. Their reasoning was based on the southern oscillation and the development of El Nino, and they were right on target. In fact, they were so much on target that they're now a little bit leery about making predictions for next winter.

One of the reasons that they were so successful was that this was an extreme event. The thing that is intriguing to me is to look at some of the research which is going on and see how it all links up. In the case of El Nino as I said, we think it has an effect on the jet stream position. Further, we think that the jet stream position has an effect on the ice coverage in the Bering Sea and if we can predict where the jet stream will come down we can make some general predictions as to whether the ice in the Bering Sea will be extensive or not. And that, or course, is of value to the people who have to transit the Bering Sea during the winter, but it's also very important for the survivability of King crab larvae. When the ice sheet is extensive the larvae don't do very well for a number of complex reasons. From a biological point of view that's a nice curiosity, but if you're a crab fisherman it is more than a curiosity, because it means that if that larval stock doesn't survive 8 or 9 years later when the crabs should be mature, then they are not going to be there. And so we begin to see that we can possibly explain some of the major fluctuations in King crab stocks as a result of the position of the ice in the Bering Sea which in turn is the result of what has happened in the tropics some year or so earlier as a result of the southern oscillation. And if you're a banker in Alaska that's important because you probably have all sorts of loans out on crab fishing vessels that are dependent on catching crabs. In any case that's an example of the kinds of linkages that I'm referring to -- in this case the linkages exist between atmospheric sciences, oceanography, fisheries, biology, and banking. Another example is what has been discovered in the fisheries laboratory in Seattle about pollock in the Bering Sea. Biologists now suggest that what we ought to do is fish the adult pollocks a little heavier because it turns out that the adult pollock is cannibalistic and eats each juvenile pollock and so if we can strip off the adult stage, we may in fact increase the size of the overall pollock population in the Bering Sea.

Well, these are just a few examples. I think that the symposium here today provides all sorts of appropriate linkages. I always see the value of a symposium like this as something that stimulates ideas rather than something that just presents ideas. We had one member of the audience this morning suggest that we should perhaps try animal husbandry techniques in maintaining populations of monk seals in the Northwestern Hawaiian Islands. That's a new idea! And it may stimulate other ideas. And so I congratulate those who have been involved with the development of this symposium. I'm delighted that it includes not only the National Marine Fisheries Service and the Sea Grant Program, both of which have a direct link to NOAA, but that it also includes our colleagues in the Department of Interior, the Fish and Wildlife Service, as well as the State of Hawaii. I think the time has come when we can no longer rely on doing research in isolated agencies but that talents and skills wherever they exist need to be pooled. So I guess in conclusion I would say, keep it up, you're on the right track and to my colleagues in Interior, I know they will provide continued funding for this important research and I can assure you that in NOAA we'll certainly do the same. Thank you very much.

LUNCHEON ADDRESS

May 26, 1983

G. Ray Arnett

Assistant Secretary for Fish and Wildlife and Parks,
U.S. Department of the Interior, Washington, D.C.

Some say there are always two sides to an issue and both should be reviewed before a decision can be rendered. Someone may quickly add, there are really three sides when you include the third party, the one rendering judgement. Counting two or three matters little to me so long as this basic management precept is followed. The approach is a good one. It functions well in business and public administration and is a key element in our nation's judicial system.

As I understand, that's why we agreed to conduct these cooperative studies, and that's why we are here today reporting on study results. Basically we are all concerned with the conservation, i.e., as Gabrielson put it, "wise use," of the fish and wildlife resources in the Northwestern Hawaiian Islands (NWHI). This use focuses on what portion can be harvested for economic return or recreational use and what portion needs to be protected, for as you all know a sound resource base makes harvest possible and sustainable. The advancement of scientific knowledge and education fits into the question of resource allocation as well.

These questions are important ones, for development and perpetuation of fish and wildlife resources are each critical to human needs in the Pacific islands, in the United States, and worldwide. The cooperative way various disciplines have gone about collecting the information required for management or further planning is admirable. It reflects professionalism of the highest quality and is important to an informed decisionmaking process. Improving the scientific basis for U.S. Fish and Wildlife Service (FWS) recommendations and decisions is an important objective by which this administration (Reagan/Watt) manages.

State-federal cooperation is another important element of the philosophy and practice this administration brings to government. I am pleased to see that cooperative philosophy in action here in Hawaii. Having experienced both the state and federal perspectives, I am well aware that issues such as the ones before us can quickly degenerate to nonproductive personal differences rather than constructive, scientific resolution. That's another reason why scientific fact is so important to an intelligent decisionmaking process. I have reviewed the abstracts of your papers and find the scope and results of your studies impressive. Although not all the questions researchers and managers seek to resolve have been answered, the data base on which future studies, plans, and decisions will be made regarding the resources of the unique and beautiful islands of Hawaii has been greatly improved.

Speaking of decisions, FWS director Bob Jantzen and I are not here today to render a decision on what is the appropriate level of fishing or wildlife protection. Under the tripartite agreement, FWS, National Marine Fisheries Service (NMFS), and Division of Aquatic Resources of the Hawaii Department of Land and Natural Resources (DLNR) agreed that those decisions would be developed through planning based upon the results of the studies.

Rob Shallenberger will be reviewing that process with you. Consequently, I'll say little about it beyond my expectations for the considerations which will enter into that process. For starters, I expect that planning by FWS will follow policies and procedures supported by the administration, as reflected in the revised "Refuge Manual" and other policy statements. Namely, these include:

- Enhance and maintain the wildlife values for which this refuge was established
- Follow the National Wildlife Refuge Master Planning System for determining the development, management, and use of the Hawaiian Islands National Wildlife Refuge (HINWR)
- Provide for public and economic uses of its wildlife resources where compatible with the primary purpose of the refuge
- Closely cooperate with the state of Hawaii and other agencies who have adjoining or overlapping interests
- Simplify regulations governing uses on the refuge
- Protect or enhance the antiquity values inherent to the refuge
- Expand the "user pay" approach as appropriate to offset costs of general and special uses on service lands

Now, to expand upon these expectations. In doing so, my discussion will reflect both national context and local specifics.

National direction calls for the maintenance, enhancement, and recovery of priority fish and wildlife resources. Closely allied to this direction is the objective to improve resource management based upon a greater reliance on objective scientifc information. Associated tasks include resolution of threats and conflicts affecting resources on service lands and the administration of the endangered species program. Results generated by scientific studies will prove helpful in resolving the use versus non-use issue, and in considering endangered species' needs through my next topic, the planning process.

Development and implementation of National Wildlife Refuge Systems Plans is one of the key tasks supporting the department's and service's objective to promote appropriate multiple use of lands administered by FWS. This effort took form with the establishment of the National Wildlife Refuge Master Planning System last December. Revision and issuance of the Management Planning chapter of the Refuge Manual, the document guiding planning and management of the 86.7 million acres of lands in 413 refuges that comprise the system, were completed in February.

A planning needs review was conducted for all refuges and a master planning priority listing developed for refuges in each region. The HINWR was ranked a top priority in this region and nationwide, meeting all national criteria. Rob Shallenberger will be announcing the formal initiation of that process here today. That process calls for an environmental impact analysis and includes opportunity for you -- the state, other federal agencies, the university, and private groups and individuals -- to interact, assist, and have your interests considered thoroughly in that planning process. As I said, the National Wildlife Refuge Master Planning System is a key element in achieving our multiple-use objective for service lands.

Expanding economic and public uses and increasing fishery management on National Wildlife Refuges (NWRs) are two other tasks supporting our objective to promote the appropriate multiple use on service lands. The issue here is not one of the service being opposed to resource utilization. Make no mistake, FWS has and will continue to support the concept and practice of harvest -- take -- as a valid tool in managing fish and wildlife resources. At the national level, the end result of our ongoing program review will be development and expansion of appropriate uses within existing funds by June 1984 and completion of state-FWS cooperative agreements to increase fishery management on selected refuges by October 1984. The appropriateness of fishing and other uses in the HINWR will be determined through refuge master planning, the fishery management assessment, and the review of potential economic and public uses. All refuges in the system are undergoing these reviews and being considered for master planning. I am pleased that these efforts will have timely application to the planning and management decisions arising from our joint study efforts here.

Regulatory reform by this administration has impacted FWS business in a positive way. We have successfully taken steps to simplify and ensure timely response to federal planning, permit, and license actions.

Regulations governing uses on NWRs have also been simplified. Hunting and fishing regulations on service lands are more closely atuned to state regulations and stand until changed rather than requiring Federal Register publication each year for each refuge. The use of a generic endangered species biological consultation for operations in the HINWR and the clarified and standardized use of the refuge special use permit process are local contributions to that effort.

Another significant contribution made by this administration deals with state-federal cooperation. On March 18, 1983 the office of the secretary published in the Federal Register, the Department of Interior's fish and wildlife policy regarding state-federal relationships. This policy was developed in close coordination with the International Association of Fish and Wildlife Agencies (IAFWA). The purpose of the policy is to clarify state and federal responsibilities, enhance cooperative relationships, and identify areas for potential cooperative agreements respecting fish and wildlife management. This policy is intended to reaffirm the role of the states in fish and resident wildlife management, especially where states have primary authority and responsibility, and to foster improved conservation of fish and wildlife. In developing and implementing this policy, the department will be furthering the manifest congressional policy of state-federal cooperation that pervades statutory enactments in the area of fish and wildlife conservation.

However, in recognition of the existing jurisdictional relationship between the states and the federal government, Congress, in the National Wildlife Refuge System Administration Act of 1966, has explicitly stated that nothing therein shall be construed as affecting the authority of the several states to manage fish and resident wildlife found on units of the system. Thus, Congress has directed that, to the maximum extent practicable, such public uses shall be consistent with state laws and regulations. Units of the National Wildlife Refuge System, therefore, shall be managed, to the extent practicable and compatible with the purposes for which they were established, in accordance with state laws and regulations, comprehensive plans for fish and wildlife developed by the states, and regional resource plans developed by FWS in cooperation with the states.

So once having passed the test of compatibility, generally a use on a refuge would also have to be consistent with state regulations. The policy also directs the following: (1) preparation of fish and wildlife management plans in cooperation with state fish and wildlife agencies and other appropriate federal agencies; (2) the use of management strategies and practices that cooperatively complement those of the states; (3) provision for public uses in accordance with state and federal regulations and within statutory and budgetary limitations; (4) consultation with affected states on recommended closure of refuge lands open to public uses; and (5) consultation with the states, and general compliance with state permit requirements, in carrying out research involving the take or possession of fish and wildlife, in the removal and disposition of surplus or harmful fish and wildlife. This same consultation and general compliance with state permit requirements applies to programs involving reintroduction of fish and wildlife.

The policy recognizes and addresses the international dimensions of fish and wildlife issues and ensures that effective programs at the state level are not weakened. In soliciting the advice of affected states in relation to the management of hundreds of millions of acres of land within the several states, the Department of the Interior will continue to seek new opportunities to foster a "good neighbor" policy with the states. Interior lands affected by this policy include those administered by the bureaus of reclamation and land management, plus NWRs, national fish hatcheries, and national parks.

In 1962 and 1966 Congress authorized the use of NWRs for outdoor recreation, provided that the use is compatible with the primary purposes for which the particular refuge was established. The principal reason for the establishment of a unit of the National Wildlife Refuge System is almost invariably the conservation, enhancement, and perpetuation of fish and wildlife; it was the reason for the establishment of the Hawaiian island bird reservation.

Consequently, federal activity respecting management of migratory birds, endangered species, marine mammals, and other wildlife utilizing units of the National Wildlife Refuge System involve a federal function specifically authorized by Congress. It is, therefore, for the Secretary of the Interior to determine whether units of the system shall be open to public uses, such as fishing, hunting, trapping, and native study, and on what terms such access shall be granted.

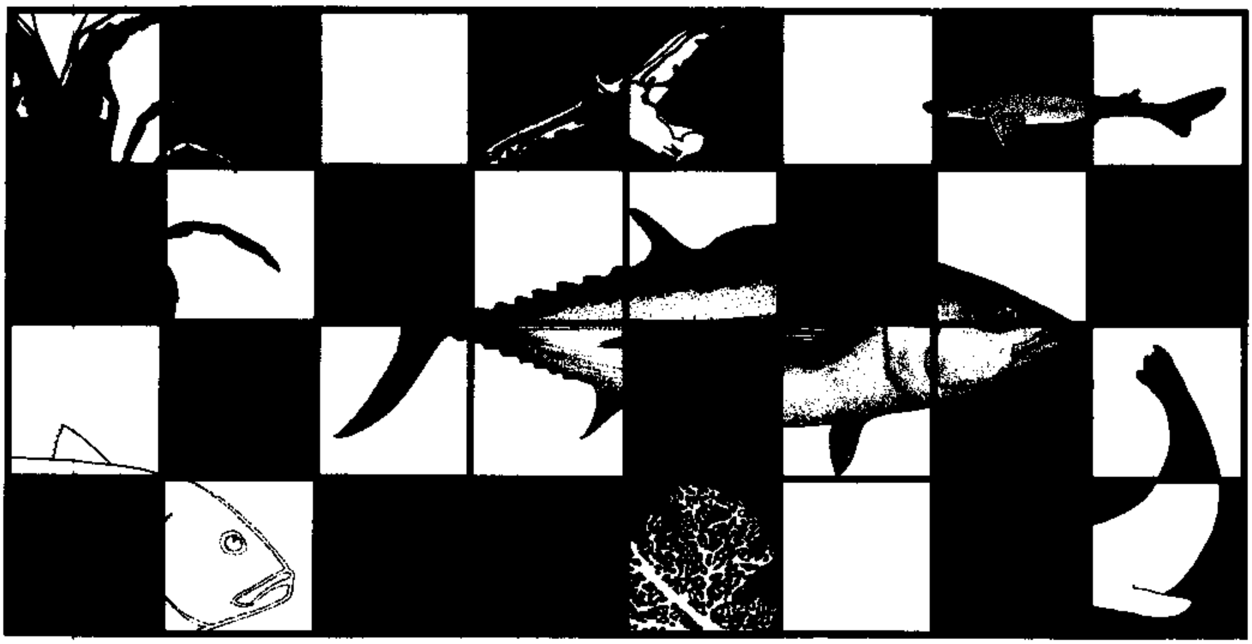
The practice of implementing cooperative agreements for a variety of fish and wildlife conservation programs is sanctioned and encouraged by the policy. Appropriate areas of cooperation are exemplified by practices here in Hawaii. Of special note are the cooperative research and inventories on and adjacent to refuge lands and waters in the Northwestern Hawaiian Islands; the agreements for the protection, development, and maintenance of endangered waterbird habitat; the support of the state's wildlife propagation program; and the agreements with Department of Defense for the management planning and assistance for fish and wildlife on their installations.

Cooperative agreements between FWS and NMFS covering shared responsibilities for the management and recovery of the Hawaiian monk seal and between FWS and DLNR for fisheries support are under consideration.

Bob Jantzen and I have had the delightful opportunity to visit French Frigate Shoals (FFS) and review the very real issues involving potential multiple use that focus on the area. Our visit to FFS, this meeting, and related discussions with many of you will be very helpful in considering resource utilization in the HINWR. I cannot predict to what degree we'll be able to accommodate the various proposed uses and interests, but I can state quite emphatically that they will be given every consideration and that the planning process will continue to solicit wide participations.

Thank you for the opportunity you have given me to participate in this important symposium. My activities during these past several days -- the dialogue with state officials; aerial surveys of endangered forest bird and waterbird habitat; on-the-ground observation of French Frigate Shoals and Tern Island; briefing by FWS and NMFS personnel; exchange of views with research team leaders; renewing acquaintances with old friends and meeting new ones -- have been an enjoyable learning experience for me. Please accept my sincere thanks for your cooperation and many courtesies extended to me. Best wishes for continued success.

Panel Discussion



OPTIMUM USE SCENARIOS

Dale T. Coggeshall*

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DEFINITION OF TERMS

The title of this section of the program is "Optimum Use Scenarios." Just what does that mean? Does it mean the same to each one of us? Most likely it does not and, chances are, it never will, simply because each of us values things differently and has different expectations.

Webster identifies optimal as an adjective meaning "most favorable or advantageous; best," and the noun scenario as "an outline of a proposed series of events." My conclusion is that my purpose at this point in the program is to outline what I see as a proposal for the best series of events for wisely utilizing the invaluable fish and wildlife heritage in the Northwestern Hawaiian Islands (NWHI).

In my view, the consideration of this panel includes the emergent islands and shoals as well as the submerged lands and waters of the NWHI out to the 200-mile boundary of the fishery conservation zone and the exclusive economic zone of the United States, the latter designated by Presidential Proclamation 5030, dated March 10, 1983. With this action, the President proclaimed sovereign rights and jurisdiction of the United States for the "purpose of exploring, exploiting, conserving and managing natural resources . . . of the seabed . . . and subsoil and the superjacent waters." For the purposes of this discussion, I will focus primarily but not exclusively on the fish and wildlife resources that inhabit the NWHI lagoons and nearshore waters. A key test of reasonableness for a scenario is that it is broad enough in geographic scope to contain the complex interrelationship of terrestrial and marine species that inhabit the NWHI.

The U.S. Fish and Wildlife Service's (FWS) mission statement provides a context appropriate for the word "use": " . . . to conserve, protect and enhance fish and wildlife and their habitats for the continuing benefit of people." The concept of public "use" is implicit in that statement. Indeed, public use of fish and wildlife resources has always been an important objective of FWS, both on and off its lands. The history of this agency reflects the importance of resource utilization.

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This administration has focused its attention on the need to explore means to expand public use opportunity, including economic use, on FWS lands. Yet, at no time in the history of this agency has the public use objective been given priority in management programs over the effort to conserve and enhance fish and wildlife populations. Where conflict has arisen between the perpetuation of these resources and the public use opportunity, the conflict is by necessity resolved in favor of the resource. Never has this been so true as when the conflict has involved threatened or endangered species.

These priorities reflect the legislative mandates that direct this agency's activities and the realization that the concept of public "use" is not restricted to the harvest of fish and wildlife resources. In fact, FWS's public use program is broad enough in scope to also include various nonconsumptive activities such as environmental education, research, interpretation, wildlife photography, bird-watching, and other forms of wildlife oriented recreation. Yet, even these activities are not always appropriate on all FWS lands as they too can conflict with the primary wildlife conservation objectives, particularly where endangered species are at stake.

During the studies and deliberations leading to this symposium, the "multiple use" approach to resource management was (and probably is) inherent in the perspectives of some individuals. Few land use agencies practice true multiple use. Even those agencies legally based on the multiple use concept are frequently viewed by the public as practicing an overriding or primary focus. Make no mistake about it, our National Wildlife Refuge System is by legal definition and practice a dominant land use program. Wildlife use is the primary purpose; economic and recreational uses are secondary and may be permitted only where compatible with the wildlife needs.

Although only inferred in the title, a time horizon requires definition. It is an unfortunate fact that a meaningful judgement is most easily attained by hindsight rather than foresight. True, the accuracy of our predictive capability increases with the accumulation of information and experience. Yet, it will be future generations who will be the best judge as to whether we, their forebearers, actually took the most "optimum" path.

All too often our sights are focused on far too short a time period into the future. This is particularly ironic when the actions we take have the real potential of affecting the survival of species who have made it to this point, over many millions of years of evolution, without our help or our hindrance.

Next year marks the 75th anniversary of the Hawaiian Islands National Wildlife Refuge (HINWR), originally the Hawaiian Islands Reservation. Recognizing the value of past experience in this management process, let us analyze our history before looking forward. A good starting point would be the year 1909. In that year, President Theodore Roosevelt recognized the inevitable future for NWHI wildlife if immediate action was not taken to protect this unique area. Although his action was critical, it did not prevent the extinction of at least three land bird species soon after. However, it did insure that the overharvest of monk seals that marked the latter half of the previous century would not be repeated. In so doing, it signaled the start of a slow recovery for this species from the brink of extinction at the turn of the century. It also led to the gradual recovery of seabird populations devastated by commercial harvest and introduced herbivores.

Interest in the commercial potential of bird, seal, and fishery resources has been a driving force that has led to the exploration of the NWHI for two centuries. Few species escaped the interest of early explorers and entrepreneurs, but most attempts at commercial harvest were short-lived due to logistic constraints, marketing problems, and, in some cases, rapidly depleted resources. For some targeted fisheries, such as the pearl oyster at Pearl and Hermes Atoll, recovery never attained pre-harvest populations. Several targeted species, including the monk seal, green turtle, and some seabirds, became the protected species of today, in part due to the lasting direct and indirect effects of the harvest. Other fishery resources, such as lobster, tuna, and bottomfish, have sustained commercial interest over several decades but are now drawing increasing attention with the development of longer-range vessels, expanding markets, and new harvesting methods.

In retrospect, would it seem safe to characterize the last century of resource "use" in the NWHI as "optimal"? I think not. On the negative side of the balance sheet, three bird species present at the turn of the century are now extinct. In spite of substantial recovery, the monk seal population is again in the midst of a dramatic downward trend.

Shared use of the NWHI for military activities has also left its mark on several islands. Exotic plants and animals have altered the ecology of these fragile, insular ecosystems. On the positive side, most seabird populations have recovered substantially from earlier impacts. The consumptive and nonconsumptive uses of NWHI resources have increased dramatically, particularly in very recent years. The results of recent research and management studies have the potential of benefiting the NWHI species and human use for years to come.

From the standpoint of commercial fishery use in the NWHI, the last century was clearly not one which, by any perspective, could be characterized as optimal. Some might more appropriately describe it as fraught with unattained expectations. Even with recent promises of substantially expanded economic potential, and the growing number of boats heading northwest, few fishermen have made large profits. Most are marginal operators at best. The development of markets and infrastructure to support the NWHI fishery has not kept pace with the growing interest to tap this resource.

Our look backwards leads us to conclude that resource utilization in the NWHI in the last century cannot be appropriately described as optimal, either in the area of wildlife conservation or fishery development. Now let us focus on the future of the Northwestern Hawaiian Islands; the future I define as the next 75 years.

Before we do, I think you should know something about my assumptions. Understanding the assumptions underlying the train of logic on which a scenario is based is every bit as important as understanding the ideas which structure that scenario. Understanding the assumptions used in each of the scenarios presented to you is also important for comparative purposes.

ASSUMPTIONS

First, I assume we will continue to hold certain tenets of western society's conservation ethics/laws to be true, that is, conservation or wise use of resources carries with that use a stewardship responsibility, a responsibility that the natural resource heritage will be available for future generations, that we hold those resources in trust for the common and future good of all.

Stated another way, the fish and wildlife resources we have inherited are a legacy, a trust (fund) from which we can only safely withdraw and use the annual interest that accrues -- the optimal sustainable yield (OSY) reflected in fishery management planning. However, that use carries with it the responsibility to ensure that the resource capital remains strong and intact, capable of providing for current and future generations. In addition, where capital resources have diminished we have a responsibility to restore them. History, administrations, and Congress have repeatedly held this truth -- this assumption -- to be self-evident in our conservation laws.

Maintaining or enhancing our trust fund is inherent in treaties and conventions with other countries for migratory birds and endangered species, in the long-standing federal aid in fish and wildlife restoration programs which make important contributions through our state fish and wildlife programs; in the Magnuson Fishery Conservation and Management Act (FCMA) of 1976 which spawned the fishery management councils and a refined role for the National Marine Fisheries Service; in the executive order and subsequent actions by Congress which recognized the unique and important fish and wildlife resources in the NWHI by the designation of the HINWR; and in the fish and wildlife management planning for Department of Defense lands such as Midway Islands under the Sikes Act.

Restoration of our resource capital to a level of optimal sustainable populations (OSP) and yield has been of growing concern and is most recently reaffirmed and strengthened by the Marine Mammal Protection Act (MMPA) and the FCMA. The Endangered Species Act also focuses on recovery of our capital stock. The MMPA provides, "The term 'optimum sustainable population' means with respect to any population stock, the number of animals which will result in the maximum productivity of the population or the species, keeping in mind the (optimum) carrying capacity of the habitat and the health of the ecosystem of which they form a constituent element."

Second, I assume the Hawaiian Islands National Wildlife Refuge will continue to exist with a primary purpose of maintaining and enhancing the associated fish and wildlife resources and a secondary purpose of permitting compatible use of those resources. Third, uses of these resources may not jeopardize the continued existence or recovery of threatened or endangered species. Fourth, these views represent the mission, goals, objectives, and policies of FWS.

EXPECTATIONS

For those who follow us to look back 75 years hence and say we followed the "optimum use scenario," we will have to achieve the following resource results:

1. The population decline of Hawaiian monk seals is reversed and recovered to the point that healthy sustainable subpopulations exist at French Frigate Shoals, Laysan Island, Lisianski Island, Pearl and Hermes Atoll, and Kure Atoll, and subpopulations at Midway Islands, Nihoa, and Necker Island are protected and not adversely affected by economic, defense, or other human-related impacts.
2. The recent trend of increasing recruitment and survival of green turtles at French Frigate Shoals has continued so that the breeding population at this site has at least doubled in size. Declines of turtle populations at Laysan, Lisianski, and Pearl and Hermes Atoll have reversed and substantial increases in survival and recruitment have been documented.
3. Populations of the four endangered land birds in the HINWR are at the carrying capacity level of their habitats, adverse effects of previously introduced pest insects and plants have been minimized, and actions to prevent future introductions or other habitat impacts have been fully implemented.
4. Seabird populations, including sensitive species, have fully recovered from effects of previous pest introductions and depredation and have reached carrying capacity on refuge islands. Effects of rodents, pest insects, and exotic plants at Midway Islands have been minimized. Critical habitats as defined in the

Migratory Bird Treaty with the USSR are effectively protected.

5. Unique opportunities for terrestrial and marine research investigations in the NWHI have been exploited without adverse impacts on species and habitat. Scientific investigations have provided useful information for addressing management problems facing fish and wildlife resources in the NWHI.
6. Recreational and educational public use of selected areas of the NWHI has been accommodated without adverse impacts. Offsite interpretive and educational opportunities have been emphasized.
7. Research has uncovered and developed effective measures to detect and combat ciguatera so as to eliminate this as a significant problem affecting fishery development or monk seal survival.
8. The U.S. fishing industry is successfully harvesting selected NWHI fishery resources at OSY without adversely impacting fish and wildlife species and their habitat.
9. Minerals and energy resources have been developed at selected sites without conflict with fish and wildlife resources and the human environment in Hawaii and the Pacific basin.

Simply stated, that's where I would like to be 75 years from today. I expect there is a lot of agreement among us that those are good objectives. What may be controversial, however, is the path to those objectives, the best way to get there from here.

GETTING FROM HERE TO THERE

Yesterday, Rob Shallenberger addressed some of the steps we see as necessary, both within and outside the HINWR, to reach those objectives. We see the best or optimum path as one that is a blend of both conservative and innovative, perhaps even, radical action. The conservative, careful approach should apply where the risk of irreversible future impacts is a legitimate concern. More decisive and timely action is appropriate to arrest and reverse disturbing trends in species populations and habitat condition. The details of these two approaches in the immediate future will be the substance of the Regional Resource Plan, recovery plans, fishery management plans, and the refuge master plan described yesterday.

Attainment of the objectives I portrayed will require the continuing cooperation of agencies which have shared in this study and all others who share a stake in the wise management of the fish and wildlife trust in the NWHI. Our task is clearly not over with the completion of this phase of scientific investigation. The hard part is yet to come, but I'm confident -- given understanding and acceptance of resource objectives, potential, and limitations -- we can get there cooperatively and effectively.

I personally have truly enjoyed the opportunity of working closely with all of you and look forward to our determination and actions to improve both the continuity and rewards of our fish and wildlife legacy.

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The objective of the Northwestern Hawaian Islands (NWHI) Tripartite Cooperative study is to gather information on the resources of the Northwestern Hawaiian Islands which would serve as a basis for management decisions. Rational decisions are essential to ensure protection of the unique wildlife resources and their habitat, and the orderly development of fishery resources of the NWHI. Optimum use of the NWHI resources requires that ecological and economic goals be balanced to protect the terrestrial and aquatic life found there, and yet carefully allow fisheries development to take place.

With the increasing demand for fish in Hawaii, and the heavy fishing of stocks around the main Hawaiian islands, the thrust of commercial fisheries development must be directed towards the NWHI. If our fishing industry is to remain a major contributor to the economy of Hawaii, development of distant-water fisheries must occur. Hawaii should not continue to import from foreign sources a large proportion of the fish consumed here. In order to reduce imports and provide growth potential for Hawaii's fishing industry, the fisheries resources in the NWHI must be utilized. However, because of the long distance from the main Hawaiian islands to the NWHI the cost of travel is high and large vessels are required. These factors tend to discourage fishing ventures. Infrastructural support for fisheries must be extended into the NWHI to shorten the distances between the fishing and landing operations. Accordingly, a NWHI use scenario with the establishment of an advance fishery support base at French Frigate Shoals is currently being proposed by the state.

It has been shown that single-resource fisheries such as lobster trapping and bottomfish handlining in the NWHI on a long-term basis are marginally feasible, economically. However, a multi-resource fishery such as proposed below could be feasible for the NWHI.

A multi-resource fishery is proposed with fishing vessels maximizing the profitability of their operation in the NWHI by conducting their fishing in two phases. The first phase, outward bound from Honolulu to the NWHI, would direct the vessels to fish selectively for species that can be stored fresh frozen in good quality. Those species could include spiny lobster, shrimp, thick-lipped ulua, white ulua, shark, mahimahi, sea bass, and ono, aimed at the restaurant/hotel markets or a frozen seafood market. Further, with live baitfish supplies from the shallow lagoon waters of Lisianski and French Frigate Shoals, the aku (skipjack tuna) associated with the extensive shoals of the NWHI would be fished and frozen for transshipment to the tuna cannery in Honolulu.

The fresh frozen catch would be offloaded from the fishing vessels to a mothership or support freezer barge anchored near Tern Island, French Frigate Shoals. The mothership/barge would supply the fishing vessels with frozen storage, fuel, water, provisions, and gear. Tern Island could be used for emergencies, short rest, and recreation stops for fishing crews and for fishing gear storage. The fishing vessel could choose to remain in the NWHI and continue fishing for the frozen seafood market, or it could return to the main Hawaiian islands.

On the return trip to the main islands, the vessel could fish for species intended for sale in the fresh seafood market. Those could include the snappers and other bottomfish, the larger yellowfin and bigeye tunas, as well as other high-value species mentioned previously. A variety of fishing gear should be utilized by each vessel to maximize the effectiveness of its fishing time.

The success of this scenario depends on the careful development and integration of frozen and fresh seafood markets in the main islands. Export as well as domestic markets should be considered. The development of this scenario would require active industry involvement in a variety of directions ranging from the vessels to marketing.

The presence of a mothership/barge support facility on Tern Island would open up the NWHI to medium-sized vessels 50 to 70 feet long as well as even smaller boats which could be towed or barged into the area. A medium-sized vessel could even serve as a mothership to a number of smaller fishing boats. This type of operation is typical of foreign distant-water fisheries.

The support facility could be operated by a private enterprise under permit from the state of Hawaii and the U.S. Department of the Interior. Since the mothership/barge would be anchored near a national wildlife refuge and Tern Island would be used on a limited basis, fishing and support operations would be stringently regulated to avoid impact on the unique wildlife and the refuge.

At the same time, the fishery support base could benefit the federal refuge operations at Tern Island through support of the research activities and logistics between the main Hawaiian islands and the refuge. Also, some of the fishing, for example for ulua or sharks, could directly benefit the endangered/ threatened species on the refuge by reducing a major predator.

Further, while we appear to lay blame on our domestic fishers for disturbance to the endangered species, we cannot neglect the foreign fishing activities taking place around the NWHI. Particularly the fishery for squid, the preferred food of seals, with its miles of nets a potential hazzard for entanglement. A real problem is also present where squid fishermen may be angered into shooting at seals that are sighted eating the squid off the nets; as we know they would.

Although not strictly a fishery resource within the NWHI, the albacore tuna fishery located in waters north and west of Midway Islands is an important area for development by the state. The larger albacore trolling vessels can fish these long-distance grounds while based in Honolulu as long as albacore tuna prices are good. Their operations are constrained by the 1,500 or more miles that must be traveled to reach the fishing grounds at great cost in fuel and fishing time, limiting the number of trips that can be made. Should a fishery support base at Midway Islands prove feasible and be established, the range of American fishing vessels would be extended into the Pacific Ocean whereby the entire western North Pacific would become available. The presence of an American fishery in these international waters would establish considerable prestige to both the state and the nation. Furthermore, the support operations at Midway Islands and French Frigate Shoals could be integrated to realize economies of scale, thus making them even more attractive.

Although there is little recreational fishing activity currently taking place in the NWHI, the potential development of fisheries resources for this purpose should not be overlooked. Sport fishermen from Hawaii now fly to Christmas Island, Alaska, and Canada on recreational fishing tours. Sportfishing ventures with no adverse impact on endangered/threatened species could offer economic as well as cultural benefits well worth pursuing. In addition to sport fishing, conservation/recreation programs such as the guided nature tours in the Galapagos Islands and more recently even to the Antarctic could be considered. However, public activity in the refuge would not be permitted if the fragile ecology of the area were to be endangered. On the other hand, extensive public wildlife-associated recreation is allowed and is consistent with the policy of the U.S. Fish and Wildlife Service for its National Wildlife Refuge System.

Finally, the state's position, as outlined in the Hawaii Fisheries Development Plan, is that the major potential for expansion of our fishing industry lies in the NWHI. To neglect this economic resource to foreign interests or non-use is wasteful to our state and nation. As a result of the tripartite study, we are in a better position to more clearly define and pursue the management objectives that allow for prudent development of the NWHI fisheries resources and at the same time maintain strong protection of the area's unique wildlife and habitat. Optimal use of the NWHI resources demands a balance between fisheries development and wildlife conservation. To sacrifice one for the other would be a grave dereliction of our charge in stewardship of the natural resources found therein. However, a status quo attitude in this day of worldwide fisheries expansion is not acceptable. We must take positive yet careful actions. We must harvest the resources, manage the resources, and conduct research on the resources; only then can we justify any controls on foreign fishing activities which may be a greater threat to the endangered/threatened species in the NWHI. Let us work together to ensure the optimal utilization of our NWHI resources.

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ABSTRACT

A general optimum use scenario is presented by highlighting the importance of the Northwestern Hawaiian Islands (NWHI) to Hawaii's changing fisheries. Support uses of Midway Islands and Tern Island are seen as being essential to the growth prospects of Hawaii's fisheries. Endangered species and fisheries interactions are discussed for the NWHI spiny lobster fishery, bottomfish fishery, the precious corals fishery, and the fisheries for migratory, pelagic fish. A conclusion is reached that Hawaii's fishermen do not compete with the animals of the refuge for food or for any other reason. Environmental concerns with respect to the use of Midway Islands and Tern Island can be dealt with through rule making, education, enforcement, and contingency planning.

multi-resource fishery
use of Midway Islands and Tern Island
fisheries and wildlife interactions

INTRODUCTION

The importance of the Northwestern Hawaiian Islands for fisheries development can be understood by examining the character and nature of the present-day fisheries in Hawaii. Since about 1979, there has been a steadily increasing number of mainland albacore troll vessels basing their operations in Hawaii. There has also been an influx of mainland boats in the NWHI trap fishery for spiny lobsters. This fishery, from its very beginning around 1976, has been characterized by many boats entering and leaving the fishery. Economic projections in the Western Pacific Regional Fishery Management Council's (WPRFMC) spiny lobster Fishery Management Plan (FMP) suggest that after initially high catch rates in the virgin NWHI fishery are reduced, the relatively low concentrations of spiny lobsters there will make it difficult, if not impossible, to achieve the scale of production that large vessels targetting on a single species need to cover their operating costs. That is why the larger boats have left the fishery and why more and more medium-sized boats are diversifying their operations into other areas such as bottomfishing, and longlining for sashimi-grade tuna.

The bottomfish stocks near the main Hawaiian islands are thought to be fully or nearly fully exploited, and some nearby stocks of opakapaka and onaga are considered to be overfished. In direct contrast, the bottomfish stocks in the NWHI are considered to be underfished with a sustainable annual yield estimated to be worth a few million dollars. The spiny lobster resources in the NWHI are considerable when compared with those in the main Hawaiian islands because there is much more habitat for this species in the former area. The WPRFMC's spiny lobster FMP estimates an "optimum yield" or a potential annual harvest in the NWHI of between 200,000 and 400,000 legal animals. This range is not a quota, nor is it a harvest target or a harvest guarantee. The potential harvest of 200,000 to 400,000 spiny lobsters is simply the WPRFMC's best estimate of the "equilibrium yield" after the virgin stocks are reduced.

The tuna handline and longline fisheries are the fastest growing segments of the state's commercial fishing fleet. Neither tuna handliners nor longliners fish to a large extent in the NWHI at present. The potential of the NWHI for further development of Hawaii's longline fleet is suggested by the pattern of foreign longline fishing in the recent past in the waters of the U.S. fishery conservation zone (FCZ) surrounding the Hawaiian Archipelago. For the 5-year period, 1973 to 1977, the NWHI produced about twice as much fish on the average for the foreign longline fleets than did the FCZ waters off the main Hawaiian islands. This is to be expected since the NWHI are nearer to the home ports of foreign fleets, since the NWHI FCZ is significantly larger than the FCZ of the main Hawaiian islands, and especially since one of the world's best fishing ground for bigeye tuna, a deluxe or premium market species in the sashimi trade, lies within the FCZ of the NWHI and just north of it on the high seas.

Foreign longline statistics on catch and effort reveal a marked seasonal variation in abundance among the billfish and tuna species. Striped marlin generally occur in greater numbers during the winter months and blue marlin during the summer months. During the 5-year period, 1973 through 1977, foreign longliners fishing in the FCZ of the NWHI caught four times as much tuna and twice as much billfish during the winter months than they did during the summer months. Striped marlin and swordfish accounted for over 90 percent of their NWHI billfish catch, whereas bigeye and albacore tuna dominated their tuna catch. Historically, the foreign longline fishery in the NWHI diminished its intensity during the summer months, shifting its focus more toward the main Hawaiian islands. Thiry-four percent of the billfish catch of foreign longliners made in the FCZ of the main Hawaiian islands during the summer months is comprised of blue marlin, followed closely by swordfish (27 percent), and striped marlin (26 percent).

The domestic fisheries for the large pelagic predators are generally summer oriented. The seasonal variations in species composition in the catches of domestic fishermen are dependent upon movements and local abundance of the migratory fish. Both of these factors are influenced by a number of environmental factors such as sea surface temperatures and the relative availability of prey. Generally speaking, it appears that striped marlin and bigeye tuna are winter fish in Hawaii responding to a different set of environmental factors from the blue marlin and yellowfin tuna which are mostly summer fish. Commercial fishermen, whether foreign or domestic, adjust their fishing strategies by reading market conditions and hope to find the fish that they are seeking on the basis on their past experiences. Foreign longline fishermen follow the fish that they are seeking by dipping in and out of the FCZ as the fish do. Domestic fishermen are not as mobile, although some local longline fishermen make trips into the waters of the NWHI.

MULTI-RESOURCE FISHERY

The WPRFMC has never advocated nor maintained, either with the spiny lobster fishery or the bottomfish fishery, that commercial vessels can be supported by a single resource. Its position has always been that the NWHI fishery can only develop as a multi-resource one. Given the character and extent of the resource base, this is the only sound strategy for development. This pattern is developing now with more and more boats mixing lobster fishing with bottomfishing and seasonal albacore trolling. Some boats are now trying their luck with deep-water shrimp. Fishermen are highly individualistic, and each has his/her own idea about whether or not to fish the NWHI and how to best fish there. The most successful fishermen are often the most guarded about their operations; it is expected that more should be heard about their failures than their successes at a public forum such as this. Fishermen, like everyone else, have a right to fail as well as succeed.

The immediate role of the WPRFMC with respect to the NWHI fisheries -- whether for bottomfish, lobsters, seamount groundfish, precious corals, or migratory pelagic species -- is to promote development within the sustainable limits of the resources. There is a sound conservation reason in doing that. By opening up Midway Islands and Tern Island for fishery support use, the risk of overfishing bottomfish stocks around the main Hawaiian islands lessens. Without the development of a distant-water fisheries, the fishing industry in Hawaii will lose commercial fishermen. The quantity of bottomfish and spiny lobsters marketed in Hawaii will decline sharply causing extremely high prices for the limited quantities that can be harvested around the main Hawaiian islands. The high prices will eventually induce more part-time fishermen to put further pressure on already reduced stocks, making present-day management problems worse.

More of the albacore boats based in Hawaii are equipping themselves with bottomfishing and longline gear, allowing them to fish for high price market species during the off-season for albacore. If the albacore tuna grounds off Midway Islands are able to sustain more boats, then more of these boats can be expected to enter the fisheries in the western reaches of the NWHI. The use of Midway Islands is essential for this kind of growth to happen.

USE OF MIDWAY ISLANDS AND TERN ISLAND

Initially, Midway Islands can be viewed as a base of opportunity, luring away more albacore boats from the mainland and even some that are now based in Hawaii. The albacore fishery will eventually diversify into multi-species operations catching bottomfish, spiny lobsters, and shrimp. If a market for frozen species can be developed, the fishery could further develop and include other species of pelagic fish besides albacore. Also, some opportunities can be seen for domestic fishermen to enter the seamount fisheries for alphonsin and armorhead, and, perhaps, even make possible a joint venture fishing operation for precious coral.

The impacts on monk seals, green sea turtles, and seabirds are not envisioned to be any different with a fishery support base at Midway Islands as they are with the present level of human uses there in support of national defense purposes. There are certain rules with respect to endangered and threatened species and seabirds that apply to present users of Midway Islands. These rules would be made applicable to fishermen using the islands. Fishermen would have to be made aware of these rules and the reasons behind them. Compliance with the rules would be a condition of the use-permit. Additional on-site enforcement presence would help guarantee compliance with the rules.

A different fisheries support role is envisioned for Tern Island. The scale of fisheries support needs there would be much smaller than on Midway Islands. The in-place fisheries support infrastructure is much more primitive on Tern Island, and the island itself is small. Albacore boats would not have need for Tern Island, because they would have access to Midway Islands. Instead, Tern Island would be used to support a small fleet of combination-gear fishing vessels from the main Hawaiian islands fishing for lobster, bottomfish, and fish caught by trolling on banks and around fish aggregation devices. Some of the products would be frozen aboard the catcher vessels and transferred to containers on a barge for subsequent shipment to Honolulu markets. Some of the fish and lobsters would be delivered in fresh form upon the vessels' return trip to Honolulu and other island ports. About 10 medium-range local boats are envisioned that would be interested in using Tern Island during the course of a year. A schedule could be worked out where no more than two or three boats could be moored in the lagoon near the island at any one time. The state of Hawaii has prepared a proposal along the lines suggested here for the use of Tern Island and has submitted it for the review to the Department of the Interior. I believe that the impacts of fisheries support use of Tern Island on monk seals and green sea turtles would be minimal if the fishery support operations are properly planned and controlled. That is the challenge that needs to be met and, I believe, can be met.

GREATER PUBLIC USE AND ENJOYMENT

To me, the word "optimum" suggests a wider spread of opportunities for our citizens to be able to fish in the waters of the NWHI, or to study or just look. To do this requires gaining controlled access to limited portions of Midway Islands and Tern Island. My long-term vision, a scenario if you will, is of more fishing whether for sport or for profit, of limited nature study tours guided by professionals, and of additional research and resource assessment and impact studies in the NWHI. The Galapagos Islands are considered to be one of the world's showcases of evolutionary processes, and yet they are not off limits to the interested lay people. Trained park rangers and natural history interpreters lead small tours of visitors through the area. Why can't a similar program be developed for selected areas of the NWHI?

FISHERIES AND WILDLIFE INTERACTIONS

My optimism for greater public use and enjoyment of the NWHI stems from my belief that fisheries impacts on food chains, and interactions of endangered species with fishing gear used by domestic fishermen, are minimal. One of the scientists who spoke the day before yesterday calculated that the populations of seabirds that roost and nest on the islands consume somewhat more than 400,000 metric tons of baitfish and other sea creatures annually. Just think about how much is eaten by the complex of pelagic tunas, billfish, mahimahi, and ono. The amount has to be staggering. Now considering that Hawaii's largest fishery, the skipjack tuna fishery, managed to produce only 16 million pounds (7,250 metric tons) in 1965, its best year ever, then a doubling or tripling or even a tenfold increase in landings of pelagic fish caught by local fishermen could not be expected to scratch the surface in terms of throwing the pelagic species ecosystem towards disequilibrium. If anything, fishermen should be encouraged to catch a heck of a lot more pelagic fishes. Whatever competition there may be in food chains, it is mostly between seabirds and pelagic species of predatory fish. The present fishing capacity of Hawaii's commercial fishing fleet is very minor compared with natural mortality in the populations of many species of migratory pelagic fish.

The lobster fishery is another example of a possible food chain interaction between a fishery and an endangered species, in this case monk seals. While an examination of a few scat and spew samples have established that spiny lobsters are a part of the monk seal's diet, the data also suggest that they are a relatively minor part of the diet and there are differences in feeding preferences among seals on the various islands. Of course, the differences may not be of preference but, rather, of prey availability. Research has shown that monk seals are opportunistic feeders, eating a wide variety of prey animals by foraging near coral reefs, over the extensive banks surrounding some of the islands, and down precipitous bank slopes, and possibly even capturing prey in pelagic waters.

By now, thousands upon thousands of lobster traps have been hauled in the eastern and central reaches of the NWHI and no monk seal/fishery interactions have been reported. There have been many observations by scuba divers at Kure Atoll and French Frigate Shoals of monk seal behavior in the presence of traps containing lobsters, but no negative interactions have been seen. To me, this suggests that monk seals, by-and-large, are not very interested in fishing traps. I would think that there is enough other prey around to satisfy the appetite and curiosity of monk seals. In short, I don't think that there is at present much of an interaction effect, direct or indirect, between the small commercial fishery for spiny lobsters and the monk seals. Neither do I anticipate a strong interactive effect between monk seals and the commercial lobster fishery in the future because I believe that the fishery will be conducted in accordance with the WPRFMC's spiny lobster FMP and that the regulations will be adhered to and enforced. I am happy to report that the federal regulations implementing the plan were put into effect on March 9, 1983. The plan is doing much to protect monk seals -- much, much more than was possible to do just 3 months ago.

I mentioned earlier that there is a budding fishery for bottomfish in the NWHI. In contrast with the main islands, the bottomfish resources of the NWHI are underutilized at the present time. The estimated annual harvest is worth a few million dollars. In the NWHI, besides the monk seal, some species of whales and porpoises, and turtles are considered threatened or endangered. None of the threatened or endangered marine species is known to feed on bottomfish, so it seems very unlikely that competition between fishermen and these animals for bottomfish as a food source can be a real factor.

The probability of incidental mortality of endangered or threatened species as a result of bottomfish handlining operations is slight, due to the great depths at which hooks are generally set for onaga, hapuupuu, opakapaka, and some other bottomfish species preferred by Honolulu's markets and restaurants. Although incidental mortality of monk seals or sea turtles can occur as a result of animals becoming entangled in lost netting or lines, domestic fishermen have never used nets to harvest bottomfish in the NWHI with the exception of a few exploratory surveys by the National Marine Fisheries Service. However, monk seals and green sea turtles have been observed tangled in net fragments. But it seems to me that the major contributors to the problem of entanglement are the foreign seamount trawl and foreign gill net vessels that normally operate on the high seas.

As a point of interest, I should mention that the apparent decline in monk seal populations in the western and central reaches of the species range happened in the virtual absence of any domestic fishery in the area. The only possible interaction in the area could have been entanglement of monk seals in fishing lines and netting materials lost or discarded by foreign fishermen operating near the area or on the high seas.

In vivid contrast, the population of monk seals has increased and shows a more normal balance in sex and age ratios precisely on those islands near where some of Hawaii's old-time fishermen have traditionally operated and where most of the recent growth in Hawaii's commercial fisheries has been. Clearly, I do not see how the present-day domestic fisheries could be implicated as a contributing factor in monk seal declines under the catch-all term "human disturbances."

Consideration has also been given to the possibility of impacts on marine mammals and endangered species of the precious coral fisheries covered by the WPRFMC's precious corals FMP. Because of the depth of the precious coral habitat and the fishing techniques used to harvest precious corals, the WPRFMC has concluded that there is little or no possibility of any such impact. While many species of fish, some of which are of commercial value, occur on or near the bottom in the depth zone of precious corals, none are known to depend directly or indirectly, on precious corals for food or habitat. Therefore, biological impacts of harvesting precious corals or other species can be expected to be less than the biological impact of harvesting precious coral itself. It is unknown what impacts could result from coral dredging on seamount groundfish habitats.

All in all, I conclude that if there are real impacts from domestic fisheries operating in the NWHI, they have to be landside impacts. Environmental problems could be caused by the illegal or emergency landing of fishermen on island preserves. The harassment of monk seals and turtles on the beach, the trampling of bird burrows and eggs as well as rare plants, and the unintentional introduction of rats and noxious weeds are all of concern to us. Monk seals and sea turtles may be displaced from their preferred habitat (NWHI beaches) due to the presence of fishing vessels that are too close or due to crew members coming ashore for either recreation or as a result of grounding. But I believe that most of these problems can be dealt with through strict rule making, education, enforcement, and contingency plans. None of these problems is insurmountable if there is a will to deal with it.

SUMMARY

In summarizing my remarks, I will say that I see Midway Islands and Tern Island as being essential to the growth of Hawaii's fisheries. Simple geography should tell us that. One cannot expect to develop a Hawaii-based fishery when major stocks of albacore tuna, seamount groundfish, bigeye tuna, and smaller stocks of bottomfish, precious corals, and spiny lobster are 1,000 miles away from Honolulu. The use of Midway Islands is essential for opening up multi-species fisheries opportunities for domestic fishermen in the northwestern end of the Hawaiian Archipelago and on the high seas.

Tern Island offers a different set of opportunities. I see a small fleet of local fishing vessels using a small portion of the island for gear storage and for rest and recreation. A barge moored off of Tern Island would serve as a depot to supply the vessels and to carry frozen catches of lobsters and fish back to Honolulu.

If carefully planned and carefully controlled, Tern Island could also eventually be used as an entry point into the NWHI for environmental education and natural history tours. Led by professional guides, the tours could include light-tackle sport fishing in areas that would not impact threatened and endangered species.

That is my general scenario of optimum-use of the NWHI. It involves more of our citizens using the area. It is based on a belief that the green sea turtle population and monk seals on each island can increase to their optimum sustainable levels in the presence of fishermen and in the presence of controls that are enforced. Hawaii fishermen have explored and used the area on an on-and-off basis since the 1930s. Names of boats like _Lanikai_, _Islander_, _Sima_, _Daikoku Maru_, _Katsuren Maru_, _Koyo Maru_, _Reliable_, _Kaku_, _Sea Hawk_, _Osprey_, and _Taihei Maru_ are legendary in the fish lore of Hawaii. Based on my own experience and on the experience of old timers, I feel that fishermen of Hawaii do not compete with the animals for food or for any other reason. I hope that I have illustrated the need for the NWHI to become more open to island fishermen who, perhaps more than any other people, are conservation and ecologically minded. In closing, I would like to suggest that perhaps it would be better to make less "last-ditch" efforts to rescue monk seals from processes which we really don't yet understand and take a more reasoned, slower, and democratic approach to wildlife conservation. I may add that by democratic approach, I mean with a small "D."

Richard S. Shomura

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INTRODUCTION

The charge to the members of this panel is for each to provide a personal view of how the resources of the Northwestern Hawaiian Islands (NWHI) can be best utilized. It should be emphasized that the viewpoints expressed in my presentation are strictly my own and do not represent those of the National Marine Fisheries Service (NMFS).

I am pleased that the discussion is organized around the concept of an optimal use strategy rather than that of advocacy positions. The former provides a more positive outlook, whereas the latter suggests a process of tearing down the opposition to make a point.

It is difficult to develop an acceptable optimal use scenario since there are many and varied interest groups to consider, and the scenario should consider the merits of consumptive and nonconsumptive resources. The interest groups include the military, commercial and recreational fishing interests, conservationists, preservationists, and the public-at-large. On the one hand the commercial interests would argue that the resources should be made accessible to provide food. They would make a further point that developing a fishery in the Northwestern Hawaiian Islands will expand Hawaii's economic base and reduce the state's reliance on imported fishery products. On the other hand, conservationists are concerned about the nonconsumptive resources and would like to see these resources maintained at optimum population levels. Of special concern are the Hawaiian monk seal and green sea turtle. Discounting the extremists, most people would like to see both objectives achieved, that is, to utilize as much of the fishery resources of the region without adversely affecting the nonconsumptive resources.

PROPOSED SCENARIO

The optimal use scenario I propose is (1) to develop Midway Islands as a major U.S. fishing base in the central North Pacific; (2) to refrain from developing all the other emerged lands of the Northwestern Hawaiian Islands, that is, allow no fishing bases or human habitation; (3) to encourage the utilization of the deep-water fishery resources, including the snappers, groupers, tunas, lobsters, and shrimp; and (4) to approach the utilization of the nearshore resources cautiously. Caution is needed to evaluate nonconsumptive resources, e.g., seabirds, Hawaiian monk seals, and green sea turtles.

The optimal use scenario I propose is based upon an assessment of the present fish marketing structure, a projection of what might happen if a number of assumptions I make are correct, and finally on a review of fishery development in the context of the nature and size of the resources in the Northwestern Hawaiian Islands.

At present, there is a limited market in Hawaii for fresh fish, especially the higher-priced snappers and groupers. If one were to discount the restaurant trade, I would guess that the consumers of fresh fish would form a pocket market. By this I mean that the demand for fresh bottomfish is not widespread. Although one could presumably overcome the marketing problem by education and promotion, a more critical problem is that of the relatively short shelf life of these species. Shelf life is of economic concern to the producers, that is, the fishermen, the dealer, and the consumer. It has been reported that the shelf life of bottomfish is about 12 days. When one considers the relatively great distance between the Northwestern Hawaiian Islands and the population centers in the state, and that the population in Hawaii is scattered over several islands, the short shelf life represents a critical problem in developing the fishery.

Within the size limits of the fishery resources in the NWHI, the growth of the fishery, in my opinion, will be dependent upon the expansion of the frozen-fish market. The expansion certainly will be dependent upon whether fish from the NWHI can be harvested and sold as frozen products at prices that are competitive with those of imported frozen-fish products. I should note that considerable advances have been made in recent years in handling and freezing fish. For example, if one agrees that the Japanese are connoisseurs of fresh fish, and a hundred million Japanese can't be wrong, then the fact that the bulk of the fish that is consumed as sashimi in Japan is landed as frozen tuna clearly demonstrates the potential for freezing fish in Hawaii.

If my premise is correct that at present there is a limited market for fresh fish in Hawaii and that the future expansion of the fishing industry to the Northwestern Hawaiian Islands depends on the development of a market for frozen fish, then the need for fishing bases in the NWHI takes on a new perspective.

Weather considerations and the lack of safe anchorages in the Northwestern Hawaiian Islands will generally restrict fishing in the area to larger vessels. Although I have not worked out the economics, I would guess that a vessel which would be capable of bottomfishing in the NWHI would probably be equipped with freezing facilities. Rather than having the catch trans-shipped from a fishing base in the NWHI, it would more likely land the catch at a port in the main islands.

Given my comments on why I do not envision a fishing base in the lower reaches of the Northwestern Hawaiian Islands, I would now like to review the resources and indicate why I feel that a fishing base at Midway Islands would be advantageous in the development of fisheries for tunas, squids, seamount resources, precious coral, spiny lobster, shrimp, deep-water fishes, and nearshore fishes.

TUNAS

For tunas we have an albacore fishery located north of the Hawaiian Archipelago at about 30°N latitude and higher. The albacore is a highly prized species with an estimated fishable stock of about 100,000 tons in the North Pacific. The U.S. catch in recent years has been in the neighborhood of 10,000 to 20,000 tons. Of this U.S. total, approximately 2,000 tons has been taken in recent years from the area north of Midway Islands. The U.S. boats in the fishery are small troll or jig boats with carrying capacities of about 30 to 60 tons. The catch is frozen on board the ship. Because of its limited capacity these albacore boats generally have to return to port several times during the fishing seasons to discharge their catch, refuel, and resupply.

In 1979, Castle and Cooke provided a mothership which operated out of Midway Islands. With a mothership, the albacore boats were able to discharge their catch at Midway Islands and obtain fuel and supplies without traversing great distances. During other years the boats had to go to Dutch Harbor (Alaska) or to Honolulu to land the catch, refuel, and resupply. Thus one can see the advantages of having a base at Midway Islands.

Based on Japanese pole-and-line fishing records, the center of skipjack tuna abundance appears to be around latitude 20°N. Skipjack tuna are also caught in the immediate vicinity of the Northwestern Hawaiian Islands. In considering the development of a Hawaii-based pole-and-line fishery to harvest this species, baitfish is a major problem. I will not go into further details of the skipjack tuna resource or discuss the yellowfin tuna resource, other than to note that purse seining is becoming the principal method of fishing for both in the central and western Pacific. It has been suggested that small purse seiners probably could operate economically in the NWHI. Thus, the albacore fishery and to a limited extent a small vessel purse seine fishery for skipjack and yellowfin tunas could make use of a base at Midway Islands.

SQUID

In recent years, fishermen from Japan as well as Taiwan have developed a fishery for squid in the higher latitudes of the central North Pacific. The squid are taken with jigging machines or gill nets. My only comment here is that a potential for a U.S. squid fishery exists in the area north of the Northwestern Hawaiian Islands. Midway Islands could serve a squid fishery in the same way it would the tuna fisheries.

SEAMOUNT RESOURCES

The seamount resources are principally armorhead and alfonsin which are taken on a number of seamounts in the central North Pacific. In recent years the Japanese have been trawling for armorhead and alfonsin in the Hancock Seamounts area. The annual catch has been less than the U.S. allocation of 1,000 tons. Similar to the squid fishery, there is a potential for the development of a U.S. fishery for armorhead and alfonsin. A base at Midway Islands would prove invaluable, especially if smaller vessels are utilized.

PRECIOUS CORAL

Several years ago foreign fishermen fishing illegally within the Hancock Seamounts area discovered new beds of precious coral in deep waters (1,000 to 1,500 m). Information on the extent of this resource is not available. Again, the precious coral represents another fishery that could be developed by U.S. interests using small fishing vessels.

SPINY LOBSTERS

At present, the spiny lobsters from the Northwestern Hawaiian Islands are being marketed live and as frozen tails. Should the market for live lobsters increase greatly, a fishing base at Tern Island could be valuable. However, if development of the frozen tail market is greater, then the need for a base at Tern Island or Midway Islands would be minimal.

SHRIMPS

Considering the very short shelf life of fresh shrimp, development of a fishery in the Northwestern Hawaiian Islands would be based on the marketing of a frozen product. A shrimp fishery, if it develops, would be capable of operating independently from a base at Tern Island or Midway Islands.

DEEP-WATER FISHES

My views of the market for the deeper-water snappers and groupers have already been presented.

NEARSHORE FISH RESOURCES

While the species composition of the nearshore fauna is different from that of the deeper-water fauna, many of the problems noted in marketing and developing the deep-water fishery resources in the Northwestern Hawaiian Islands would also prevail for the nearshore resources. One further consideration is that the effect on the nonconsumptive resources in the NWHI is much greater for the nearshore resources than it is for the deeper-water fishes. This would need to be taken into consideration in any decision on the development of fishing bases.

NONCONSUMPTIVE RESOURCES

I would like to conclude my discussion on resoures with a brief review of the nonconsumptive resources. My guess is that there are very few commercial or recreational fishermen who would take the extreme position of not caring at all about the fate of nonconsumptive resources. In fact, most commercial pole-and-line tuna fishermen are very concerned about the well being of seabirds since they depend on the flocks of feeding seabirds to locate tuna schools. For those whose priorities lean towards the nonconsumptive resources, the best thing that could happen perhaps is that no fishing bases at all would be established in the Northwestern Hawaiian Islands.

The major concern in establishing a fishing base at Tern Island would primarily be its effect on the green turtle and monk seal populations at French Frigate Shoals. The Honolulu Laboratory of NMFS is currently undertaking a study to assess the stock size of the green sea turtle. Unfortunately, French Frigate Shoals, which has been identified as the major nesting site for the green turtle, is being considered as a site for a fishing base. If one were to guess the adult turtle population in the Northwestern Hawaiian Islands I would venture to say that the figure was around 1,500 animals. Thus, for the turtles, it appears that French Frigate Shoals is extremely important. For the Hawaiian monk seal a similar situation exists in that French Frigate Shoals supports the largest fraction of the monk seal population in the chain. Based on recent animal counts, the French Frigate Shoals population represents more than 53 percent of the total population.

The question may be raised as to what effect the development of a fishing base at Midway Islands would have on the nonconsumptive resources of the region. As most of you are aware, Midway Islands has been and still is a military base; thus, people have lived there for a long time. Whether this has resulted in the present low number of turtles and monk seals is not a point that I wish to argue. It should only be noted that currently turtles and monk seals are not numerous at Midway Islands. For seabirds, the most abundant species are the Laysan and black-footed albatrosses. Roughly 40 percent of the total albatrosses counted in the Northwestern Hawaiian Islands are on Midway Islands. From all accounts the albatross population appears to be holding its own despite the presence of humans at Midway Islands. Other species that make up a large percentage of the seabird population in the NWHI include the red-tailed tropic bird, sooty tern, and white terns.

CONCLUSION

In summary, I hope I have made a case for the establishment of a single fishing base in the Northwestern Hawaiian Islands. A fishing base at Midway Islands would meet the needs of fishery development in the region while minimizing the impact on the non-consumptive resources in the area. Given the projected future direction that the fishing industry will probably be taking, there appears to be no need for a fishing base in other sectors of the Northwestern Hawaiian Islands.

Skip Naftel

Commercial Fisherman

Today I would like to address some of the points which I think are really important on issues of both developing and preserving the Northwestern Hawaiian Islands (NWHI). I don't have to answer to anybody but myself. Some people walk on the right-hand side of the road and stand a chance of getting hit by a car; others walk down the left-hand side and also stand a chance of getting hit by a car. But if you do as I do, that is, walk down the middle of the road, you stand a chance of getting hit by two cars. I think that most of the people in this symposium have been on one side or the other of the issues. As far as I am concerned, both sides have got to meet in the middle.

For example, the Tern Island issue has been going on for 11 years. I will dispute the fact that you can't medivac people out of there. I've medivacted three of my crew members out of Tern Island. The Hawaii Princess operation transported an important hydraulic part to Tern Island which the U.S. Fish and Wildlife Service people were gracious enough to put on a plane and it saved their operation. So Tern Island, I feel, has already played an important role in fishery development in the NWHI. But to let Tern Island turn into a fishing camp, if it be for support gear, support fuel, R&R, or whatever, is ludicrous -- it is just absolutely ludicrous. Anybody who has been there, and gone in and out with a boat, worries about the channel. You'd have to take dynamite and blow up part of the reef. I'll tell you, it's a no-win proposition for the fishing industry to take on the environmental concerns in the NWHI. We're going to lose!

I'd like to see the fishermen give up on Tern Island and concentrate on developing the infrastructure at Midway Islands. This is the crux of the problem if Hawaii is to become a major fishing state in the union. Many species in the seamount and albacore fisheries, as well as pelagic species, shrimp, and Kona crab have been totally overlooked near the end of the chain. Granted, there is no opakapaka up there, but the ehu fishery is unbelievable. In the Midway Islands area you put four hooks down and you catch ehu. In the seamounts area I have personally trapped alfonsin and armorhead. As for shrimp fishing efforts, we catch shrimp all the way up and down the chain. Hence, I see Midway as a major stepping stone for Hawaii to develop its fisheries.

I was wrong on lobsters. I can stand up here and look everybody in the face and say that. I wish I had 15,000 trap nights before I did what I did, but it didn't take very long to see that the lobster fishery is a small mom-and-pop operation for the John Dominis restaurant or a frozen tail market. It is not the kind of fishery that we used to talk about in spending $5 million in the last 5 years to develop in the Northwestern Hawaiian Islands.

I see four possible fisheries that could return truly high volume. The first is pelagic fish. The Japanese, Taiwanese, Filipinos, and everybody else, are all fishing it, but we're just barely into it.

The second, of course, is the seamount fishery. Within 200 miles of Midway Islands there is a tremendous volume of fish that could support a tremendous effort, but it needs the support of a fishing base at Midway Islands. Fishermen aren't going to run from Seattle or Honolulu to fish there. It doesn't make economic sense on the world market with the kind of price you get for the fish. But a small, versatile trawler, such as the kind used on the East Coast, could use Midway Islands as a base for that fishery. It is a tremendous fishery as proven by the Russians, the Japanese, and the U.S. National Marine Fisheries Service.

Number three is the squid fishery, but I'm a strong advocate of not using nets. That's where the problems are coming from. Squid can be caught by jig machines. The Japanese are using them now, but unfortunately about half the boats out there use drift nets. I think we should lobby through the international whaling commission and other bodies to get rid of the nets. They represent a tremendous potential menace to monk seals and sea turtles. So, the third fishery potential is there but only with the development of jigging machines.

Number four is the domestic, fresh-fish fishery. I believe there are about 44 longline boats fishing out of Honolulu and they're exporting the excess fresh fish out of the state. These exports are very good for the state. There is no reason why fresh fish can't be flown to Honolulu from Midway Islands. There are two MAC flights a week which go up with cargo and come back empty.

In conclusion, let me again say that we, as fishermen or conservationists, or as people working within governments, or as scientists, all have to get together and give up on Tern Island. It's a "no-win proposition." There's just not enough economic return to justify jeopardizing the wildlife. There are two endangered or threatened species there. If Tern Island were to be opened up to fishing it would just be a matter of time before somebody made a mistake, and all the seals or turtles or some birds were lost forever. So, I advocate developing Midway Islands with a processing plant and freezer facility. Let's put all of our emphasis and focus on Midway Islands where the biggest return on our investment lies. Tern Island belongs to the seals and the turtles.

REACTION PANEL

Louis K. Agard

Commercial Fisherman

I appreciate having been here for the past 3 days and being able to develop some points of view even though they may not be exactly consistent with what you have heard. And I don't expect everyone to agree with me.

It is evident that the Northwestern Hawaiian Islands make an excellent laboratory. As a member of the commercial fishing sector some observations may be in order. To put things into perspective, first as a former Sunday School teacher attending a Baptist college in California, I'd like to say that the Bible makes reference to fishermen and their role in society. Fishermen in olden times, as now, did offer a service. Today fishermen still provide an important function or they would not exist. In contrast, I have not found any reference in the Bible to fishery biologists. In this regard, with the completion of the 5-year tripartite-Sea Grant study an important question might be: what has been done on behalf of the fishermen in the Northwestern Hawaiian Islands? More regulations, more stringent restrictions? I suppose it's a natural thing to condemn previous exploiters including fishermen. I know one thing for sure, the answer is not clear but it does serve to polarize fishermen.

This all started about 81 years ago when President Roosevelt created the Hawaiian Islands Wildlife reservation. You may find this strange but some fisheries are not dependent on emergent lands, Tern Island, or Midway Islands. I do not speak against those that advocate the use of emergent lands, but there are fisheries that are practical without the need for lands in the Northwestern Hawaiian Islands. But the reason we have been here for the past 3 days is an essential difference in philosophy between a group of fishermen who are talking about harvesting renewable resources and an opposing group with a view speculating about the fate of wildlife species in the Northwestern Hawaiian Islands. A conclusion seems to have been drawn that human presence, especially fishermen, will be detrimental or even fatal to the wildlife. In this regard, there has been an argument for some time that the Northwestern Hawaiian Islands do not have sufficient resources to sustain a fishery, and therefore we should not have fisheries. I believe this is prejudicial. For example, stock assessment studies show that there might be some 150 million pounds of reef fish including large amounts of baitfish for tuna production, which is extremely important to Hawaii. I've had the experience of loading up tuna boats with bait at French Frigate Shoals in the past. Other studies reflect that there are relatively high productivity rates for the same region.

Fishermen work at their own risk and with their own capital. They are not seeking to be paid to fish, but rather to be self-reliant and self-sufficient. An overly restrictive climate in Hawaii has precluded several proposals for feasibility studies using baitfish from the lagoons of the Northwestern Hawaiian Islands for harvesting tuna. Saltonstall-Kennedy funds for this purpose have been lost. Bait is in short supply in Hawaii and the tuna industry is currently depressed. A vital element to the fishing industry in Hawaii is the tuna cannery. Some canneries have already closed down elsewhere in the world. Hopefully, these conditions will not contribute to the closing down of our long-established cannery in the near or even distant future. With regard to the economics I believe that all of us, every single one of us, has the right to choose a profession and we also have the right to fail, and I don't think that someone in Washington, D.C. or wherever should be making decisions on behalf of people who are going to put up their own capital and attempt to do a job. Fishing is important to us in Hawaii since our per capita consumption of fish is higher than any other state in the union. Even so, Hawaii still imports millions of pounds of fish; in fact it is estimated that about 75 percent of the fish we consume is imported. Harvesting renewable fisheries resources, although difficult, is essential. Hawaii's population has doubled in the last 40 years and the number of tourists has quadrupled. Fishermen are helping to meet the increasing demand for food; hence, there should be less rather than more constraints on fishing. It would seem inadvisable to try to stop immigration to Hawaii or to strangle tourism simply because we cannot manage our renewable resources.

For those of you who have not gone to sea to fish commercially -- if you'll pardon me for saying this -- you have missed a great American experience of wondering where the next dollar is coming from. And at the same time you have missed an opportunity to appreciate the real world. This is the world of fishing and, contrary to being the terrible exploiter, the fishermen is more often the exploited. They have as much at stake in the wildlife as any other segment of our society, particularly in the birds that help them to locate tuna fish schools.

Unfortunately, fishermen do not have assured incomes and must spend much of their time at sea to earn a living. This means that they have little time to be involved in popular causes which work to their disadvantage. As an example, many decisions made by policymakers do not reflect the fishermen's interests and it is not clear whether such decisions are free from severe bias. However, it seems that Congress has expressed a view that fishery rule-making should involve fishermen at every level and that fisheries should be regulated with their input. This seems to be a reasonable approach. The fluctuations of the animal populations in the Northwestern Hawaiian Islands are not solely related to domestic fishing but more often to predator-prey interactions. For example, there has been no effective fishing in the lagoon at

French Frigate Shoals since 1957 and yet declines in some species have occurred there.

In summary, fishermen question the procedure used to establish the reservation in 1903 and its relevance to the present. What benefits are offered by the reservation and to whom do they accrue? With the lack of data going back to 1903 in spite of the tripartite-Sea Grant studies, can the resources be effectively managed? Is an ever expanding governmental role envisioned with broader jurisdiction? Instead, cannot society consider the question of resource management in terms of cost-benefits? What may be overlooked is the importance of the fishermen's contribution to the gross national product, not to mention the taking of a natural resource and converting it into a benefit to society, and creating something where possibly nothing otherwise would exist -- possibly not even research.

Robert A. Jantzen

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Good morning. I'll take a part of my 10 minutes first to thank you all for your hospitality and the opportunity to attend and participate in this symposium. I also had an opportunity to visit Tern Island and so this has been a wonderful experience for me. Now I know what you're talking about. And I'd like to particularly congratulate the people who had the foresight to enter into the tripartite agreement 5 years ago. You recognized the need for information in a situation that certainly called for a solution and you had the ability to go after the information before you sat down to work on the solution. Quite often I find that's not the case. One is often in the middle of a conflict situation and must base an opinion on deductive reasoning, but it is mostly opinion and usually in a forum like this any person's opinion is just as good as anyone else's. But here you do have the facts or at least some of them.

I'm not a marine fisheries scientist or a biologist, but some of the facts kind of stick out -- for example, you have depleted fisheries around the Hawaiian islands. I think a number of people have alluded to that. There are probably a number of reasons for it. Another fact, one which came out from Mr. Shomura's talk, is that the stocks in the Northwestern Hawaiian Islands are not as high as originally thought. However, in some areas near Midway Islands apparently a significant number of harvestable fish are present. We've heard people from the commercial fishing sector speak about their efforts to develop some of these fisheries; the spiny lobsters stick in my mind, and Mr. Naftel's experience with them. Suggestion has also been made that markets can be better developed. I think we all know that can happen to a certain extent, but this brings to my mind the analogy of leading a horse to water. You can get him there but you can't make him drink. So I think that the market place has to be given an opportunity to work. You can manipulate it to a certain point but not completely.

The responsibility of the U.S. Fish and Wildlife Service on the refuge is twofold. You've heard a description of the planning process that we plan to enter into, based on an 18-month time schedule, and there's a possibility that we can accelerate that to some extent. Contrary to what some of you might believe, Hawaiian island issues are a high priority with the U.S. Fish and Wildlife Service within Region 1. We have the mainland issues too, but we are not forgetting the Hawaiian islands. The master planning effort will fold in the endangered species responsibility that we have with the green sea turtle with that of the Hawaiian monk seal, and also the overriding responsibility we have with migratory seabirds. It will help us determine what is compatible as far as the use of the refuge is concerned. Mr. Arnett mentioned yesterday that we will encourage public utilization, recreational use, and commercial use in the National Wildlife Refuge System; this is true. But what I'd like to point out is that there is no one set of criteria that can be applied universally to all 413 refuges. I'm sure you appreciate that they were all created for different reasons. All have different geographies and climatic conditions, so multiple use compatibility on a refuge is really determined on a case by case basis.

The public use question in the NWHI has been talked about in terms of commercial fishing and recreational or sport fishing. We will do our best to accommodate these concerns. And I will make this commitment to you, to take these aspects into consideration in our planning process. But it must be an open process. It has to be by law. It will allow all of you a voice in the planning process. I know the land use issue regarding the use of the refuge is in dispute and Mr. Yee commented on this. I'm not prepared to debate the issue here but if there is a dispute and it is over legal ownership, perhaps it should be settled legally in court. It may change the planning process that I'm talking about but until it does, we have a responsibility to follow accepted procedures and to meet our responsibility in protecting the wildlife.

I would like to leave you with one last thought -- another analogy. I come from the southwest United States where there is a great need for energy and transmission lines that cover great distances, and what popped into my mind in listening to this discussion and the proposal was that perhaps Midway Islands might be the place to start. It is kind of like installing a transmission line where there is an existing corridor. And I think it makes good sense that, instead of putting down another corridor, utilization be made of the one already existing. It makes good sense from a land management standpoint.

Perhaps you're looking at somewhat the same sort of a thing here, in talking about developing a fishing facility at Midway Islands vs Tern Island. If you are, I think that you're going to have to take into consideration very early, from an administrative standpoint, the main mission of the Department of Defense at Midway Islands and try and make them a full partner. I think perhaps there could be an accommodation here and I would encourage you to look at that. If you want to fully utilize state of Hawaii resources, personally, I think that an extension to Midway Islands would be much more effective than stopping at Tern Island. However, we will seriously consider the uses that can be made of Tern Island based on the information that has been presented here and the information that is going to be forthcoming.

Sheila Conant

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Just because a culture or society has a conservation ethic, it doesn't necessarily mean that its conservation measures work. Let me point out two figures to you. Since 1776, 23 endemic Hawaiian birds have become extinct. Between the time these islands were colonized by Polynesians and 1776, at least 40 species of birds are known to have become extinct. I think it's an interesting and pertinent thing to keep in mind as this discussion continues. And I want to comment or add something to what Buzzy Agard said: Thank goodness birds and lilies are mentioned in the Bible, although I haven't seen any mention of ornithologists.

The approach that I see which has dominated this symposium, and in fact much of the tripartite-Sea Grant research, has been to see if protecting wildlife resources in the Northwestern Hawaiian Islands will negatively impact fisheries. Some of us approach it from a different point of view. We want to see whether or not the fishery proposed within the wildlife refuge is going to negatively impact the wildlife. It's the same question turned around, but it makes a difference.

In my talk this morning, I really do have some optimistic conclusions, providing existing enforcement measures are effective and providing accidental landings do not result in the introduction of noxious organisms. The development of a fishing industry does not necessarily need to negatively impact the wildlife resources in the NWHI. And I do want to say that we hear an awful lot about seals and green sea turtles but I want to remind you that 12 endemic plants, probably 100 endemic insects, and 7 endemic birds also live out there. I don't hear these figures often enough so it makes my ears feel good to hear them repeated.

But again, I think the implementation of effective protection measures does not necessarily need to negatively impact the fishing industry.

Now then, it's time for me to pick my side of the road and walk down it, and I can't help it if the cars want to risk getting hit by me! I guess I'm like an albatross in that regard. Now, what are the essentials for the protection of wildlife resources out there? First of all, it's essential to minimize disturbance to the wildlife, and of particular interest here are the ones that are designated endangered or threatened, that is, green sea turtles, monk seals, and four land birds. Another essential priority is to avoid reducing seabird food sources and seabird populations. A third thing is to minimize landings -- intentional, accidental, illegal, or whatever -- on all uninhabited refuge islands to avoid introducing exotic organisms and to avoid disturbing the unique terrestrial ecosystems. It is a problem and it deserves very careful attention. There are, of course, existing federal and state laws that mandate the kind of protection I'm talking about.

If we're going to develop a fishing industry out there, there are going to be a lot of costs involved. Fisheries development is certainly risky, we all know that; the Nightingale which ran aground on Midway Islands 2 days ago is an example. With fisheries development, the need for protection will increase. Therefore, I propose in all seriousness that the fishing industry share in the increased cost. I'm not saying it must take over the cost of the U.S. Fish and Wildlife Service in sending people out to monitor resources or do research, but I do feel it should share the cost of increased monitoring and increased enforcement. For example, the U.S. Fish and Wildlife Service has already sent a biologist to Midway Islands to check the situation regarding the Nightingale. Who should pay for this? This is a legitimate question to ask. The U.S. Fish and Wildlife Service has not fared well budgetarily on the national scene so this is a fair question.

I would like to discuss a few things that I think we should consider as limitations to the development of fisheries in the wildlife refuge area. But I would like to first emphasize that we should not put all of our focus in the NWHI; let's also look at our fisheries right here in the major islands. Why are our fisheries depleted here? Let's be sure that we don't use the depletion of fisheries here as the reason to develop fisheries out there. Let's also be concerned about the health of fisheries throughout the Hawaiian Archipelago. First of all, I'm very concerned about the negative impact of inshore fisheries and I agree with Richard Shomura that nearshore development has to be approached very cautiously. And I'm very skeptical about the development of a fishery for baitfish, for example at Tern Island where there are large populations of monk seals and green sea turtles. Baitfishing involves approaching very close to land and it increases the likelihood of accidental landings (accidental introductions of plants and animals) that could result in negative impacts.

When it comes to the question of public education and public recreation, if you want to increase public appreciation at Midway Islands, that's fine. However, I believe it is highly inappropriate to even consider such a thing on uninhabited refuge islands such as Nihoa. Allowing researchers ashore is bad enough, but the public-at-large would be too hard to educate and control. I certainly think that public education is essential, but I do not advocate any kind of nature tours to uninhabited refuge islands. Midway Islands, Kure Atoll, and possibly a very limited use of Tern Island should be all that is considered for this. And it is really not appropriate to compare the Hawaiian islands, particularly the Northwestern Hawaiian Islands, to the Galapagos. The Galapagos islands are much larger, and most of them have rats and an extensive, exotic biota. When it comes to Tern Island I just have one thing to say and that is "God bless Skip Naftel." I really don't think I have to say anything more about that.

I would certainly agree with Richard Shomura and the others who are looking very optimistically at the development of a fisheries infrastructure on Midway Islands. It seems highly appropriate to me. All kinds of exotic biota already exist there so the chance of negative impact on the terrestrial ecosystems as a result of further introduction of exotic organisms is minimal. The monk seal and sea turtle populations have already suffered seriously.

Let me summarize my points. A conservation ethic does not necessarily produce good conservation. A very good enforcement infrastructure is required. So again, I think industry needs to consider sharing in the cost of increased monitoring and enforcement. I think we need regular aerial surveys of fishing boats to make sure that regulations are being followed. And I think we also need to consider the judiciary. Let's have no more $25 fines, "slaps on the wrists" as it were. Let's talk about some serious fines, and this may require educating the judiciary. I also think it should be written into fisheries development plans and refuge management plans that a response to monitoring efforts is required. For example, if seal or turtle populations begin to decline, we should target what fishery is involved and try to mitigate the impact. One of the biggest problems, of course, is that we don't know what contributes to a significant population decline so we've got to continue monitoring in order to find out.

Finally, I would like to conclude by saying that I feel the wildlife resources in the Northwestern Hawaiian Islands are clearly a matter of global significance scientifically, aesthetically, and culturally. I also feel that fisheries resources in the NWHI are primarily, because of their scale, of local and limited significance. In other words, I feel the economic returns must justify the risks that we are proposing to take and there seems to be considerable skepticism in this group that the economic returns are going to be great enough. Certainly people should have the freedom to decide how they are going to make their living, but they had better be ready to bear the responsibility entailed. That obligation extends far beyond Hawaii and far beyond the United States. It is an important obligation that we must not lose sight of in optimizing resource management in the NWHI.

William G. Gordon

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Ladies and gentlemen, I would first like to congratulate not only those who organized this outstanding program of research but also all those researchers who spent time and effort in completing what must now be considered indeed a major programmatic achievement.

Rather than comment too intensively on the talks that have already been given, I would like to raise several new issues and questions as a challenge to you. First, I think people should think very carefully about the magnitude of investment that the United States has made in the refuge system and the research and enforcement that is associated with it. This program represents a multimillion dollar investment over the years, similar in kind to what we have in fisheries management. I think we're learning from the experiences of the past that, by and large, the major problems have been caused by the misinformed, the short-sighted, and the very greedy. We have to understand that man is the ultimate predator and will remain so. I wonder what Queen Isabella would have done had she had a conservation ethic and a concern for the biota of North America before she turned Columbus loose. But nevertheless, the fishing industry in the United States, I believe, is one that has a tremendous growth potential unlike the textile, auto, steel, and a number of other industries which are giving way to more competitive foreign markets. When I look at fishing from my perspective, I wonder why we're buying 50 percent or better of what we consume in this nation when we have roughly 15 percent of the world's living marine resources that are all renewable within our conservation zone. At the same time we allow a variety of foreign countries to enter our zone to fish and take the product to the world market. In looking around, you candidly have to agree that perhaps in our haste we have overregulated a number of industries in this country. As a result we have been losing ground to the rest of the world and we'll continue to lose ground unless this trend is reversed. The Magnuson Fishery Conservation and Management Act of 1976 (FCMA), which the rest of the world looks upon as one of the most far-reaching fisheries management acts ever passed, provides a good foundation for management of fisheries as well as other resources. It calls for the best scientific information to be used, but candidly, I wonder if the best scientific information is always used. We give way to emotion, short-sightedness, and greed in many of the decisions we make in this political world. There can and should be multiple use and wise use, particularly if we are to use our scientific information correctly.

Some people speak about U.S. presence in the Pacific which has been very great since World War II. We were handed the custodianship for a vast number of islands and I think we can turn and look at that custodianship and say we have done very well. However, some of these islands have turned from almost a self-sufficient economy to one where they import most of their food including fish. Is that trend going to continue or can we turn it around? There has been a lot of talk during the last 3 days about the scientific aspects but very little comment on the socioeconomic aspects of the island communities. I submit that we must change the way we manage our fisheries. Take the major Hawaiian islands as an example. The comment has been made several times here that the nearshore resources of these islands are depleted. I ask the question, why? Where is that conservation ethic? In my 25 years with the fishing industry, I think I can say that many fishermen are biologists without the benefit of a degree. Of course sometimes they don't see the big picture. We have to inform them of the big picture. Once the fishermen, the leaders of the fishing community who make their livelihood from the sea, understand the big picture, I find that most of them are ardent conservationists, demanding better management. Unfortunately, it's not the professional fishermen who generally cause the problem. In my view, it is a group that would exploit for the short term without wisdom or concern regarding the results of their exploitation.

I think too we must examine international aspects and take them into full consideration. One problem is by enforcing withdrawal of foreign fishing fleets to areas outside of our 200-mile limit, they may intercept resources destined for our 200-mile zone. Another problem is the highly migratory species which, I think, are going to be seriously impacted by fisheries beyond the 200-mile zone where there is no conservation ethic. It's a situation of catch today before someone else does tomorrow. So let's not be too hasty in regulating inside of our 200 miles until we face up to implications of managing international waters.

A number of people have made comments on the U.S. budget. When fully one-third of the national budget is aimed at entitlement programs such as unemployment, food stamps, and retirement systems; about one-quarter is spent on defense; about one-eighth is interest payment on the money that the goverment has borrowed from somebody; and about the same amount is available to all other civilian components of the government; then who pays for conservation programs? Within the FCMA we can sock it to the foreigners, but the law says we can't charge any of the domestics other than for administrative costs of issuing a permit to fish. I go back to my point: should we not change the way we manage fisheries?

Lastly, I'd like to talk about the role of science. I have heard that we are going to use science in a regulatory mode. Why don't we turn that around and use science so we don't have to regulate. Management does not necessarily imply regulation. Let's apply the science in a way which minimizes the impact of regulations, if that is at all possible. What we are trying to do is achieve better and wiser use of our living resources. And we should use science to inform the uninformed, and use regulations to get at the short-sighted and the greedy.

I will leave you with one final point, and that's the role of animal husbandry in the management of our living resources. Humankind is not too concerned about using genetics when it comes to cows or chickens or pigs, or fish. And some would claim that the world hasn't changed much since the Pleistocene, and that everything is static. But what happened to the saber-toothed tiger and the woolly mammoth? Now I don't think man wiped them out -- nature did. And evolution is still ongoing for even us. I don't remember too many 7-foot tall basketball players when I was in college. So let's think about how we can apply some of the techniques of animal husbandry to preserve, maintain, and enhance our fishery resources rather than just accept the fact that all we can do is lock it up or let nature take care of it.

Craig D. MacDonald

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Let me begin by stating that the state of Hawaii in general, and the Department of Planning and Economic Development in particular, is committed to improving the climate of business in Hawaii by supporting and protecting Hawaii's existing productive enterprises and diversifying the local economy by developing new, preferred-growth industries such as commercial fisheries. Currently, Hawaii's fishing industry accounts for only about eight-tenths of 1 percent of the gross state product. There is no question that the potential for expanding the industry is found in the distant-water fisheries of the Northwestern Hawaiian Islands. But there is the question of how best to proceed. Even though the optimum use scenarios have not stated so specifically, there is a distinct division of opinion that focuses on whether Tern Island at French Frigate Shoals should become a fisheries support station or whether it should remain a field station in support of a wildlife refuge. This polarization of opinion could seriously retard development of the multi-species fishery resources of the Northwestern Hawaiian Islands unless the Tern Island question can be resolved.

First, let me emphasize that French Frigate Shoals is important to the state of Hawaii as a wildlife refuge. The bird resource there is of national and international significance. In excess of 90 percent of all green turtles in Hawaii breed and nest there. In excess of 53 percent of the total population of Hawaiian monk seals live there. The highest diversity of fish and coral in the Hawaiian Archipelago is at French Frigate Shoals, including corals of the genus Acropora, which are very notable ecologically. Let's also consider the finding that the establishment of fishery development facilities at Tern Island apparently may not generate revenues large enough to offset probable environmental impacts.

In this regard, it is important also to realize that the potential impact of fishery development on the biological systems of the entire archipelago is of a much greater scale today than heretofore experienced in Hawaii's history. We only have to think about the profound differences in fishing power now relative to just a few years ago. And what about the even more efficient technological advances of tomorrow? Also consider the difficulties that have arisen in managing fisheries throughout the world. Even in cases where the data base is extensive enough to afford elegant, sophisticated mathematical treatment the record of management is not flawless. Then too think about the information that still needs to be collected to best manage our natural resources in the Northwestern Hawaiian Islands. Collectively we've made great strides in assessing the resource potential over the past 5 years, but we are just beginning to understand the dynamic complexities that are involved. It therefore makes sense to preserve options for doing new things in the future by exercising restraint in the way we harvest resources now. Now is the time we should experiment with new schemes of management to gain experience and better understanding.

Considering both the biological complexities and the sociopolitical problems associated with development of a multi-species fishery adjacent to a wildlife refuge, I believe managers of both sets of resources should be concerned with two major questions involving the interaction between wildlife and fisheries. First, what kind of practical benefits might the wildlife refuge have for managing adjacent fisheries? Second, what fishery practice would be most compatible with the management of the wildlife refuge? In answer to the first question my studies on spiny lobsters afford an example. The fisheries research I conducted on Hawaiian spiny lobsters since 1979 has been done almost exclusively within state and federal wildlife refuges in the Northwestern Hawaiian Islands. This research has provided, and continues to provide, much of the biological information required by the Western Pacific Regional Fishery Management Council in managing the commercial fishery for spiny lobsters in this area.

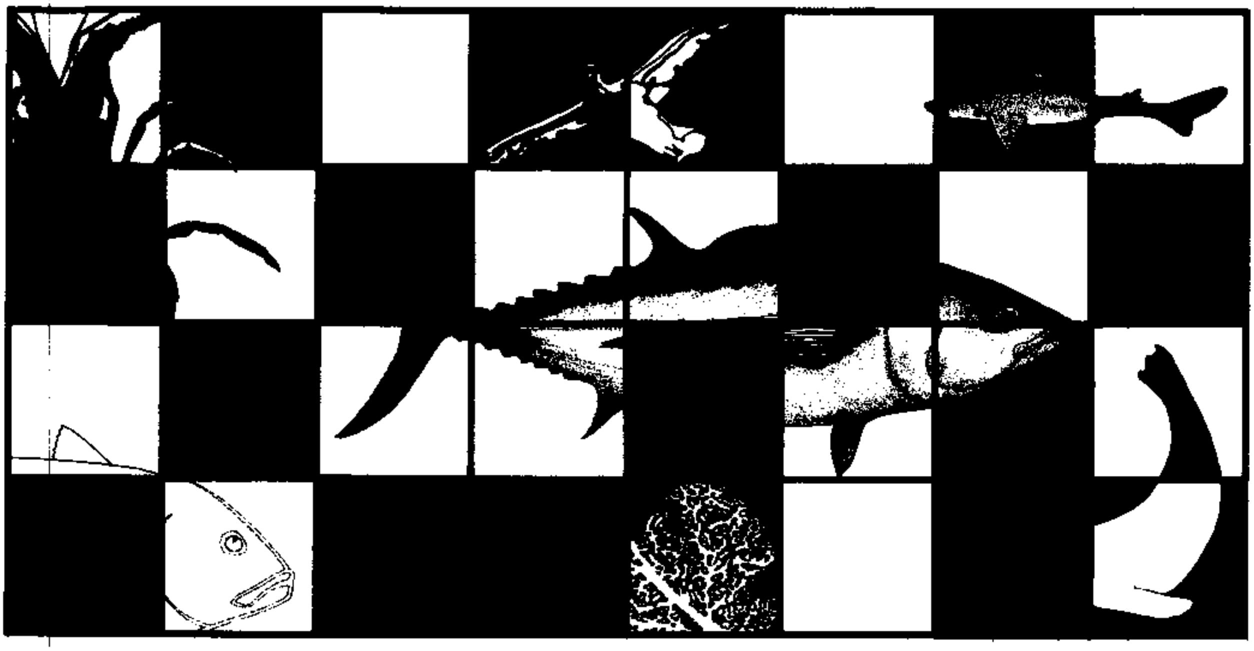
A wildlife refuge can thus provide fishery managers the opportunity to assess population characteristics of commercially important species in the absence of any history of fishing. Additionally, a refuge can provide the opportunity to assess the effects of a variety of fishery management regimes either through controlled experimentation within the refuge or by comparison with changes occurring outside the refuge. These opportunities simply will not exist on the commercial fishing grounds unless fishing is temporarily halted, or unless areas are closed, and such steps could be detrimental to the fishermen.

In answer to the second question, I suggest that fishery support operations that exist entirely at sea would be most compatible with management of a wildlife refuge. In this regard, I believe that all of the support functions necessary for a multi-species fishery for bottomfish, lobsters, and shrimp in the Northwestern Hawaiian Islands conceivably could be based entirely from a mothership. Given an appropriate mothership, local fishermen could fish from their own boats and sell their catch to the mothership while receiving fuel, ice, bait, and fresh water as part of a negotiated agreement. The savings and direct costs to local fishermen could be comparable with any analogous nearshore support operation based in the Northwestern Hawaiian Islands but should not involve environmental risks to the refuge.

However, let me present just a brief scenario as an example to demonstrate that we haven't begun to exhaust options for management. If an appropriate mothership is not available locally, an international joint venture with a country fishing the high seas around the seamounts north of Hawaii might be considered. Additional benefits of such a joint venture, also exist. Frozen bottomfish, for example, for which there is little present demand in Hawaii, could be marketed immediately through established channels within foreign markets and thereby accelerate development of that fishery. Ex-vessel prices paid to local fishermen presumably could be stabilized because there would be no market glut. Tax revenues paid to the state would increase along with productivity -- exchange of know-how, technological advances, and deeper cultural ties all of which are important to Hawaii's future would increase. The terms of any such agreement could be set for a limited number of years with options to phase in or out as economic conditions dictate. This could prevent overcapitalization of the local industry. Fresh fish could also be provided to traditional markets whenever local fishermen return to the main Hawaiian islands. This is just one possible option that could be developed, simply to indicate that our thinking doesn't have to be set in concrete.

Finally, I agree that fisheries operations in the vicinity of Midway Islands, either as a shore-based operation or in association with a mothership, appear to involve far fewer environmental risks and potentially much higher yields. Thus, I feel that fisheries development in that region of the archipelago should be particularly encouraged.

Public Discussion



PUBLIC DISCUSSION

This portion of the panel discussion was open to audience participation. Individuals were instructed by the chairman to identify themselves and then either make a comment or direct a question to one of the panelists.

Richard Grigg, Chairman: The discussion is now open to the audience.

John Carroll: I'm John Carroll, a former state legislator here in Hawaii. I suppose Wadsworth Yee, Alika Cooper, and Frank Goto, and perhaps James Whatton will want to give me a thrashing after this comment but nonetheless. First of all, I've had the legislative experience of trying to introduce over a 10-year period measures which were designed to protect resources in the Northwestern Hawaiian Islands and I was delighted to hear Mr. MacDonald's comments because they seem to be diametrically opposed to what I heard in the legislative sessions during the time that I was there. I introduced legislation particularly with respect to the protection of lobster populations and during that time, which was between 1976 and 1978, testimony was presented against the bill by Skip Naftel, Leo Ohai, and others. About 3 years ago Leo Ohai came forward with a log book showing catch records for Necker Island of about 5,000 to 6,000 lobsters taken per night at the beginning and 18 months later when the catch was reduced to 17, 18, 2, 3, and 0. The bottomline in commercial exploitation, as far as I'm concerned -- and I'm speaking only as a private citizen -- is profit. Over the same period of time that the state was allowing lobster fishing at Necker Island, three of the people who went up there ended up either bankrupt or abandoning the fishery. I understand what Skip Naftel said, and I certainly applaud his comments, as well as his courage to make them.

To the extent that we can rely on the data that has been produced by the tripartite-Sea Grant studies we should go forward and maximize or optimize harvest in the fisheries area. But the final point -- and I think this is a key point -- is that we're looking at maximizing the returns from commercial uses but we must not overlook the fragile nature of these islands. If you have not been on the islands I don't think it is possible for you to understand. And I say this to Wadsworth Yee, who I know has been up there, and others that if we allow the intrusions, if we allow anything to happen to disturb the nearshore ecosystems, we're going to need two, three, or perhaps several hundred years for recovery to take place. I think we need to maximize the use, but we cannot afford to do anything that will threaten or destroy the use of these ecosystems.

I congratulate you folks for coming together. While I used to stand alone in the legislature on this subject, it sounds like somebody in the Ariyoshi administration is getting the word, and I appreciate everybody's involvement here. Thank you.

Chairman Grigg: Mr. Carroll's comments were directed at several panelists so I invite any of you to react. Do you have any reactions? Wadsworth Yee.

Wadsworth Yee: Yes, I too am a former legislator like John Carroll and I hope the state and federal governments will see fit to declare us an endangered species. Well all kidding aside, the reason I opposed the resolution is that we asked one of the experts, Dr. Craig MacDonald, for the best available information and it was his findings that we had used to determine the extent of harvesting lobster in the Northwestern Hawaiian Islands. It wasn't our idea. Now you talk about Skip Naftel and why he gave up. I don't know why, but I remember at one time Skip wouldn't give us information for the lobster management plan. And we were going with a much larger quota then than what was finally adopted. Our management plan accommodated Skip Naftel and he knows it. These are facts.

Chairman Grigg: Existing law provides for modification of MSY [maximum sustained yield] to OY [optimum yield] to take into account socioeconomic considerations. The lobster case is an example where MSY was modified for socioeconomic reasons.

Skip Naftel: First of all what Wadsworth Yee and John Carroll said is correct. Back in the seventies, we were fishing with one boat, engaging in a very small effort compared with the effort which has been expended recently. Pure and simple, the reason that I got out of lobster fishing is that the numbers did not hold up. Marine biologists made a model on the data base that we first experienced out there. The Cromwell was fishing only 28 to 35 traps per night at Necker Island and we went through 1977, 1978, and 1979 and the catch held up. Since then it has increased to a 2,000 trap per night effort, and the catch has really dropped. The natural turnover of the lobster was not enough to support this kind of effort. At the same time I fished the 2,000 traps, two other boats were fishing 2,000 traps at night. So at one time there was a 6,000 trap per night effort compared with a 28 trap effort back in 1975. Basically, it was just a problem of overcapitalization.

Alika Cooper: My name is Alika Cooper. I feel this seminar has been very detrimental to the fishing industry. I think it's biased and I think it represents brainwashing. What I see here is a lot of PhD's, a lot of transient people, and a lot of intelligent people. Most of the speakers are transients; we have heard from only one native Hawaiian on the panel and there are probably only two of us in this whole room. I hope that the audience will be broad enough to look at the Northwestern Hawaiian Islands as a whole, and not be brainwashed by this seminar. I would like to address the following things. One is that the Northwestern Hawaiian Islands are ceded lands -- some 3.5

acres. These lands belong to the state of Hawaii, held in trust for the Hawaiian people. They do not belong to the federal government. The territory leased these lands to the U.S. Coast Guard, then to Buzzy Agard, then back to the Coast Guard, and when Tern Island was returned it passed illegally from the Coast Guard to the U.S. Fish and Wildlife Service, and the Fish and Wildlife Service doesn't own these islands. I want this to be clear.

I'd also like to address the scientists who spoke. I think in the tripartite agreement the scientists were employed to do scientific research on their subjects, not to make decisions whether anybody can fish in the area or if anybody cannot. And I would appreciate it if the audience would remember that.

I want to talk about the birds. You had a lady speak of birds who is very biased towards the fishing industry. I don't think she understands that Kaahumanu, who was Kamehameha's favorite wife, went to the Northwestern Hawaiian Islands in the early 1800s for two purposes: one, to get bird feathers, and two, to reclaim the Northwestern Hawaiian Islands as our eighth ocean. The Northwestern Hawaiian Islands are our eighth ocean. Hawaiian people from Niihau went to the Northwestern Hawaiian Islands for many years to get the bird feathers. They didn't kill the birds, they got the feathers from the bolsom bird. You look at the kahilis. On the Big Island you only have white feathers. In the Northwestern Hawaiian Islands they're all colored. Hawaiian people lived on Nihoa, Necker Island, French Frigate Shoals, and possibly some other islands as well. These are our ancestors -- these are Hawaiians.

I now want to talk a little about the seals. We have been brainwashed; for years we've heard that the commercial fishermen are guilty of killing all the seals. When we left French Frigate Shoals in 1951, there were twice as many seals as there are now. Now, nobody's fished there all these years, except on occasion. Let's look at what happened to the seals. In the upper Hawaiian island chain you have ciguatera, one of the main causes of the seal population dropping tremendously. The second cause is humans -- transient people, the Coast Guard people, the people in the Navy. For them it was nice to kill a young monk seal for the pelt. It was a big trophy. And they took their helicopters and worked the close islands. I talked to a chief who had been at French Frigate Shoals and he said, "Well we used to shoot glass balls but we also shot a hell of a lot of seals and turtles." So I don't want the fishing industry to be blamed for this. When we fished there the population grew, not only the seals and the birds but the turtles too because we caught a hell of a lot of sharks. I don't appreciate pictures of dead turtles and some dying and another transient person saying this is a commercial fisherman from Hawaii in 1959. The picture of that turtle could have been shot anywhere. I think that's a low blow! We did take turtles -- I caught turtles -- but we never took anything smaller than 200 pounds, and we never took more than the market demanded and we could have never supplied the market -- it was just a part-time thing. And I think the turtle stock today is better than it's ever been. For the last 15 years the turtle stock has increased.

In this symposium I have heard nothing about aborigine rights. What about native Americans? All you panelists, don't they have any rights? Why do we go to court year after year after year winning all the big cases? We even beat Laurence Rockefeller for fishing and trail rights. Now why can't we be included in planning? Why can't we be included in the beginning? We've fished in the Northwestern Hawaiian Islands; our ancestors fished there. The fishing industry was not really included in the tripartite-Sea Grant study, just a few choice people -- people like Naftel, you know, mainland fishermen. The problem is that we were not included so we don't have a say, and if this body or any other body is going to govern our destiny, then we damn well better have our people in there. This is very important.

The last thing I want to say is the Governor of Hawaii, Governor Ariyoshi, Sus Ono, Land and Natural Resources, and DPED, not including this transient fellow who spoke, have done a tremendous job in trying to make our fishing industry viable. They've worked very hard and we in industry really appreciate it. I wish some day I could say the same about the federal government -- maybe when their track record gets better, we can. But I will leave you to say that I hope you're not going to be brainwashed by these people and I hope next time there's something like this we have equal representation. Thank you very much.

Chairman Grigg: Thank you Alika for voicing your point of view and making it a part of the published record. Would any of the panelists like to respond?

Sheila Conant: I think that a lot of things that Alika Cooper said is also biased. I'm getting a little bit too old to sit here and listen to this kind of thing. Mr. Cooper asked me some questions on Monday which I could not answer. There are a lot of things I don't know. When I asked him for some information he told me to go do my homework and then he would talk to me. I wish that if this information which is so important for aboriginal rights and for planning fisheries development exists, that he would tell us where it is instead of just telling us that we should do our homework. I've been doing homework for years and I don't know who's been making the assignments, but I feel that I am learning a little bit. Queen Liliuokalani went to Niihau in 1885 with 200 people to collect feathers. They set fire to the island and burned down most of the vegetation. Again, I really feel that if this information is so important we should be apprised of it.

Alika Cooper: We'd like to give it to you. Of course at this time we're tired of giving free information to everybody so if you'd like to pay for it we'd be very happy to give it to you.

Chairman Grigg: Is there any other reaction from the panelists?

Dale Coggeshall: This is strictly a reaction to Alika's concern, but it also addresses Buzzy Agard's concern. I concur with Agard's comments that fishermen, or other user groups, have had a great deal to do with developing a conservation ethic in our country. The same applies to those involved in the management of public lands, government service, and the management of public resources. My point is that under the conditions at the time those activities occurred, attitudes and the level of our understanding were different. We cannot and should not condemn people individually or collectively for them. Pointing fingers, assigning blame, or identifying bad guys does nothing to help manage resources better in the future. As Skip Naftel pointed out in reference to lobsters, let's use the information we have, and profit from our past mistakes to improve upon management decisions in the future.

Chairman Grigg: Thank you Dale. Skip will you like to add to that?

Skip Naftel: Alika, first of all you are correct. I'm from the mainland but I love these islands as much as you or anybody else in this room. Last year I filled out 86 W2 forms. I didn't hire one guy from the mainland. I presently have 43 local boys working for me. Now, I know you're insulted but I just have to say that many people love these islands -- the native Hawaiians, the haoles, and even your ancestors. And I want to work hard with you and every other fisherman out there. I just believe there's room for all of us to work together.

John Craven: I want to address this issue, and I think it's a very delicate and difficult issue to address publicly but I want to start out in my characteristic style by being somewhat facetious. The first point is that the Hawaiian people are relatively recent arrivals to these islands in terms of the history of man. The second point is that all of us are qualified under some regulation or other of being an aborigine from somewhere. I am an aborigine from the Iberian Peninsula. My ancestors were aborigines in the Iberian Peninsula. In 1493, the Pope declared that the navigable waters of the Pacific (and Atlantic) were under the sovereign jurisdiction of the Iberian peoples. For the next few centuries nations fought with the Iberians and maintained that the Pope's edict was an illegal appropriation by the aborigines of the Iberian Peninsula. Since that time there have been other actions taken by many other people with respect to the jurisdiction over these islands. Thus, a long sequence of actions of appropriation and misappropriation, some of which are still legal and some of which are not legal and will need to be rectified. But the situation that we do face is that whatever claims there are still valid with respect to legal jurisdiction over these Hawaiian Islands and whatever legal arrangements are still in force with the Hawaiian aborigine people should be honored. Some of these legal arrangements are not clarified and should be clarified, but when they are clarified we should operate in full concert with them. It is equally true that 25 years ago, Hawaii became a state of the United States of America. And one of the rules about the United States of American is that there are no citizens of one state alone. We are all citizens of any state in the union. Now this is the nature of the law of the land that every citizen of the United States is a potential citizen at his or her election of the state of Hawaii. Therefore every citizen of the United States is part of the public interest and public concern as to the future of these islands. I think as we approach the future we will do well to realize that we are all *Homo sapiens*, all aborigines of somewhere or other but we must exist here now with some form of law and order and within that framework we ought to be able to accommodate and deal appropriately with the rights of each subgroup of the human species.

Hugh Wright (Department of Defense): I'll start out by saying that the Navy as an entity would like to support fishing proposals within the guidelines and regulations that we have to live with. We, of course, have certain missions that oblige us to secure the island for certain periods of time without prior notice. When that happens there are restrictions on people moving around, particularly on Sand Island at Midway. Some individuals on Midway Islands may also have to move out. I don't know why, I just know that these things come up from time to time. As far as supporting the facilities that have been proposed, they will have to be self-supporting. We're not in the business of transporting live fish through MAC flights to Hawaii. Also the MAC flight is down to one per week now. And we are not allowed to sell fuel. These are federal laws that we have to deal with. We've helped out the researchers in the past, but only one time. That was it! The one and only time! As far as this being an on-going thing I don't think it will happen.

Proper planning for fishery development at Midway Islands has not taken place. You talked about everything else, but when you come right down to it you've come up with Midway Islands as being the most important facility to support outside fisheries in the state. Yet I have not been contacted nor has the Navy been represented on this panel. With proper planning they could have been. Thank you.

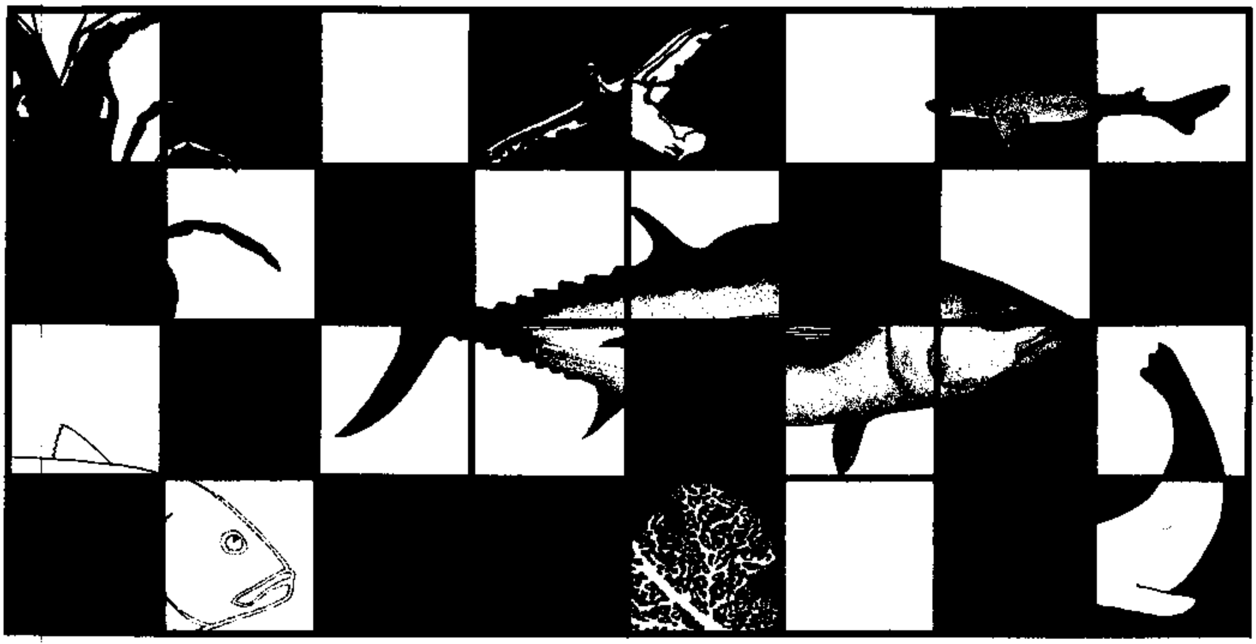
Chairman Grigg: If I could retain your attention for a moment. I think what Mr. Wright is saying is that the Navy is receptive to helping the state establish a facility for fishing at Midway Islands that is controlled in such a way that will solve security problems. It looks like the door is open and the

Navy is willing to entertain a dialogue so let's look upon this as an opportunity worth pursuing.

Henry Sakuda: As a point of clarification, if you remember we didn't have an approved fishery base in 1979 at Midway Islands. It was only a mothership. Since then, the industry has not been able to come up with another ship to maintain the operation. The Navy has been very hospitable, in fact, very cooperative. They've done all they could do. It's just that the economics of the operation has not been able to produce a mothership or any other kind of operation at this time. Now we're talking mainly about establishing a fishery base at Midway Islands. Nothing else. Midway Islands fisheries are real; the boats are out there fishing right now. There are trawlers from the West Coast and also some from here. We're not talking about something that is pie in the sky. We're trying to establish a fishery base and the capability for transshipment to Honolulu. The state of Hawaii and the legislature have appropriated funds for a study of the feasibility of these plans. We have engaged a consultant group to come up with various scenarios for Midway Islands and this has to be done with the full concurrence of the Navy. All these scenarios must comply with Navy regulations. The study is planned to be completed before the next session of the legislature begins. We want to present the results to the legislature. However, before we do this some decisions must be made on recommendations. This will involve the fishing industry, the National Marine Fisheries Service, the Western Pacific Regional Fishery Management Council, certainly the Hawaiian Fishery Council, and I imagine the U.S. Fish and Wildlife Service. The decision whether or not to build a fisheries base at Midway Islands could very well be the deciding factor in determining the future of fisheries development in Hawaii for years if not decades to come.

Chairman Grigg: Thank you very much Henry for wrapping things up so neatly, especially since the time is up for the public discussion.

Concluding Remarks



CONCLUDING REMARKS

John P. Craven

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What can we now know, that we did not know, before the completion of this remarkable investigation of the Northwestern Hawaiian Islands? We now know so much more of substance about the Northwestern Hawaiian Islands and the main Hawaiian islands that we will no longer let anyone engage in discussion about this area with vague and unspecific generalizations. There is now no area of concern for which there is not significant scientifically based information from which we can start.

What do we know? We know the geological development, the interaction of the geological-biological processes of the formation of our islands and how they have grown and are growing and how they are sinking in the ocean. We all know where the Darwin Point is. We know that there are 14 million seabirds, of these, we know that there are 6 million residents and 8 million visitors. These 6 million residents and 8 million visitors eat more biomass in total than the 1 million human residents and 4 million human visitors to these Hawaiian islands eat.

We know that we have a leeward chain of Hawaiian islands which have a unique and fragile terrestrial community. We know that the monk seals are their own worst enemies when it comes to their survival. We know that whole green turtles can be consumed by an individual shark. We know a lot about stock assessment. We have a somewhat modified understanding now of the energetics, the predator-prey and toxin relationships.

We now know that the reef community can produce, under appropriate management, a meaningful, sustainable yield -- and I choose the word meaningful; socially, culturally, and possibly economically, sustainable yields in the reef community. We know that we can have a significant but not major -- from a world standpoint -- yield of alfonsin, armorhead, and other bottomfish. We know we can have a significant yield of shrimp and pelagic fish and we can have a major yield of squid. e can have a culturally and perhaps economically sustainable yield of precious coral. We know the bounds and the nature of primary and secondary production in the waters of the Hawaiian Archipelago; and we can derive the limit of the total productivity of these waters.

And quite surprisingly and quite magnificently, we now have a simplified and linear model of the ecosystem which, when calibrated with our knowledge about the top level of the chain and our primary productivity, gives us the ability to fairly safely interpolate in between. And we know that we can employ this model to examine adaptations and to determine what happens as we introduce humans as the top level predator in this ecosystem. We have learned from our studies that while it may be easy to introduce humans into this particular model we know less about the behavior of humans, their energetics, their management, and their capabilities than we would like, but we do know more about the behavior of humans as a result of the tripartite-Sea Grant studies than we did before.

I learned something about my own behavior. Last week, a good, kind friend tried to explain to me that the reason I get fired every month is because I am dogmatic and rigid. I now discover that so are 35 percent of my colleagues. We have also found out that market place economics do not and cannot explain our decisionmaking processes nor is it even possible to explain market place economics by the generation of "utility functions." But we do know that the preservationists, as a tribe, and that the exploiters, as a tribe, have viewpoints which are not markedly different from each other. They differ only in shade and tone, or in sharp disagreement over specifics (i.e. whether Tern Island is a concrete aircraft carrier or a natural fragile part of the total ecosystem).

We do know that there are regimes of the chain which suffer from lack of jurisdictions and management. Those jurisdictions that do exist bear little relationship to the geographic migrations of the resource or the harvest of these resources. We realize once again that the green sea turtle, in his life cycle starts out in a wildlife reserve, enters disputed waters to a depth of 10 fathoms, then proceeds through state waters up to the 200-mile economic zone; it may wander through federal protection out in international waters, it comes back into state waters, it will probably migrate through areas still under aboriginal protection in terms of konohiki rights before it completes its entire life's journey.

So we have learned all of these facts about the Northwestern Hawaiian Islands and we've learned these facts with less detail as we would have liked but in more detail and with more understanding than most of us had thought, and we've learned about the linkages between them and how they relate in various models.

While we have been learning, what has been happening to these islands? Fortunately, while this process of learning has been going on, there have been no recent major irreversibilities in the ecosystem of the Northwestern Hawaiian Islands. We have heard that the land environs are still -- I think I'll quote Sheila Conant's words -- "relatively pristine environments." There is still much to be preserved and to be nondisturbed and which is sufficiently primitive and pristine that we must learn more about. While we were learning we have pulse-fished two fisheries. We have pulse-fished the lobsters and we've learned about the limited sustainable yield which does exist, but we have not destroyed lobsters as a fishing resource. Other people have pulse-fished the alfonsin and the armorheads, but we have not destroyed that resource.

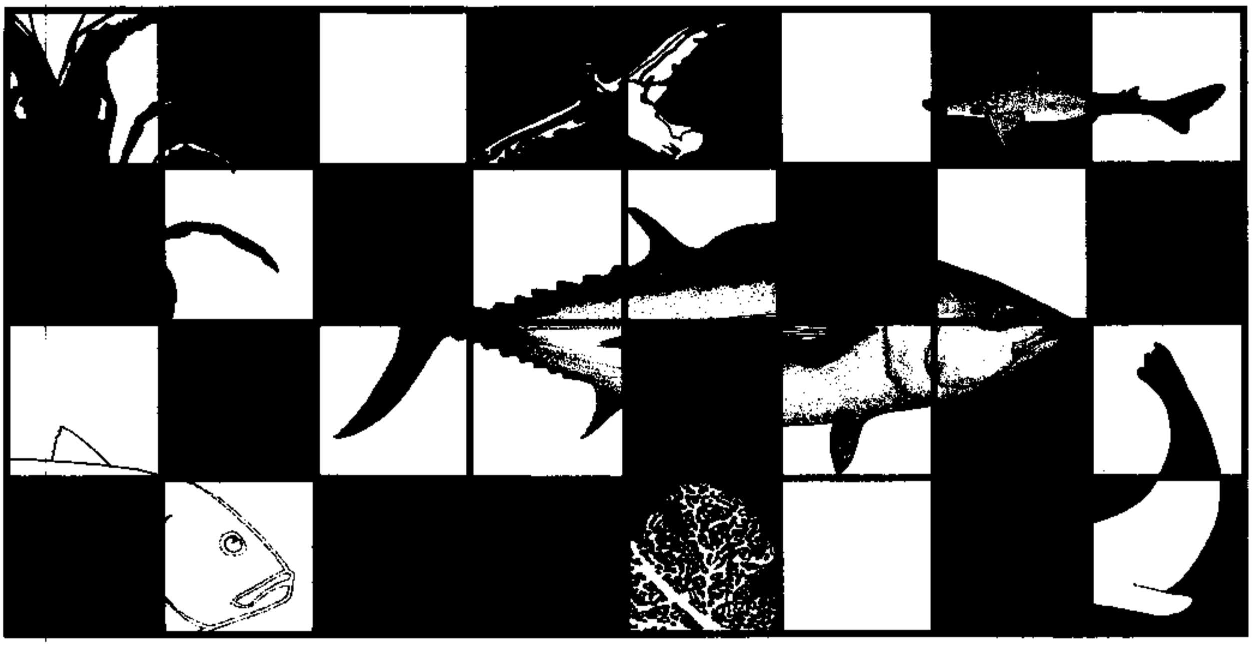
So while we have been studying we've had no major irreversibilities. Thus, in a timely manner we may face the key question that this whole study has lead us to. And that is, are we not now ready to start to take specific management actions? Do we not now have enough information to permit us to start in a meaningful way to manage this resource in the way it should be managed? Are we now not ready to publish pamphlets and distribute them to everyone which explains the procedures and measures of conducting ourselves so that we can be appropriate visitors to the islands; on those rare occasions when we must visit these islands either as shipwrecked people, as military, as fishermen, or as researchers.

Are we not now ready to make a significant reduction in the shark population, not only for the value of this resource but in order to eliminate this top predator and permit some relief to the green sea turtle and to open up the development of other resources which this predator has taken? Are we not now ready to establish protection areas for the spawning of lobsters, counting upon the currents to carry the larvae to all areas of the region, and are we not ready to eliminate the carapace restriction in the harvesting of lobsters recognizing that as we toss the illegals over the fantail we are merely feeding the ulua? Are we not now ready to castrate a significant number of the male monk seals?

Are we now not ready to take action as far as human organization and management with respect to this Northwestern Hawaiian Islands? Are we now not ready to have the Congress introduce legislation that will make Midway Islands, Palmyra Atoll, and Johnston Island a part of the state of Hawaii so that the entire chain falls under one jurisdiction? But more importantly, are we now not ready for the legislative introduction of a state, federal, and aborigine compact to establish a Northwestern Hawaiian Islands management authority? Can we not use a cooperative management . . . so that we have need no longer to worry about the question as to whether we are being managed? Above all, can we relieve the green sea turtle of its concern as to whether it will be managed by the U.S. Fish and Wildlife Service, or the National Marine Fisheries Service, or by Sus Ono, or by Alika Cooper.

Chairman Grigg: Thank you very much John for those very exhilirating remarks. And I think all the researchers here today are greatly appreciative and gratified. I think we've enjoyed this program. It's almost sad to see a large part of it come to an end. As far as being ready to better manage, I think only time will tell, perhaps in the next 18 months. Not only will time tell but it will also inform us whether we can manage the system better than we have. Now I'd like to ask all of you to bear with me just for a few minutes. I've had a great deal of help in putting on this symposium and I'd like to acknowledge these people who have over the past 3 or 4 months really been there for me. I'd like to thank Donna, Patty, Colleen, Lisa, Holly, and Joan Yamada and Joan Choy for organizing that effort and Peter Rappa, Sea Grant Extension Service information specialist, who coordinated that activity. I'd also like to thank Wendy Nakano who is the artist at Sea Grant, who so skillfully designed the logo that has been used for just about everything including our name tags. And I'd like to thank the people at Saga for providing the luncheons, our sound people, and the projectionist. Publication of the abstracts in your registration packet was provided by Kitty Simonds of the Western Pacific Regional Fishery Management Council. Finally, I'd like to thank all of you for coming, for caring, and for making this not just a symposium but the milestone that I think we all hoped that it would be. I thank our speakers for their excellent presentations, our panelists -- so provocative and stimulating with new and fresh ideas -- and again, I thank John Craven. He always seems to have just the right thing to say, to leave us with a feeling of inspiration and an idea of where we might go from here. And I think in the next 18 months that the body of knowledge that has been developed here will be put to better use so that the resources in the Northwestern Hawaiian Islands can be better managed and that the resources that need preservation will indeed in the next 75 years thrive and in some cases increase as we heard Dale Coggeshall so idealistically project. So thank you all and at this point I would like to officially close this symposium.

Research Reports



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AGE DETERMINATION, GROWTH, AND ENERGETICS OF THREE SPECIES OF CARCHARHINID SHARKS IN HAWAII

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ABSTRACT

Three species of carcharhinid sharks are the most abundant top predators in the shallow water (<150 m) reef community in the Northwestern Hawaiian Islands (NWHI), but very little is known about their age, growth, or energetics. These are the gray reef shark (*Carcharhinus amblyrhynchos*), the Galapagos shark (*C. galapagensis*), and the tiger shark (*Galeocerdo cuvier*).

Vertebral samples from 62 gray reef, 45 Galapagos, and 28 tiger sharks were obtained primarily from longline fishing efforts in the NWHI. Vertebral centra were cleaned and stained with silver nitrate to allow the visualization and counting of presumed annual growth rings. These age data were used in conjunction with length and weight information to generate growth curves for the three species. These curves correlate well with curves obtained independently from length frequency analysis of earlier fisheries statistics for Hawaiian sharks. The close correspondence between the two types of growth estimates used verifies the annual nature of the vertebral rings in these sharks.

Respirometry measurements of captive sharks, combined with the growth estimates and estimates of reproductive energy, allowed computation of ingestion rates by solving a simplified energy budget. Population estimates were made, and the sharks' diets were determined through stomach content analysis. Data and estimates were combined to obtain a very preliminary suggestion of the predatory impact of these sharks on the shallow-water reef fauna of French Frigate Shoals and Midway.

energetics
growth rates
age determination
carcharhinid shark
Northwestern Hawaiian Islands

INTRODUCTION

Three species of carcharhinid sharks are the largest top predators found in the Northwestern Hawaiian Islands reef habitat and occur commonly in shallow water (<150 m) (Taylor and Naftel, 1978). However, little work has been done on determining their growth rates or estimating their energy budgets. The three species are the tiger shark, *Galeocerdo cuvier*; the Galapagos shark, *Carcharhinus galapagensis*; and the gray reef shark, *Carcharhinus amblyrhynchos*. Information on their growth, energetics, and diet are particularly important. Any management plan for the NWHI must consider the predatory impact of these sharks on other reef fauna.

Age Determination and Growth

Estimation of age in elasmobranchs has been accomplished by counting the number of rings on vertebral centra or other ossified parts. A summary of species aged and the methods used is given in Table 1.

Respiration and Energetics

Little work has been done on estimating the respiratory rates of sharks, particularly for *Carcharhinus* spp. Gruber (personal communication) reported an estimate of 200 to 300 mg O_2/kg-hr for *Negaprion brevirostris* (Carcharhinidae) in Florida and Bimini. Estimates of oxygen consumption using flow-through respirometry, combined with growth and reproductive energy data, permit preliminary solutions of the energy budget (Ricker, 1968; Webb, 1978):

$$AI = G + B + R + E$$

where

I = food ingested
G = growth
B = respiration
R = the energy cost of reproduction
E = loss due to excretion
A = the assimilation coefficient

TABLE 1. REVIEW OF METHODS OF AGE DETERMINATION USED TO ESTIMATE GROWTH RATES IN VARIOUS ELASMOBRANCHS

Species	Area	Method	Verifications	Author
Carcharhinidae				
C. leucas	Gulf of Mexico	Silver nitrate/ section	None	Haskell (1948)
C. taurus (= *leucas*?)	NW Atlantic	Alizarin red-S	None	La Marca (1966)
C. leucas	NE Atlantic	Section/histology	None	Hoenig (1979)
C. obscurus	NE Atlantic	Section/histology	None	Hoenig (1979)
C. falciformis	NE Atlantic	Section/histology	None	Hoenig (1979)
Prionace glauca	NE Atlantic	Silver nitrate	Leng.-freq.	Stevens (1975)
Negaprion brevirostris	Florida Bay	Tetracycline	Tagging	Gruber (in progress)
Sphyrna lewini	NE Atlantic	Section/histology	None	Hoenig (1979)
Mustelus manazo	NW Pacific	Histology	Time of ring formation	Tanaka and Mizue (1979)
Lamna nasus	NW Atlantic	X-rays/section	Leng.-freq.	Aasen (1963)
Cetorhinus maximus	NE Atlantic	Sectioning	Leng.-freq.	Parker and Stott (1965)
Squalus acanthias	NE Pacific	Read directly	Leng.-freq., tag	Ketchen (1975)
	NE Pacific	X-ray spectroscopy	Correlated temperature	Jones and Geen (1977a)
Rajiidae				
Raja fusca	NW Pacific	Histology	Leng.-freq.	Ishiyama (1951)
R. eleganteria	Delaware Bay	Histology	Leng.-freq.	Daiber (1960)
R. calvata	NW Atlantic	Tetracycline	Tagging	Holden and Vince (1973)

Respiration in this case would be a measure of the energy expended in basal metabolism and swimming at low speed. Since these sharks swim continuously without resting, this total respiration represents a kind of standard metabolic rate that is the lowest rate of long-term ecological interest. Based on the above energy budget, estimation of the growth rate, respiratory metabolic rate, rate of reproductive energy use, excretion rate, and assimilation coefficient permits estimation of the ingestion rate.

MATERIALS AND METHODS

Most fishing was conducted with standard longline fishing methods to permit comparisons with earlier studies (Ikehara, 1961; Tester, 1969; Fujimoto and Sakuda, 1972; Naftel et al., 1976; Naftel and Taylor, 1976; Taylor and Naftel, 1978). A few sharks were also caught by handlining in shallower waters, and some small sharks were caught incidentally in lobster traps in deeper waters. Most sets were made for about 12 hours overnight; some day sets were also made. All fishing was done on or near coral reefs in water depths of 1 to 40 m. Standard longlining permitted the recording of catch per unit of effort data necessary for population estimates.

After landing, sharks were identified and measured. Vertebrae were sampled below the first dorsal fin and frozen for storage and later analysis in the lab. Stomach contents were either frozen or fixed in 10 percent Formalin and later analyzed in the lab. Reproductive condition was also noted, and most shark fetuses were saved for later analysis.

Age Determination

Age was estimated using vertebral centra following the method of Stevens (1975). The centrum surface was cleaned of all connective tissue using a spatula to peel off the tissue without damaging the centrum. Stevens (personal communication) stored his samples in 70 percent ethanol which denatured the connective tissue, but a similar condition of the connective tissue can be achieved if the vertebrae are cleaned while still frozen. Although it is nearly impossible to remove the tissue once it has thawed, it can be refrozen to facilitate removal.

Vertebrae were soaked in three changes of distilled water for 5 minutes each to clean the samples and then placed in a 0.06-M silver nitrate solution and "developed" for a few minutes on each side, in the presence of a 366-nm, 115-v ultraviolet light (Ultraviolet Products UVL-22), until the rings were visible. Stained vertebrae were rinsed in distilled water and placed in a 0.2-M solution of sodium thiosulfate for 4 to 6 minutes. This acted as a fixative and stopped the activity of the silver nitrate. Vertebrae were next placed in a final rinse of distilled water for 5 minutes. The rings were counted while held at reading distance or under 10x magnification. Vertebrae were stored in 70 percent ethanol for a permanent record.

EDAX analysis on a scanning electron microscope and x-radiographs proved less satisfactory than visual examination in detecting and counting rings. Further details of procedure are available in De Crosta (1984).

Growth Estimates

Vertebral counts were used, together with measured precaudal length, to generate the best fitting von Bertalanffy growth curves using the methods of Walford (1946) and Ricker (1958), assuming the rings are annual. In order to confirm the time scale of growth, these curves were then compared with those generated from length-frequency analyses of Tester's (1969) earlier data, using the method of Cassie (1954). Tester's (1969) data were used because that study produced a much larger sample size and would therefore give more reliable results than an independent length-frequency analysis.

Independent estimates of growth rates were also made using the method of Holden (1974). In this method, von Bertalanffy growth curves are generated from an extrapolation of the embryonic growth. The von Bertalanffy growth curve,

$$L = L_\infty (1-e^{-K\ (t - t_0)})$$

can thus be simplified to

$$L_{t+T} = L_\infty (1-e^{-KT})$$

where

L_{t+T} = length at birth
L_∞ = maximum observed length
T = gestation period

With these values, the equation can be solved for K which is used with the L_∞, and T values to estimate a von Bertalanffy equation. Values for L_∞ were used from Tester's (1969) data. Gestation period was estimated at 1 year for gray reef sharks (Ikehara, 1961; Wass, 1971; this study) and for tiger sharks (Holden, 1974). Gestation period for Galapagos sharks was assumed to be 1 year; these data are lacking for this species but other carcharhinid sharks have a value of about 1 year (Holden, 1974).

Mass-length relationships were derived for all three species using a combination of earlier data (Tester, 1969; Taylor and Naftel, 1978) and data from this study. Growth rates for each age class were determined by converting average age class lengths to mass and estimating the average growth rate for that age class. Data were then used for growth estimates in the energy budget.

Change in mass of the sharks was converted to calories to standardize the energy budget. Caloric values were obtained from a near-term *Carcharhinus amblyrhynchos* fetus that was homogenized in a blender and aliquots taken, dried, and burned in a bomb calorimeter.

Respiration Measurements

Estimates of respiration rates were obtained from performing flow-through respirometry measurements on a congeneric species, *Carcharhinus melanopterus*, the reef black-tip shark. Specimens of this shark were available for use through the cooperation of the Waikiki Aquarium. Attempts to return live specimens of the three main species of this study from the NWHI were not successful, and attempts to catch the sharks alive around Oahu failed. It was assumed that respiration rates for *C. melanopterus* could be extrapolated to estimate respiration of the other species because it is ecologically similar to *C. amblyrhynchos*. Currently, there are no published respirometry data for a *Carcharhinus* species with which to compare the results of this study.

Flow-through respirometry was used in this study in order not to stress the sharks with low oxygen concentrations (Fry, 1957). Two Yellow Springs Model 57 polargraphic sensor oxygen meters were calibrated concurrently and used to measure oxygen concentration upstream and downstream of the shark swimming in a 1,000-liter oval tank. The chamber was about 30 cm high and designed to allow the shark to swim about normally. Water entered at one end of the tank and exited at the other. The shark was placed in the chamber with the top sealed for about 3 hours, until readings stabilized. Temperatures ranged from 24 to 25 C and oxygen concentrations from 3 to 6 ppm. Flow rates of 4 to 6 liters/min were used. Oxygen concentration upstream and downstream, shark swimming speed, and temperature were recorded every 15 minutes. When the concentration of the oxygen exiting the chamber had stabilized, the system was assumed to be at equilibrium, and the flow rate and difference in oxygen concentration were used to determine the sharks' oxygen consumption.

Respiration rate measurements were made on six juvenile *C. melanopterus* on display at the Waikiki Aquarium. These values were adjusted for the mass of each shark, averaged, and converted to calories using an average factor of 4.8 kcal/liter oxygen consumed (Schmidt-Nielsen, 1975).

Diet

Stomach content samples were sorted and identified to the lowest possible taxonomic level and, when possible, the mass and length of the prey items were measured or estimated. Caloric information on diet items was obtained from the literature, permitting the energy value of the diet categories to be compared with the computed energy demands.

RESULTS

More than 200 sharks were caught during the course of this study, resulting in a sample size of about 30 to 65 for each species considered in these determinations. All species of sharks caught and catch rates by island and cruise are recorded in Table 2. Pooled data from all islands included 95 gray reef sharks caught, 52 percent with stomach contents; 65 Galapagos sharks, 46 percent with stomach contents; and 35 tiger sharks, 80 percent with stomach contents.

Growth

Of these, 62 gray reef, 45 Galapagos, and 28 tiger sharks were sampled for vertebrae and their ages estimated. The equations for the von Bertalanffy growth curves, assuming the rings are annual, are:

gray reef shark: $L_t = 134\ (1-e^{-0.294\ (t\ +\ 0.869)})$

Galapagos shark: $L_t = 230\ (1-e^{-0.172\ (t\ +\ 0.541)})$

tiger shark: $L_t = 335\ (1-e^{-0.155\ (t\ +\ 0.619)})$

where length is in centimeters and age in years after birth. These relationships are plotted in Figure 1.

The hypothesis that vertebral rings are formed annually is strongly supported by the close correspondence of these von Bertalanffy growth curves with curves generated from the length-frequency analysis of Tester's (1969) data (Figure 1). These data were from 158 gray reef, 144 Galapagos, and 204 tiger sharks. The respective equations for the length-frequency based curves are:

gray reef shark: $L_t = 137\ (1-e^{-0.237\ (t\ +\ 0.802)})$

Galapagos shark: $L_t = 230\ (1-e^{-0.197\ (t\ +\ 0.670)})$

tiger shark: $L_t = 337\ (1-e^{-0.150\ (t\ +\ 1.27)})$

with units as before.

There is also close agreement with growth curves derived by using the method of Holden (1974). These curves are:

gray reef shark: $L_t = 146\ (1-e^{-0.230\ (t\ +\ 1)})$

Galapagos shark: $L_t = 217\ (1-e^{-0.228\ (t\ +\ 1)})$

tiger shark: $L_t = 332\ (1-e^{-0.149\ (t\ +\ 1)})$

with the same units. This correspondence is further evidence for annual formation of the vertebral rings, assuming that the estimates for gestation period are reliable.

TABLE 2. CATCH PER UNIT OF EFFORT AT FIVE NORTHWESTERN HAWAIIAN ISLANDS LOCATIONS FOR ALL SHARKS CAUGHT BY STANDARD LONGLINE FISHING (NUMBER OF SHARKS PER 100 HOOKS)

Location	Date	No. of Fishing Days	Species Caught*							No. of Sets	No. of Hooks/ Set
			C. a.	C. g.	G. c.	C. l.	C. m.	C. o.	S. l.		
Maro Reef	9/78	4	5.0 (4)	18.8 (1)	5.0	2.5	0	0	0	5	16
Nihoa	11/78	3	0 (4)	25.0	31.3	0	0	0	0	1	16
Necker	11/78	1	25.0	18.8	12.5	0	0	0	0	1	16
French Frigate Shoals	11/78	3	9.4	6.3	9.4	3.1	0	3.1	0	2	16
	3/79	2	6.3 (4)	0 (3)	31.3 (1)	0	12.5	0	0	1	16
	10/79	4	11.8	8.3	4.2	0.7	0	0	0.7	5	16
	5/80	3	10.4	7.3	0	0	0	0	0	2	32
	10/80	15	7.4 (5)	7.4	0.7	0	0	0	0	5 2 3 4	16 32 6 3
Midway	8/80	22	2.6 (17)	0	10.3	0	0	0	0	9 1	4 3
	12/80	2	0	12.5	25.0	0	0	0	0	2	4

Note: Numbers in parentheses are total number of sharks caught by handline.

*C. a. = *Carcharhinus amblyrhynchos*, C. g. = *C. galapagensis*, G. c. = *Galeocerdo cuvier*, C. l. = *C. limbatus*, C. m. = *C. milberti*, C. o. = *C. obscurus*, S. l. = *Sphyrna lewini*

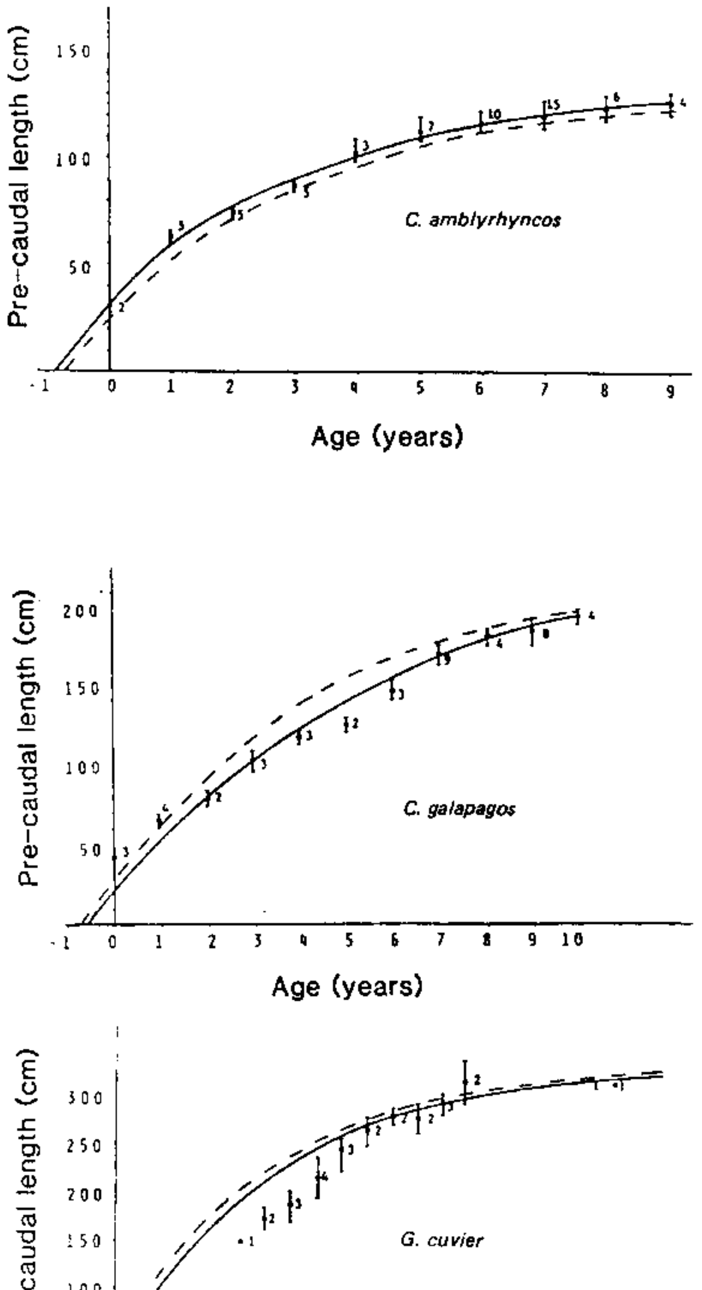

Figure 1. Von Bertalanffy growth curves calculated from the vertebral age determination data (solid line) -- with the mean length of year class indicated by dots, the range by bars, and the sample size by numbers -- and from a length-frequency analysis of data from Tester (1969) (dashed line). See text for equations.

Relationships between mass (M) and pre-caudal length (L) were determined for all three species of sharks using data from Tester (1969), Naftel and Taylor (1976), and this study. These relationships are:

gray reef sharks: $M = 1.25 \times 10^{-5} L^{3.05}$, with $r = 0.993$, based on $n = 164$ specimens

Galapagos sharks: $M = 8.07 \times 10^{-6} L^{3.14}$, with $r = 0.997$, based on $n = 67$ specimens

tiger sharks: $M = 6.21 \times 10^{-6} L^{3.16}$, with $r = 0.994$, based on $n = 29$ specimens

where M is in kilograms and L is in centimeters. These relationships were then used to compute growth curves in terms of mass. Instantaneous growth rates were estimated graphically for each age class by determining the slope of the tangent of the von Bertalanffy growth curve (Ricker, 1958) (Table 3). Caloric equivalents of these values were used in the energy balance to estimate ingestion rate.

TABLE 3. ESTIMATES OF AGE-SPECIFIC YEARLY GROWTH RATES OF SHARKS IN THIS STUDY (KG/YEAR)

Age Class	*Carcharhinus amblyrhynchos*	*Carcharhinus galapagensis*	*Galeocerdo cuvier*
1	3.13	2.78	7.75
2	4.54	6.29	17.0
3	4.98	9.46	26.2
4	4.71	11.4	32.1
5	4.01	12.3	37.6
6	3.47	12.9	40.7
7	2.67	13.9	39.9
8	2.06	11.5	37.0
9	1.58	11.0	39.0
10	1.32	12.0	37.0
11		9.19	34.0
12		7.73	28.0
13		8.20	25.0
14		6.29	26.0
15		4.31	18.0
16			19.0
17			19.0
18			15.0
19			10.0
20			10.0
21			11.0
22			10.0

Respiration

The mean respiration rate for six individual *Carcharhinus melanopterus* weighing about 1.5 kg each was determined to be 246 mg O_2/kg live mass-hr with a standard deviation of 26.9. This value agrees well with the range for lemon sharks (Carcharhinidae: *Negaprion brevirostris*) of 200 to 300 mg O_2/kg live mass-hr for sharks of similar size (Gruber, personal communication). Oxygen consumption, B, in vertebrates is usually considered to be related to body mass by a function such as $B = aM^b$. In most fishes, b is between .75 and 1.0 (Paloheimo and Dickie, 1966; Mann, 1965; Winberg, 1956, 1961). Using the respirometry results and body mass, a functional relationship between B and M was developed and this equation was used to estimate the oxygen consumption for all sizes of sharks. Caloric equivalents of the B values were used in the energy balance to estimate ingestion rate.

Diet

Results of the stomach content analysis are given in Table 4. These data suggest that the tiger shark is a very opportunistic feeder, preying on a wide range of fauna, including seabirds (in 75 percent of all predator specimens), sea turtles (33 percent), lobsters (30 percent), cephalopods (22 percent), and slow-moving, "well-protected" tetraodontiform fish (15 percent). It may also take monk seals, porpoise, other sharks, and other teleost fish groups in smaller quantities.

The Galapagos shark showed the most restricted range of diet items, primarily cephalopods (43 percent), tetraodontiform fish (21 percent), eels (14 percent), and parrotfish (7 percent).

The gray reef shark appears to be the most highly piscivorous of the three species, with perciform fish occurring most frequently (51 percent) and eels (>12 percent) also important. Cephalopods also make up a major part of their diet (>22 percent), but not to the same extent as in Galapagos sharks.

DISCUSSION

The von Bertalanffy growth curves generated fit the age determination data fairly well (Figure 1). This model may thus be considered a good descriptor of the growth of these sharks, as it has been for other carcharhinid sharks (Olsen, 1954; Moss, 1967, 1972; Wass, 1971, 1973; Holden, 1974; Stevens, 1975; Tanaka et al., 1978; Tanaka and Mizue, 1979; Hoenig, 1979; Francis, 1981) and for sharks from other families (Aasen, 1963; Holden, 1974; Ketchen, 1975; Jones and Geen, 1977b; Hoenig, 1979). The curve fits best for the gray reef shark (Figure 1), which may be due partly to the larger sample size. For the other two species, sample sizes are adequate to fit an approximate curve, but some points are considerably off the curve, and for tiger sharks, data are lacking for a number of age classes.

TABLE 4. PERCENTAGE OF OCCURRENCE OF FOOD ITEMS IN SHARKS (ALL ISLANDS POOLED)

Prey Items	*Carcharhinus amblyrhynchos*	*Carcharhinus galapagensis*	*Galeocerdo cuvier*
Monachus shauinslandi	—	—	7.1
Stenaella longirostris	—	—	7.1
Aves	—	—	75
Chelonia mydas	—	—	33.3
Chondrichthyes	—	—	7.1
Anguilliformes	12.4	14.1	3.6
Muraenidae	—	3.6	—
Congridae	2	—	—
Ariosoma sp.	2	—	—
Ophicthidae	2	—	—
Myrichthys maculosus	2	—	—
Beloniformes			
Cypselurus sp.	—	—	3.6
Gastereosteiformes			
Aulostomus chinensis	2	—	—
Mugiliformes			
Sphyraena sp.	—	—	3.6
Perciformes	51	28.3	14.8
Apogonidae	—	—	3.6
Carangidae	—	—	3.6
Scaridae	2	7	—
Scarus sp.	2	3.6	—
Calotomus sp.	—	3.6	—
Acanthuridae	2	—	—
Acanthurus nigroris	2	—	—
Cottiformes			
Scorpaenidae	2	3.6	—
Tetraodontiformes	2	21.3	14.8
Balistidae	—	3.6	3.6
Monocanthidae	2	14.3	3.6
Pervagor spilosoma	2	10.7	3.6
Diodontidae	2	3.6	7.1
Diodon sp.	2	3.6	7.1
Chilomycterus affinis	—	—	3.6
Decapoda	4	—	29.6
Heterocarpus sp.	—	—	3.6
Palinuridae	2	—	25.9
Panulirus marginatus	2	—	11.1
Scyllaridae	—	—	18.5
Scyllarides squammosus	—	—	11.1
Cephalopoda	22.4	42.9	22.2
Octopus sp.	20.4	39.2	14.8
Teuthoidea	4	10.7	18.5
Charonia tritonis	—	—	7.1
	N = 49	N = 30	N = 28

The von Bertalanffy growth curves fitted to length-frequency data from the earlier Tester (1969) study agree closely with the curves from the vertebral age determination data (Figure 1). The convergence of these independent results forms the basis for the conclusion that the rings are laid down annually. This method of correlation has been used in a number of studies (Ishiyama, 1951; Aasen, 1963; Parker and Scott, 1965; Ketchen, 1975; Stevens, 1975).

The close agreement of the previous curves with the calculated von Bertalanffy growth curves using Holden's (1974) method is a good test of the efficacy of Holden's technique. His method allows for the determination of the growth curve and age-specific growth rates of elasmobranchs using only the length of gestation period (T), size at birth (L_{t+T}), and maximum observed length (L_∞), which are often obtainable from the literature. In this way, first order approximations of growth can be made and used in preliminary management decisions when data are minimal (Holden, 1974; Francis, 1981). The ability to manage in this way may become important as sharks become increasingly sought after as a source of protein and other products in new fisheries.

The energy costs of female reproduction were also considered for the calculation of caloric expenditures in the energy budget. Of the sharks caught around the high Hawaiian islands, 63 percent of the mature female gray reef sharks, 17 percent of the Galapagos sharks, and 24 percent of the tiger sharks were carrying pups (Tester, 1969). In the present study, 63 percent of the mature female gray reef sharks were found to be pregnant. Average pup number per female was 5 for gray reef sharks, 9.5 for Galapagos sharks, and 34.5 for tiger sharks (Tester, 1969). Age at first reproduction for females was determined at 6 years for the gray reef shark and 10 years for Galapagos and tiger sharks. Average pup masses were 329 gm for gray reef, 1.14 kg for Galapagos, and 754 gm for tiger sharks. The annual reproductive energy cost for each species of shark was obtained using these pup masses, the average pup numbers above, the percentages of pregnant females, and a caloric value of 970 kcal/kg live mass. The results were applied to the energy balance computations for all reproductively mature age classes.

The estimates of growth, respiration, and reproduction permitted a preliminary and approximate solution of the energy budget to estimate ingestion, I:

$$I = \frac{G + B + R}{A}$$

The caloric value of ingestion was computed separately for each shark species, for each age class using the age-specific growth rate, age (size) specific respiration rate, and the energy cost of reproduction (based on an estimate of the proportion of mature females in each age class). All terms in the budget were expressed in kilocalories.

Rough, preliminary estimates of shark populations at French Frigate Shoals, Midway, Maro Reef, and Pearl and Hermes Atoll (Taylor and Naftel, 1976) were attempted in this study using the method of De Lury (1947), which estimates the original population size from declines in catch per unit of effort. Probably the most reliable results are those from French Frigate Shoals and Midway where fishing effort was greatest. No gray reef sharks were caught at Pearl and Hermes Atoll.

With an estimate of the population size of the sharks and a determination of their energy needs, a rough calculation of total shark predation and predation on various prey items is possible. The ingestion rate calculated from the energy budget for each age class for each species was multiplied by the number of sharks in that age class as determined by the estimate of the population of sharks for each island and the distribution over the age classes of the sharks caught (Tester, 1969; and this study). These values were then totaled for each shark species.

French Frigate Shoals yielded:

gray reef shark: 1.25×10^8 kcal/yr total food intake

Galapagos shark: 2.56×10^8 kcal/yr

tiger shark: 3.73×10^8 kcal/yr

An independent estimate of the total ingestion rate was also obtained by dividing the sum of the total growth and energy allocated to reproduction by an assumed average gross growth efficiency of 20 percent. These latter calculated values are between 5 and 8 times lower than the former estimates from the energy budget determinations. This may be due to an underestimate of the value for reproductive cost and/or the error associated in extrapolation of respiration to very large sharks. However, these estimates do permit first approximations.

The consumption of various prey groups by the shark populations was estimated based on the relative importance of the prey groups in the sharks' diets as revealed by stomach analysis (Table 4). The values of total consumption by the populations of the three shark species on the various diet groups for French Frigate Shoals were obtained using both estimates of total ingestion (to provide a range of possible values) (Table 5). Results are given in terms of biomass of the prey groups eaten per year. This was converted to number of prey individuals by dividing these values by the average mass of a prey individual. No attempt has been made to compare these derived values with independent, direct estimates of production of these prey. Such production figures may become available through ecosystem studies being coordinated by J. Polovina, NMFS, Honolulu Laboratory.

TABLE 5. ESTIMATE OF YEARLY SHARK PREDATION AT FRENCH FRIGATE SHOALS

Prey	Mass (kg)	Number
Monk seals	1,000	2-4
Dolphins	1,000	2-4
Sea birds	12,000-56,000	4,000-18,000
Turtles	42,000-200,000	2,700-13,000
Sharks	8,800-42,000	440-2,000
Eels	5,250-37,000	5,000-35,000
Perciform fish	21,000-150,000	13,000-100,000
Parrotfish	4,000-29,000	2,000-14,000
Tetradontiforms	9,000-29,000	4,500-14,000
Spiny lobster	600-3,000	1,500-9,000
Slipper lobster	200-1,000	500-2,000
Octopus	31,000-180,000	45,000-220,000
Squid	1,400-9,000	10,000-80,000
Triton	260-1,300	400-2,500

Note: Estimated concentration of sharks (number sharks/100 km^2) based on De Lury method (see text) -- _Carcharhinus amblyrhynchos_, 93; _C. galapagensis_, 324; _Galeocerdo cuvier_, 50

Values for annual biomass consumption were computed similarly for Midway. The general trends are much the same in the two locations, although absolute values at Midway are much lower due to smaller area and smaller shark populations. The relative abundance of the three shark species is about the same in the two locations.

Shark energetics may also be considered from the perspective of total ecosystem productivity and idealized trophic levels. At French Frigate Shoals, where the best data are available, an average net primary productivity value of 6 x 10^9 kcal/km^2-yr might be estimated (Grigg and Hirota, personal communication).

Assuming a constant efficiency of 10 percent in transfer of energy from one trophic level to the next, going through five hypothetical trophic levels would reduce this value by a factor of 10^5, resulting in a value of 2-3 x 10^4 kcal/km^2-yr. Total shark productivity is estimated at 2.65 x 10^4 kcal/km^2-yr, a very similar value. If all the primary productivity that passed up the trophic pyramid came to sharks, this would imply that sharks are about fourth order carnivores. The evidence from stomach content analyses suggests that they average not higher than second or third order carnivores. If so, then some of the production passed to their trophic level is available for other carnivores such as ulua and other reef sharks, and some energy may be exported from the reef ecosystem to pelagic sharks and tunas or lost from the reef at lower trophic levels. The estimate for shark population production is generally reasonable enough by comparison with primary productivity to lend credibility to the above estimates of shark population and energy terms. If 25 to 50 percent of the annual shark productivity is taken as an estimate of maximum sustainable yield, 6,500 to 13,500 kg of shark meat per year would be available to a fishery at French Frigate Shoals. Other constraints on a shark fishery would be imposed by the advanced age at reproductive maturity and possible effects on the sharks' food base caused by development of fisheries for other species.

Ecosystem modeling studies can provide valuable insights for the fishery management process. It is important to determine the effects of sharks on the system because of their high trophic position and their large energy flows. This may be especially true for the tiger and Galapagos sharks which are the two largest fish in the system and can consume an important variety of large prey.

For considerations of protecting sensitive species, it is significant that the tiger shark is a major predator of the threatened green sea turtle and may also attack the endangered monk seal. Another management consideration is that these sharks are, or will be, in direct competition with present and potential fisheries for lobster and finfish in this area. A suitable ecosystem model can provide predictions of the effects of this competition on catches and on populations of various components of the ecosystem. The results and preliminary interpretations of the present research on sharks provide important initial approximations for such a model.

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ADDITIONS TO SPECIES OF FORAMINIFERA FOUND IN SHALLOW WATER SEDIMENT OF THE HAWAIIAN ISLANDS

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ABSTRACT

During 1980 and 1981, 138 benthonic and 13 planktonic foraminiferal species were collected off Oahu and the Northwestern Hawaiian Islands from Nihoa through Pearl and Hermes Atoll. Shipeck sediment grab samples were taken by the scientific personnel of the NOAA R/V Townsend Cromwell and the research vessel Janthina VII. The greatest species diversity was found off Oahu (100 species), Necker Island (69 species), and French Frigate Shoals (82 species). Fifty-one species were added to the number of foraminifera reported from the Northwestern Hawaiian Islands from the Tanager Expedition.

Foraminiferida
Northwestern Hawaiian Islands

INTRODUCTION

Nearshore sediments surrounding the Hawaiian Islands are composed of up to 25 percent foraminifera, according to Moberly and Chamberlin (1964). Other major sediment components are coral fragments and coralline algae which form a substrate for living forams.

Phillips (1977) has summarized the early reports on foraminifera from the shallow waters of Hawaii. Other reports are from the Bishop Museum's Tanager Expedition from Kaula to Midway by Cushman (1925); reef and shore fauna of Hawaii by Edmondson (1946); recent and fossil nearshore marginal marine material by Resig (1969, 1974); sediment production by Muller (1974); sediments in Kahana Bay using foraminifera as sediment tracers by Coulbourn and Resig (1975); and shallow-water samples from off Kahe Point, Oahu by Phillips (1977).

Methods of obtaining samples from earlier cruises involved tangles, bucket and Petersen grabs, various types of trawls, and, from the Tanager Expedition, soap on the bottom of lead sound lines. Much of the shallow-water nearshore work involved scuba and fouling panels.

METHODS

Sedimentary material was examined from three 1981 cruises to the Northwestern Hawaiian Islands and off Oahu by the NOAA R/V *Townsend Cromwell* of the National Marine Fisheries Service. Thirty-eight bottom samples from Nihoa to Pearl and Hermes Atoll were taken using a Shipeck grab over ground where Kona crab populations had shown promise for commercial exploitation at depths ranging from 22 to 84 m. A single Shipeck sample from 94 m from the *Townsend Cromwell* and a bucket dredge sample from 52 m from the *Janthina VII* from Mamala Bay, Oahu, were examined for comparison with the more northerly fauna.

Qualitative sorting of 13 cc unsieved sand from each sample was made using a Bausch and Lomb stereozoom M4 dissecting microscope generally at a magnification of 20x to 25x. Sorting continued for 2 hours after no additional species were found. Identifications were made using an M5 Wild stereodissecting microscope and a Greenough Olympus stereoscopic binocular microscope.

RESULTS AND COMMENTS

Sediments examined were generally fine to fairly fine sand composed of coral and foraminiferal material, with additional coarse fragments of coralline algae and coral limestone. Most grab samples were from 100 to 2,000 cc. Small samples of 5 to 50 cc of sand were obtained when there was a thin layer of sediment over a hard bottom. The common components of the sand were the larger foraminiferal species, *Amphistegina lessoni*, *A. lobifera*, and *A. bicirculata* with lesser amounts of *Marginopora vertebralis* and *Heterostegina suborbicularis*. *Sorites marginalis* was abundant at only one station, although it was found frequently in minor quantities at other stations.

The common shallow-water foraminifera of the Northwestern Hawaiian waters are quite similar to the fauna from other Indo-Pacific areas and Oahu. However, some species that form sand in the Philippines and Guam are missing in the Hawaiian chain. Only one Cellanthus specimen was found, although it is very common in the far western Indo-Pacific and Cornuspira and Cornuspiroides occurred only in deeper waters off Oahu. Fairly large numbers of foraminiferal species are common in the tropics and subtropics, but many are represented by very small numbers. Except for the few species that were extremely abundant, usually only one to five specimens of a species were found at a station. Up to 50 specimens per species were very rarely found.

In our studies, 100 species were found at the two stations from Mamala Bay, Oahu, although 400 estimated by Phillips (1977) were found to occur off Oahu in shallow water off Kahe Point in a series of stations.

A complete listing of the location and depth of each station is given in Table 1. Each station is numbered consecutively from east to west and each different area is given a different letter. The species found from all of the stations at each area are shown in Tables 2 and 3. Few pelagic species (13) were found, as is usual in shallow-water nearshore depths. All three foraminiferan suborders are represented. Few textulariina were found in all areas with 9 species from Oahu and 5 species from the Northwestern Hawaiian Islands; Miliolina were represented by 49 species off Oahu and 51 species in the Northwestern Hawaiian Islands. Rotaliina were more abundant in the Northwestern Hawaiian Islands with 74 species compared with only 46 species from Oahu. The species found in depths of 10 to 49 m in the Northwestern Hawaiian Islands are frequently collected in slightly deeper waters of 100 to 200 m off Oahu. Some species were relatively more abundant in certain localities. Species and specimens of Rotaliina increased from French Frigate Shoals northwest to Pearl and Hermes Atoll, although species composition differed between stations and between areas.

Thirty-eight benthic species were found widely spread from Oahu to Pearl and Hermes Atoll. These were 2 Textulariids, 15 Miliolids, and 21 Rotaliids, all reported in shallow waters from Samoa (Cushman, 1924), the Philippines (Graham and Militante, 1959), and Guam (Todd, 1966).

Cushman (1925) found 67 species of foraminiferids between Nihoa and Pearl and Hermes Atoll during the Tanager Expedition. Eighty-five (72 percent) of the 118 species taken in the same area by the *Townsend Cromwell* were not reported from the earlier expedition. While confirming the work of Cushman that *Operculina philippinensis*, the Calcarinidae, and *Homotrema rubrum* were missing from the northwestern island chain, it was noted that *Miniacina miniacea* growth forms replace the typical Western Pacific *Homotrema rubrum*.

In Figure 1 the differences in the numbers of species found in the Northwestern Hawaiian Islands and the two Oahu stations are summarized. There were fewer species at stations of 20 to 49 m than from those beyond 50 m. Species diversity was almost twice as great off Oahu than in the Northwestern Hawaiian Islands, except for one station at French Frigate Shoals and another at Pearl and Hermes Atoll. However, the number of species increased from Maro Reef to Pearl and Hermes Atoll.

TABLE 1. STATIONS FROM OFF OAHU AND THE NORTHWESTERN HAWAIIAN ISLANDS ARRANGED FROM EAST TO WEST

Code	Station Number	Date	Locality	Latitude (North)	Longitude (West)	Depth (M.)
01A	BURCH-80047	06/21/80	Mamala Bay, Oahu	21°16.4'	157°51.1'	52
02A	TC8104-129	08/27/81	Mamala Bay, Oahu	21°16.9'	157°53.2'	94
03B	TC8101-043-02	02/20/81	Nihoa	23°10.8'	161°50.7'	64
04C	TC8101-012-03	02/09/81	Bank No. 3	23°13.2'	163°08.9'	84
05C	TC8101-018-02	02/09/81	Bank No. 3	23°12.8'	163°09.2'	68
06D	TC8101-042-08	02/19/81	Necker Island	23°25.6'	164°18.1'	56
07D	TC8101-042-04	02/19/81	Necker Island	23°26.5'	164°18.8'	58
08D	TC8101-037-05	02/17/81	Necker Island	23°40.2'	164°38.7'	82
09D	TC8101-037-04	02/17/81	Necker Island	23°40.0'	164°39.2'	82
10D	TC8101-037-03	02/17/81	Necker Island	23°39.7'	164°39.3'	56
11D	TC8101-037-02	02/17/81	Necker Island	23°39.5'	164°40.5'	60
12D	TC8101-037-01	02/17/81	Necker Island	23°39.7'	164°40.7'	78
13E	TC8103-011	06/14/81	French Frigate Shoals	23°49.0'	166°19.0'	14
14E	TC8103-008	06/13/81	French Frigate Shoals	23°50.0'	166°20.0'	12
15E	TC8104-116	08/18/81	French Frigate Shoals	23°45.0'	166°21.7'	26
16E	TC8104-115	08/18/81	French Frigate Shoals	23°44.7'	166°22.7'	50
17E	TC8104-114	08/18/81	French Frigate Shoals	23°45.2'	166°22.9'	54
18E	TC8104-119	08/18/81	French Frigate Shoals	23°49.4'	166°22.9'	56
19E	TC8103-017	06/16/81	French Frigate Shoals	23°46.0'	166°23.0'	?
20E	TC8104-113	08/18/81	French Frigate Shoals	23°45.8'	166°23.1'	62
21E	TC8104-117	08/18/81	French Frigate Shoals	23°49.2'	166°23.1'	54
22E	TC8104-018	07/24/81	French Frigate Shoals	23°41.3'	166°18.3'	23
23F	TC8104-032	07/26/81	Gardner Pinnacles	24°59.0'	168°14.8'	34
24F	TC8104-095	08/17/81	Gardner Pinnacles	25°00.9'	168°02.7'	32
25F	TC8104-096	08/17/81	Gardner Pinnacles	25°01.8'	168°05.8'	30
26F	TC8104-105	08/18/81	Gardner Pinnacles	25°00.8'	168°06.0'	32
27F	TC8104-106	08/18/81	Gardner Pinnacles	25°00.5'	168°06.0'	30
28F	TC8104-097	08/17/81	Gardner Pinnacles	25°02.3'	168°07.8'	34
29F	TC8104-098	08/17/81	Gardner Pinnacles	25°02.7'	168°11.6'	34
30G	TC8104-089	08/16/81	Raita Bank	25°38.3'	169°25.2'	34
31G	TC8104-087	08/16/81	Raita Bank	25°34.8'	169°25.7'	34
32G	TC8104-086	08/16/81	Raita Bank	25°33.0'	169°26.0'	34
33H	TC8104-043	07/28/81	Maro Reef	25°22.5'	170°52.0'	72
34H	TC8104-044	07/28/81	Maro Reef	25°22.5'	170°52.0'	70
35H	TC8104-042	07/28/81	Maro Reef	25°22.2'	170°52.2	70
36H	TC8104-041	07/28/81	Maro Reef	25°23.4'	170°52.6'	68
37H	TC8104-038	07/28/81	Maro Reef	25°24.3'	170°52.9'	70
38I	TC8104-078	08/10/81	Lisianski Island	26°03.7'	174°02.3'	?
39J	TC8104-065	08/07/81	Pearl and Hermes Atoll	27°46.2'	175°47.5'	73
40J	TC8104-066	08/07/81	Pearl and Hermes Atoll	27°46.3'	175°47.7'	69

TABLE 2. PLANKTONIC FORAMINIFERA FROM OAHU TO PEARL AND HERMES REEF

Species	Location									
	A	B	C	D	E	F	G	H	I	J
Globorotalia menardii	-	-	P[*]	P	P	-	-	P	P	P
Globorotalia menardii ungulata	-	-	-	-	-	-	-	-	-	P
Globorotalia tumida	P	-	-	-	P	-	-	-	-	P
Globorotalia truncatulinoides	-	-	-	-	-	-	-	-	-	P
Globorotalia sp.	-	-	-	P	-	-	-	-	-	P
Globigerina bulloides	F[†]	-	-	-	P	-	-	-	-	P
Globigerina sp.	-	-	P	F	F	P	P	F	-	P
Globigerinoides conglobatus	P	-	-	-	P	-	-	-	-	P
Globigerinoides ruber	-	-	-	-	-	-	-	F	-	-
Globigerinoides sacculifera	P	-	-	-	-	-	-	-	-	-
Globigerinoides sp.	-	P	P	C[§]	-	-	-	-	-	-
Orbulina universa	P	-	P	P	-	-	-	-	P	-
Candeina nitida	-	-	-	P	-	-	-	-	-	-

Note: A = Oahu, B = Nihoa, C = Bank No. 3, D = Necker, E = French Frigate Shoals, F = Gardner Pinnacles, G = Raita Bank, H = Maro Reef, I = Lisianski Island, J = Pearl and Hermes Atoll

[*] P = Present
[†] F = Few
[§] C = Common

TABLE 3. BENTHIC FORAMINIFERA FROM THE HAWAIIAN ISLANDS (OAHU TO PEARL AND HERMES ATOLL)

Species	Location									
	A	B	C	D	E	F	G	H	I	J
Alveolophragmium sp.	–	–	P[*]	–	–	–	–	–	–	–
Textularia agglutinans	F[†]	–	–	–	–	–	–	–	–	–
Textularia foliacea	C[§]	–	–	–	–	–	–	–	–	–
Textularia pseudogramen	F	–	–	–	–	–	–	–	–	–
Textularia sagittula fistulosa	P	–	–	–	P	–	–	–	–	–
Textularia semialata	P	–	–	–	–	–	–	–	–	–
Textularia sp.	F	–	P	F	P	–	–	F	P	P
Gaudryina siphonifera	P	P	P	C	F	P	–	P	–	–
Gaudryina sp.	–	–	–	–	F	P	–	P	P	–
Textulina conica	P	–	–	–	–	–	–	–	–	–
Cylindroclavulina bradyi	F	–	–	–	–	–	–	–	–	–
Cornuspiroides foliaceus	–	–	–	P	–	–	–	–	–	–
Wiesnerella auriculata	P	–	–	P	–	–	–	–	–	–
Spiroloculina angulata	F	–	–	–	F	–	–	–	–	–
Spiroloculina communis	C	–	–	–	P	–	–	–	–	P
Spiroloculina corrugata	–	–	–	–	P	–	–	–	–	P
Spiroloculina robusta	P	–	–	–	P	–	–	–	–	–
Spiroloculina sp.	P	–	P	P	F	F	P	F	–	P
Nubeculina divaricata	–	–	–	P	–	–	–	–	–	–
Nubeculina sp.	P	–	–	–	–	–	–	–	–	–
Vertehralina striata	F	–	–	F	P	–	–	P	P	P
Quinqueloculina anguina arenata	P	–	–	–	–	–	–	–	–	–
Quinqueloculina auberiana	C	–	–	–	P	P	–	P	O	F
Quinqueloculina berthelotiana	P	–	–	–	P	–	–	–	–	–
Quinqueloculina cf. *boueana*	P	–	–	–	–	–	–	–	–	–
Quinqueloculina funafutiensis	P	–	–	–	–	–	–	–	–	–

Note: A = Oahu, B = Nihoa, C = Bank No. 3, D = Necker, E = French Frigate Shoals, F = Gardner Pinnacles, G = Raita Bank, H = Maro Reef, I = Lisianski Island, J = Pearl and Hermes Atoll

[*] P = Present
[†] F = Few
[§] C = Common
[#] A = Abundant

TABLE 3. BENTHIC FORAMINIFERA FROM THE HAWAIIAN ISLANDS (OAHU TO PEARL AND HERMES ATOLL) (continued)

Species	Location									
	A	B	C	D	E	F	G	H	I	J
Quinqueloculina lamarckiana	-	-	-	-	F	-	-	-	-	-
Quinqueloculina limbata	-	-	-	-	F	-	-	-	-	-
Quinqueloculina parkeri	F	P	P	F	C	-	P	F	P	F
Quinqueloculina polygona	F	-	-	-	-	-	-	-	-	-
Quinqueloculina seminula	C	-	-	-	P	-	P	F	-	P
Quinqueloculina striatula	P	-	-	-	-	-	-	-	-	-
Quinqueloculina sulcata	P	-	-	-	-	-	-	-	-	-
Quinqueloculina sp.	C	-	-	F	C	F	F	C	P	F
Quinqueloculina tropicalis	P	-	-	P	P	P	-	P	-	-
Flintina bradyana	F	-	-	-	-	-	-	-	-	-
Massilina granulocostata	P	-	-	P	F	-	-	F	-	-
Massilina reticulata	C	-	-	-	-	-	-	-	-	-
Massilina sp.	P	-	-	-	P	-	-	P	-	-
Pateoris sp.	-	-	-	-	-	P	-	-	-	-
Pseudomassilina australis	F	-	P	P	-	-	-	-	-	P
Pyrgo denticulata	F	-	-	F	F	-	-	F	P	P
Sigmoilina sp.	P	-	-	-	-	-	-	-	-	-
Triloculina affinis	F	P	-	P	P	-	P	-	-	-
Triloculina angularis	P	-	-	-	P	-	-	-	-	-
Triloculina concisiformis	P	-	-	-	-	-	-	-	-	-
Triloculina ducaniana	P	-	-	-	-	-	-	-	-	-
Triloculina fichteliana	P	-	P	P	-	-	-	-	-	-
Triloculina linneiana	F	-	-	-	P	-	-	-	-	P
Triloculina reticulata	P	-	-	P	P	-	P	-	-	-
Triloculina irregularis	-	-	-	-	P	-	-	-	-	-
Triloculina oblongata	P	-	-	P	-	-	-	-	-	-
Triloculina striatotrigonula	P	-	-	-	-	-	-	-	-	-
Triloculina sp.	F	-	-	-	F	-	-	F	-	-
Triloculina trigonula	C	-	-	P	P	-	-	-	-	P
Miliolinella subrotunda	F	-	P	P	F	P	P	F	-	F
Nummoloculina sp.	-	-	-	-	-	-	-	P	-	-
Hauerina orientalis	-	-	-	P	P	P	-	F	-	-
Hauerina pacifica	P	-	-	P	F	-	-	F	-	P
Schlumbergerina alveoliniformis	P	-	-	-	P	P	-	P	-	-
Articulina pacifica	F	-	-	P	-	P	-	-	-	-
Parrina bradyi sufflata	F	-	-	-	P	P	P	P	-	P
Peneroplis pertusus	P	-	-	-	P	-	P	P	-	-

TABLE 3. BENTHIC FORAMINIFERA FROM THE HAWAIIAN ISLANDS (OAHU TO PEARL AND HERMES ATOLL) (continued)

Species	Location									
	A	B	C	D	E	F	G	H	I	J
Peneroplis planatus	P	-	-	-	-	F	-	P	-	-
Monalysidium politum	P	-	-	P	P	-	-	-	-	-
Spirolina arietina	-	-	-	P	-	P	-	P	-	-
Sorites marginalis	A#	-	P	-	F	F	P	F	P	F
Marginopora vertebralis	C	P	A	A	A	A	A	A	F	F
Borelis schlumbergeri	P	-	P	F	C	F	-	F	P	P
Borelis sp. 2	-	-	P	-	-	-	-	-	-	-
Alveolinella quoyi	F	P	-	P	F	-	-	-	-	-
Nodosariidae	-	-	P	P	-	-	-	-	-	-
Amphicoryna scalaris	P	-	-	-	-	-	-	-	-	-
Dentalina advena	P	-	-	-	-	-	-	-	-	-
Lagena sp. 2	-	-	P	-	-	-	-	-	-	-
Lagena sulcata spicata	P	-	-	-	-	-	-	-	-	P
Saracenaria sp.	-	-	-	P	-	-	-	-	-	-
Robulus sp.	-	P	-	-	-	-	-	-	-	-
Bolivinella elegans	-	-	-	P	-	-	-	P	-	-
Sigmoidella elegantissima	P	-	-	-	-	-	-	-	-	-
Oolina sp.	-	-	P	-	-	-	-	-	-	-
Fissurina marginata	P	-	F	F	-	P	P	-	-	-
Bolivina globulosa	-	-	-	-	-	-	-	-	-	P
Bolivina limbata	F	-	-	-	P	C	-	P	-	-
Bolivina sp.	-	-	-	P	P	-	-	P	-	P
Pavonina flabelliformis	P	-	-	F	F	P	-	P	-	P
Chrysalidinella dimorpha	P	-	P	P	F	-	-	P	-	-
Fijiella simplex	P	-	P	F	F	F	F	C	P	F
Uvigerina cf. *canariensis*	P	-	-	-	-	-	-	-	-	-
Uvigerina flintii	P	-	-	-	-	-	-	-	-	-
Siphogenerina annulata	-	-	-	P	-	-	-	-	-	-
Siphogenerina raphana	-	-	-	-	P	-	-	P	-	P
Trifarina sp.	-	-	-	P	-	-	P	P	-	-
Rosalina concinna	-	-	-	-	P	-	-	-	-	-
Rosalina floridana	P	-	-	-	P	-	-	-	-	-
Rosalina micens	P	-	-	-	-	-	-	-	-	-
Rosalina n.sp. *Brady*	-	-	-	-	P	-	-	-	-	-
Rosalina orientalis	P	-	-	-	F	F	F	F	-	P
Rosalina sp.	-	-	-	F	F	P	P	P	P	P
Tretomphalus millettii	-	-	-	-	P	P	-	-	-	P
Tretomphalus planus	-	-	-	P	P	P	-	P	-	P
Rotobinella mira	P	-	-	P	A	C	F	C	P	P
Spirillina denticulata	-	-	P	-	P	-	-	P	-	P
Spirillina sp.	-	-	-	-	P	-	-	-	-	-

TABLE 3. BENTHIC FORAMINIFERA FROM THE HAWAIIAN ISLANDS (OAHU TO PEARL AND HERMES ATOLL) (continued)

Species	Location									
	A	B	C	D	E	F	G	H	I	J
Spirillina tuberculatolimbata	P	-	P	F	F	P	-	P	-	P
Patellina corrugata	-	-	P	P	-	-	-	-	-	-
Ammonia beccari tepida	P	-	-	-	P	P	-	P	-	P
Elphidium oceanicum	P	-	-	-	-	-	-	-	-	-
Elphidium reticulosum	P	-	-	-	-	-	-	-	-	-
Elphidium sp.	P	-	-	P	-	-	-	P	-	-
Cellanthus craticulatus	P	-	-	-	-	-	-	-	-	-
Operculina phillipiensis	A	-	-	-	-	-	-	-	-	-
Heterostigina suborbicularis	A	P	P	A	A	F	C	A	P	P
Eponides repandus	F	P	P	F	F	-	-	F	-	P
Eponides schreibersi	P	-	-	-	P	-	-	P	F	F
Amphistegina bicirculata	A	C	A	A	A	P	P	C	F	A
Amphistegina lessonii	A	A	A	A	A	A	A	A	A	A
Amphistegina lobifera	F	-	-	A	A	A	A	A	-	A
Cibicides floridanus	P	-	-	-	-	-	-	-	-	-
Cibicides lobatulus	P	-	P	-	P	-	-	P	P	F
Cibicides praecintus	P	-	-	P	P	-	-	P	-	-
Cibicides refulgens	P	-	-	-	P	-	-	-	-	F
Cibicides sp.	-	-	-	P	F	P	F	C	P	P
Acervulina inhaerens	-	-	P	P	P	-	P	P	-	-
Gypsina globula	P	-	P	-	P	-	-	-	-	P
Planogypsina sp.	-	-	-	-	-	-	-	F	-	-
Cymbaloporetta bradyi	P	-	-	-	F	-	-	-	P	P
Cymbaloporetta squammosa	P	P	P	P	P	F	P	C	P	P
Miniacina miniacea	-	F	-	A	C	-	-	P	P	P
Casidulina minuta	-	-	-	-	-	-	-	-	-	P
Casidulina sp.	P	-	P	P	-	-	-	-	-	-
Nonion sp.	-	-	-	P	P	-	-	-	-	-
Florilus sp.	-	-	-	-	-	-	-	P	-	-
Pullenia sp.	-	-	-	-	-	-	-	P	-	-
Cibicidoides sp. 1	-	-	-	-	P	-	-	-	-	P
Melonis sp.	-	-	P	-	-	-	-	-	-	-
Anomalina colligera	F	-	-	-	-	-	-	-	-	-
Stomatorbina cocentrica	-	-	-	P	-	-	-	-	-	-

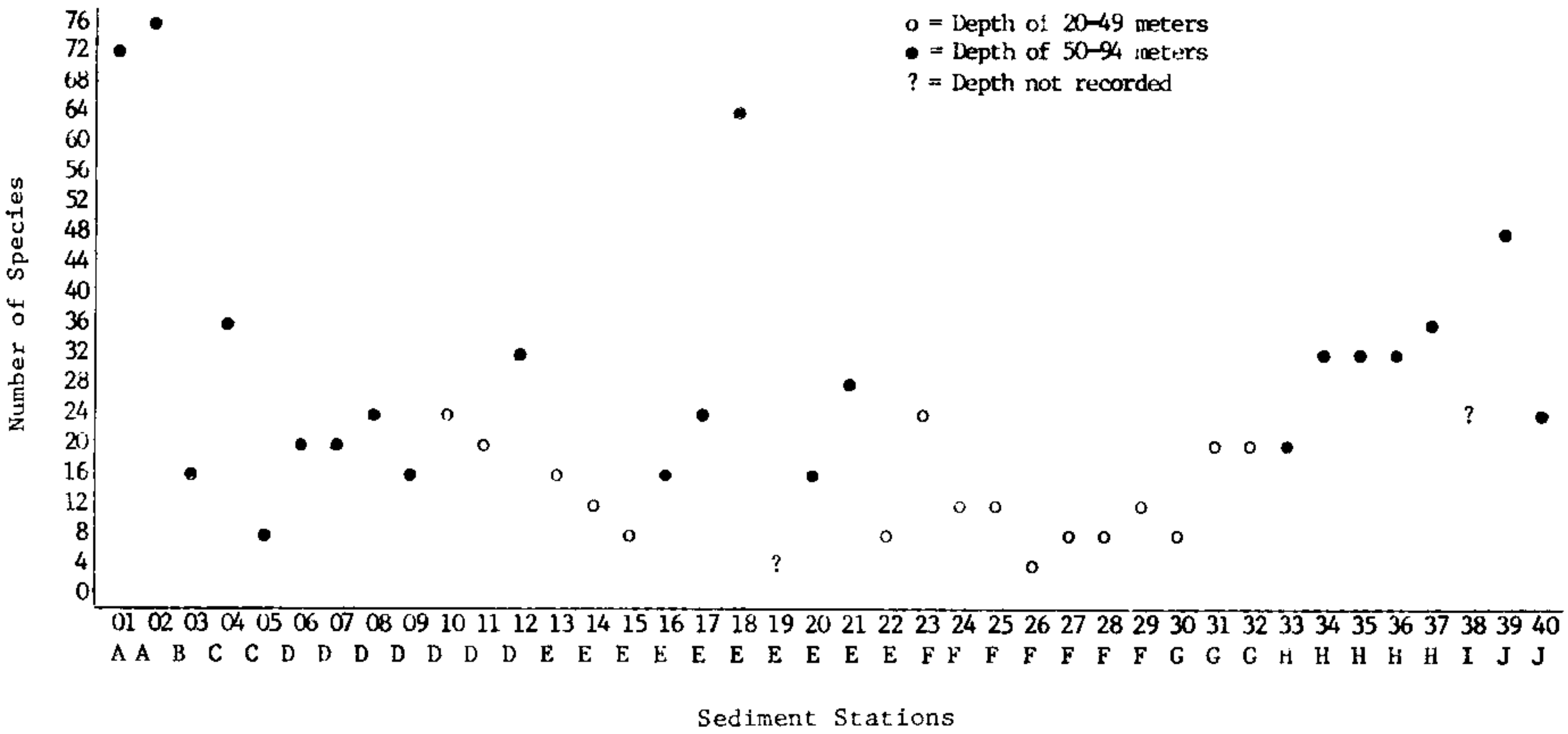

Figure 1. Number of species per station arranged from Oahu (east) to Pearl and Hermes Atoll (west) by depth

Although the *Townsend Cromwell* samples have increased the number of known foraminifera found in the Northwestern Hawaiian Islands, it is clear that the list of species is far from complete as only shallow-water sampling was done. Further collections, particularly from the deeper waters of the area, can be expected to show differences between the NWHI and more tropical areas.

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RESULTS OF CIGUATOXIN ANALYSIS BY ENZYME-IMMUNOASSAY (EIA) OF FISHES IN THE NEARSHORE WATERS OF THE NORTHWESTERN HAWAIIAN ISLANDS

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ABSTRACT

An enzyme-immunoassay (EIA) procedure for the detection of ciguatoxin (CTX) in fish tissues has been used to examine fish from clinically documented ciguatera cases and to assess a 1982 survey of a variety of fish species from nearshore waters of the Northwestern Hawaiian Islands (NWHI). Results demonstrated that the EIA procedure distinguished between documented toxic fish tissues and non-toxic tissues. Evaluation of the NWHI survey by EIA indicated that samples from a number of species contained CTX-like toxin. Species having higher percentages of EIA-positive and borderline samples included Cheilinus rhodochrous (a frequently implicated species in ciguatera), Caranx ignobilis, and Acanthurus triostegus. Of the larger fish examined, liver samples gave significantly higher EIA absorbance values than corresponding muscle tissue. Studies with A. triostegus showed that males gave higher EIA values than females and that there was a slight negative correlation between fish weight and EIA values. Based on results of this study, the EIA procedure has been shown to be sensitive, practical, and specific for CTX-like toxins, and has value in routine analysis of suspected fish in ciguatera outbreaks.

INTRODUCTION

The nearshore waters of the Northwestern Hawaiian Islands have been shown to have excellent potential for the development of the fishing industry of the state of Hawaii (Okamoto and Kawamoto, 1980). The recent increased attention given to the terrestrial and marine resources in the NWHI has mandated a need to develop a rational plan for utilization of these resources (Craven, 1980). In addition to the enumeration of the nearshore species of fishes and evaluation of resources, the Hawaii Department of Land and Natural Resources (DLNR) has undertaken studies to determine the distribution and identification of potentially toxic fishes in the NWHI. An earlier preliminary report (Ito and Uchida, 1980) was presented on ciguatoxin distribution by the National Marine Fisheries Service (NMFS), Southwest Fisheries Center Honolulu Laboratory, using the radioisotope method (Hokama et al., 1977).

Ciguatera is a kind of fish poisoning associated with the ingestion of a variety of fishes of tropical and subtropical regions (Bagnis, 1973; Halstead, 1970; Banner, 1976; Banner et al., 1960). A few hours after consumption of toxic fish, victims suffer from a variety of neurological, gastrointestinal, and cardiovascular symptoms (Bagnis et al., 1979). An important clinical diagnostic feature is the temperature reversal sensation when cold objects feel hot. All patients do not share the same clinical symptoms (Bagnis et al., 1979; Okihiro et al., 1965).

A major area of concern in the study of ciguatera has been the development of a practical and specific assay for detection of toxin directly in fish tissues. Earlier assays, some of which are still in use, relied on determining the toxicity of either whole tissues, crude extracts, or partially purified CTX in animal models or on isolated tissues (Bagnis, 1973; Banner, et al., 1960; Banner et al., 1961; Granade et al., 1976). A recently developed RIA procedure (Hokama et al., 1977) has been extensively examined and proven to be effective in screening _Seriola dumerili_ (kahala) and for assessment of CTX distribution in the NWHI (Kimura et al., 1982a; Ito and Uchida, 1979). Utilizing the same immunological principles, an enzyme-immunoassay has been recently developed (Hokama et al., 1983). This procedure has been utilized to assess the 1982 survey of a variety of species obtained from the nearshore waters of the NWHI by DLNR. This study has a twofold purpose: (1) to assess the prevalence of toxic levels of CTX in several species from the NWHI; and (2) to evaluate the EIA procedure.

MATERIALS AND METHODS

Source of Fish Samples

Fish samples were obtained from the 1982 survey of the NWHI by DLNR. Both a section of tissue designated A from the anterior-dorsal musculature (Kimura et al., 1982a, 1982b) and, in larger fish, a section from liver designated L were collected and examined using the EIA method. The species examined and catch locations in the nearshore waters of the specific NWHI islands are presented in Table 1. Data collection for each species included sex, total and fork length (in cm), and weight (in kg). For some samples of the _Caranx_ group, the weight was estimated from the total length.

TABLE 1. SPECIES AND LOCATION OF FISH SAMPLES COLLECTED FROM THE NWHI AND EXAMINED USING THE EIA METHOD

Species	Location
Abudefduf sordidus	Nihoa, Laysan Island, Lisianski Island
Acanthurus nigroris	Necker Island
A. triostegus	Nihoa, Necker Island, French Frigate Shoals, Maro Reef, Laysan Island, Pearl and Hermes Atoll, Lisianski Island
Bodianus bilunulatus	Necker Island, French Frigate Shoals, Maro Reef, Laysan Island, Lisianski Island, Pearl and Hermes Atoll
Carangoides hemigymnostethus	Lisianski Island
C. orthogrammus	Necker Island, Maro Reef, Lisianski Island
Caranx ignobilis	French Frigate Shoals, Gardner Pinnacles, Maro Reef, Laysan Island
C. melampygus	French Frigate Shoals, Maro Reef, Lisianski Island
Carcharhinus amblyrhynchos	Pearl and Hermes Atoll
C. galapagensis	Pearl and Hermes Atoll
Cheilinus rhodochrous	French Frigate Shoals, Maro Reef, Laysan Island, Pearl and Hermes Atoll
Galeocerdo cuvieri	French Frigate Shoals
Kuhlia sandvicensis	Nihoa, Necker Island, French Frigate Shoals, Laysan Island, Pearl and Hermes Atoll
Kyphosus sp.	Nihoa
Mugil cephalus	Pearl and Hermes Atoll
Mulloidichthys flavolineatus	Laysan Island
Myripristis amaenus	Nihoa, French Frigate Shoals, Maro Reef, Pearl and Hermes Atoll
M. berndti	Nihoa, French Frigate Shoals
M. kuntee	Nihoa
Neomyxus leuciscus	Nihoa
Parupeneus porphyreus	French Frigate Shoals, Pearl and Hermes Atoll
Polydactylus sexfilis	French Frigate Shoals, Lisianski Island, Pearl and Hermes Atoll
Caranx cheilio	French Frigate Shoals
Sargiocentron spiniferum	French Frigate Shoals
Seriola dumerili	French Frigate Shoals, Maro Reef, Lisianski Island, Pearl and Hermes Atoll
Thalassoma purpureum	Laysan Island, Maro Reef
Triaenodon obesus	Pearl and Hermes Atoll

Antibody to Ciguatoxin

Sheep anti-CTX (S-anti-CTX) was prepared and purified by DEAE-cellulose chromatography as described in previous reports (Hokama et al., 1977; Kimura et al., 1982a, 1982b).

Sheep-anti-CTX-HRP Conjugate

The purified IgG fraction of S-anti-CTX was coupled to horseradish peroxidase (HRP, Type VI, RZ:3.3, Sigma Chemical Co., St. Louis, MO) according to the one-step glutaraldehyde method of Voller et al. (1980). The S-anti-CTX-HRP conjugate was divided into aliquots and stored at -20°C until used. Other aliquots were lyophilized and stored at 4°C. Each aliquot was thawed or rehydrated only once and the remaining excess conjugate discarded.

EIA Reagents

Tris buffer contained 0.05-M Tris (hydroxymethyl) aminomethane, pH 7.5 ± 0.05, with 0.1 percent human serum albumin (HSA) and 0.01 percent sodium azide (NaN_3). The H_2O_2-methanol fixative contained 0.3 percent H_2O_2 in absolute methanol prepared just before use (stable 1 hour at room temperature). The 4-chloro-1-naphthol substrate was prepared fresh just before use by adding 25 ml of 0.3 percent H_2O_2 in Tris buffer without HSA and NaN_3 to 10 mg of 4-chloro-1-naphthol crystals dissolved in 0.125-ml absolute ethanol. After thorough mixing, the substrate was filtered through Whatman #1 filter paper.

Enzyme-immunoassay

Fish tissue samples for testing were cut into uniform 3-mm thick slices with parallel razor blades mounted on a handle. Four discs were then punched out from each slice with a stainless steel borer, 3-mm in diameter, and each disc was placed in a well of a 96-well polystyrene microtiter plate (Flow Laboratories, Inc., Hamden, CT). Samples were washed once with 0.2-ml Tris buffer. After the wash solution was aspirated, each sample was fixed in 0.2 ml of H_2O_2-methanol fixative for 30 minutes at room temperature. Samples were then transferred to clean wells and 0.2 ml of a 1:100 dilution of S-anti-CTX-HRP conjugate in Tris buffer was added to each well. The plate was then incubated at room temperature for 1 hour. The S-anti-CTX-HRP was removed by aspiration, and the tissues were immersed for 5 minutes in 0.2-ml Tris buffer. Each sample was transferred to clean wells and incubated for 5 minutes at room temperature with 0.2 ml of 4-chloro-1-napthol substrate. The final steps involved removal of the tissue and addition of 0.015 ml of 3-M sodium hydroxide to stop the enzymatic reaction. Absorbance readings at 405 nm of each well were obtained in the Titertek Multiskan (Flow Laboratories, Inc.).

In each microtiter plate, quadruplicate samples of known toxic (positive) and nontoxic (negative) control fish tissues were tested in parallel with the unknown samples.

Interpretation of Results

To facilitate data evaluation, test absorbance readings were converted to ratios by dividing the mean absorbance value of the quadruplicate samples from each tissue of unknown test fish by 0.235, the mean absorbance value of all tissue A samples with absorbances less than 0.350. For evaluation of the samples tested, tentative toxicity ranges of these ratios have been established based on results of clinically documented toxic fishes:

Toxicity Level	Test:Control Ratio
Negative (n)	< 1.30
Borderline (b)	1.30 - 1.49
Positive (p)	≥ 1.50

Samples rejected include borderline and positive tissues.

RESULTS

EIA Results with Clinically Documented Toxic and Nontoxic Fishes

The results of all the clinically documented toxic and nontoxic fishes examined using the EIA method are summarized in Table 2. A total of 8 clinically documented toxic fish samples all positive with the RIA gave EIA O.D. values at 405 nm from a low of 0.351 (eel species) to a high of 0.442 (*Elagatis bipinnulatus*). The nontoxic consumed fishes showed mean absorbances ranging from 0.169 (*Caranx* sp.) to 0.320 (*S. dumerili*). The 76 samples of *S. dumerili* examined a total of 109 times were previously shown to be negative with the RIA procedure (Kimura et al., 1982a) and consumed by the public without an incident of ciguatera poisoning. The calculated ratios (using the negative *S. dumerili* mean value of 0.233) for all 8 toxic fishes ranged from 1.51 to 1.91 and for the nontoxic fishes, from 0.73 to 1.37. However, when the mean absorbances of nontoxic fish of the same species were used to calculate ratios, the ratios for the toxic fishes increased (values in parenthesis in Table 2). For example, with the toxic *Caranx* sp., the ratio changes from 1.54 to 2.12 when the mean absorbance for the toxic *Caranx* sp. is divided by the mean absorbance of nontoxic *Caranx* samples. A similar case is indicated for the *Scarus* sp.

Summary of EIA Results of all Species from NWHI Survey

Based on EIA results of all NWHI species tested, the highest rejection percentage was shown by *Cheilinus rhodochrous* (25 percent) and the lowest by *Caranx melampygus* (0 percent, Table 3). In contrast with *C. melampygus*, *C. ignobilis* demonstrated 17.6

TABLE 2. RESULTS OF THE EVALUATION OF CLINICALLY DOCUMENTED TOXIC AND NONTOXIC* FISH TISSUES BY EIA

Fish Tissue	n[†]	Mean Absorbance ± SEM at 405 NM	Toxic / Nontoxic Control	Ratio[§]
TOXIC				
Elagatis bipinnulatus (Rainbow runner, Midway, 1980)	31	0.442 ± 0.011	1.90	
Elagatis bipinnulatus (Rainbow runner, Midway, 1982)	35	0.417 ± 0.019	1.79	
Caranx sp. (Jack, ulua)	19	0.359 ± 0.015	1.54	(2.12)[#]
Red Snapper (Virgin Islands, 27 pieces may include several species of fish)	27	0.410 ± 0.013	1.76	
Scarus sp. (Parrotfish, uhu)	2	0.393	1.69	(2.09)[#]
Scarus sp. (Parrotfish, uhu, cooked)	6	0.374 ± 0.029	1.61	(1.99)[#]
Cephalopholis argus (Grouper)	6	0.445 ± 0.038	1.91	
Cheilinus rhodochrous (Rose-colored wrasse, po'ou)	2	0.408	1.75	
Eel, sp. (unknown)	2	0.351	1.51	
NONTOXIC				
Seriola dumerili 1981 (76 marketed specimens, amberjack, kahala)	109	0.233 ± 0.004	1.00	
Caranx sp. (Jack, ulua - 6 specimens examined)	29	0.169 ± 0.0007	0.73	(1.00)[#]
Scarus sp. (Parrotfish, uhu, green)	3	0.188 ± 0.003	0.81	(1.00)[#]
Scarus sp. (Parrotfish, uhu, red)	3	0.260 ± 0.030	1.12	(1.38)[#]
Seriola dumerili	22	0.279 ± 0.016	1.19	
Seriola dumerili	1	0.296 ± 0.045	1.27	
Seriola dumerili	1	0.320 ± 0.018	1.37	
Seriola dumerili	13	0.204 ± 0.015	0.92	

Source: Hokama et al., in press

*Nontoxic fishes caused no toxic symptoms after consumption, these included marketed fishes.

[†] n = number of times samples examined in quadruplicate.

[§] Negative control value from *S. dumerili*, 109 samplings = 0.233 O.D.

[#] Ratios in parenthesis based on nontoxic tissue O.D. of the same species. Example: *Caranx* sp. 0.359/0.169 = (2.12)

TABLE 3. EIA RESULTS OF FISH SAMPLES FROM THE 1982 NEARSHORE NWHI SURVEY

Species*	Total No.	EIA Results[†]			% Rejection (b + p)
		n	b	p	
Acanthurus triostegus	122	104	17	1	14.8
Bodianus bilunulatus	41	36	1	4	12.2
Caranx ignobilis	68	56	6	6	17.6
Caranx melampygus	14	14	0	0	0
Cheilinus rhodochrous	12	9	2	1	25.0
Kuhlia sandvicensis	99	87	8	4	12.1
Myripristis amaenus	35	34	1	0	2.9
Myripristis berndti	25	24	1	0	4.0
Polydactylus sexfilis	38	33	1	4	13.2
Seriola dumerili	14	13	1	0	7.1
All others (less than 7 specimens)	43	40	3	0	7.0
TOTAL	511	450	41	20	11.9

*Tissue samples taken from the anterior-dorsal musculature (A)

[†] Numbers of fish having negative (n), borderline (b) and positive (p) results

percent rejection, a difference which may be in part due to the smaller number of C. melampygus examined. Percentage of rejection rates of Acanthurus triostegus, Kuhlia sandvicensis, Bodianus bilunulatus, and Polydactylus sexfilis were essentially similar, ranging from 12.1 to 14.8 percent.

Comparison of EIA Results of Tissue A and Liver Samples

There were significant differences ($P < 0.05$ to 0.01) between EIA ratios of tissue A and liver samples (Tables 4 and 5). All species examined demonstrated higher levels of toxicity in liver than in flesh. Occasionally, samples with higher toxicity in flesh have been encountered, especially in P. sexfilis, thus contributing to smaller differences between the ratios (Table 4). Table 5 summarizes the comparison between EIA results of tissue A and liver samples from all species and shows the higher rejection rate of liver samples.

TABLE 4. COMPARISON BETWEEN TOXICITY LEVELS IN FLESH (A) AND LIVER (L) TISSUES OF SEVERAL FISH SPECIES

Species	Tissue Sample	n	Ratio* $\bar{x} \pm$ S.D.	P†
Bodianus bilunulatus	A	15	1.04 ± 0.29	< 0.05
	L	15	1.98 ± 1.21	
Caranx melampygus	A	13	0.88 ± 0.15	< 0.01
	L	13	1.47 ± 0.20	
Caranx sp.	A	82	1.01 ± 0.27	< 0.01
	L	82	1.39 ± 0.33	
Polydactylus sexfilis	A	33	1.08 ± 0.23	< 0.05
	L	33	1.25 ± 0.22	

$$^{*}\text{Ratio} = \frac{\text{mean absorbance of test sample}}{\text{mean absorbance of all samples}}$$

†Significance of difference between A and L tissues of each species

TABLE 5. COMPARISON OF EIA RESULTS BETWEEN TISSUE (A) AND LIVER (L) SAMPLES FROM ALL FISH SPECIES AND LOCATIONS OF CAPTURE

Tissue Sample	Total No.	No. of Samples with Following EIA Results			% Borderline and Positive
		Negative	Borderline	Positive	
Flesh (A)	528	472	40	16	10.6
Liver (L)	165	68	42	55	58.8

Examination of EIA Ratios Relative to Capture Location and Sex

In Table 6 the levels of toxicity in *A. triostegus* and *Kuhlia sandvicensis* in relationship to location of capture are summarized. Significantly higher EIA ratios were shown for *A. triostegus* from Nihoa to Maro Reef and progressively decreasing ratios were found among samples from locations moving toward Pearl and Hermes Atoll. The latter area showed a significant decrease in toxicity levels in *A. triostegus* ($P < 0.01$). *K. sandvicensis* showed a similar trend in activity, although the ratios of samples from various locations were not significantly different. In Table 7 an interesting finding of higher mean EIA ratios in male compared with female *A. triostegus* ($P < 0.01$) is

TABLE 6. COMPARISON OF EIA RATIOS OF TISSUES FROM *ACANTHURUS TRIOSTEGUS* AND *KUHLIA SANDVICENSIS* RELATIVE TO SAMPLING LOCATION IN THE NEARSHORE WATERS OF THE NORTHWESTERN HAWAIIAN ISLANDS

Location	*A. triostegus**			*K. sandvicensis*		
	No. of Samples	Ratio ($\bar{x}$ ± S.D.)	p[†]	No. of Samples	Ratio ($\bar{x}$ ± S.D.)	p[†]
Nihoa	23	0.985 ± 0.177	< 0.01	4	0.903 ± 0.159	> 0.10
Necker Island	3	1.167 ± 0.206	< 0.01	20	1.099 ± 0.201	n.s.
French Frigate Shoals	20	1.202 ± 0.163	< 0.01	17	1.100 ± 0.337	n.s.
Maro Reef	19	1.162 ± 0.226	< 0.01	—	—	—
Laysan Island	19	1.028 ± 0.159	> 0.10	20	0.951 ± 0.276	> 0.10
Lisianski Island	16	1.052 ± 0.203	n.s.	19	1.036 ± 0.133	n.s.
Pearl and Hermes Atoll	20	0.933 ± 0.158	> 0.01	19	1.043 ± 0.163	n.s.
TOTAL	120	1.046 ± 0.201	—	99	1.044 ± 0.202	—

*Tissue samples were taken from anterior-dorsal musculature (A). See Table 4 for explanation of ratio.

[†] Significance of difference between mean ratio of samples from each location and mean ratio for all samples; n.s. = not significant.

TABLE 7. COMPARISON OF EIA RATIOS OF TISSUE A FROM FEMALE AND MALE *ACANTHURUS TRIOSTEGUS* FROM ALL LOCATIONS

Group	No. of Samples	EIA Ratio $\bar{x} \pm$ S.D.	P
Female	80	1.015 ± 0.199	< 0.01
Male	34	1.137 ± 0.183	

summarized. Similar analysis of *K. sandvicensis* and *C. ignobilis* showed no significant relationship between levels of toxicity and sex.

Analysis of Weight vs. Toxicity Levels

A comparison of fish weight with levels of activity (EIA ratios) is shown in Table 8. Two species with the largest number of samples were evaluated. As shown in Table 8, an inverse relationship is suggested for toxicity levels vs weight (negative r). Essentially, the larger fish showed lower activity levels than the smaller fish in both *A. triostegus* and *Caranx* sp. No significant differences were shown between weight and toxicity in these two species.

TABLE 8. LINEAR REGRESSION ANALYSIS OF RELATIONSHIP BETWEEN FISH WEIGHT (IN KG) AND EIA RESULTS (ABSORBANCE VALUES) OF TWO SPECIES

Species	No. of Samples	Tissue*	Correlation Coefficient (r)	P[†]
Acanthurus triostegus	42	A	-0.226	n.s.
Caranx sp.	92	A	-0.092	n.s.
	95	L	-0.035	n.s.

*Tissue samples were taken from the anterior-dorsal musculature (A) and liver (L).

[†] n.s. = not significant

DISCUSSION

Results utilizing the EIA for assessment of 1982 NWHI fish samples suggest the presence of CTX-like toxin in several species. Previously reported studies evaluating the S-anti-CTX antibody currently used in the EIA procedure suggested that the antibody may react with other compounds (such as okadaic acid) having a polyether structure similar to CTX (Kimura et al., 1982b). The EIA results were similar to those reported in the 1977-79 survey using the RIA procedure (Ito and Uchida, 1980) and include the overall rejection rate of 11.9 percent for all species and the consistently high rejection rates for species such as C. rhodochrous (wrasse) implicated in ciguatera poisoning, especially in the major Hawaiian islands. The rejection rates were high when livers were examined; findings support data obtained earlier with bioassays showing a significantly higher level of toxins in liver tissue, especially in eels (Banner, 1976). On the other hand, data obtained did not support the general contention based on earlier observations that bigger fishes within a species have more toxin (Banner, 1966). The data obtained for A. triostegus and Caranx sp. were comparable with results observed recently by Kimura et al. (1982a) in a 2-year examination of S. dumerili using the RIA procedure. Nonetheless, examination of as many species as possible needs to be done, since the metabolic processes and incorporation of toxin into tissue may vary with each species.

Analysis of the EIA procedure reveals the following critical technical factors which one should be aware of in running the test: (1) the size and shape of the tissue samples should be uniform, and replicate samples from each area should be tested; (2) the fixation step of the fish tissue with methyl or ethyl alcohol is essential (isopropyl, butanol, and acetone are not satisfactory); and (3) both fresh and cooked fish tissues may be examined using this procedure, provided the tissues are firm and not flaky. Further studies are needed to determine optimal tissue sampling sites. In this regard these preliminary studies show that liver samples can be tested using the EIA procedure, unlike the RIA method (Hokama et al., 1977).

Based on the data presented in this study, it is suggested that the EIA procedure may be the acceptable choice for the routine direct assessment of CTX in fish tissues. The procedure is sensitive (it can detect approximately 0.01 to 0.05 ng CTX at the lower level) and practical and has specificity for CTX. The procedure warrants further examination and evaluation. Thus, this procedure is currently being used for routine survey of new fishing grounds and for analyzing fishes from clinically documented ciguatera outbreaks.

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AGE ESTIMATION AND GROWTH OF THE GRAY REEF SHARK *CARCHARHINUS AMBLYRHYNCHOS* FROM THE NORTHWESTERN HAWAIIAN ISLANDS

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ABSTRACT

The gray reef shark, *Carcharhinus amblyrhynchos*, is a common inhabitant of coral reef environments in the Northwestern Hawaiian Islands and could be subject to developing shark fisheries. Yet, little information on its life history -- especially on age, growth, and reproduction -- is available, making effective utilization and management of this species difficult. In this study, gray reef sharks captured by longline fishing methods were aged using rhythmic laminations on sectioned vertebral centra. Ages ranged from young-of-the-year individuals measuring 590 to 840-mm total length (TL) to adults with 12 bands measuring up to 1,688-mm TL. Von Bertalanffy growth curves fit the estimated age and length data well, resulting in an asymptotic length of 1,879-mm TL, considerably smaller than the maximum reported length of 2,540-mm TL. Because gray reef sharks are reported to mature between 1,300 and 1,350-mm TL, their age at maturity is estimated to be between 6 and 8 years. Preliminary data from electron microprobe analyses for calcium and phosphorus in centrum sections provided support for the hypothesis that one opaque band is produced during the summer, and another, more translucent, band during the winter. This study has demonstrated new techniques for age determination and verification, and has provided life history information which will be useful in modeling the population dynamics of elasmobranch fishes.

INTRODUCTION

Sharks, which are high-level predators, are important in the functioning of coral reef ecosystems due to their trophic position (Volterra, 1928; Hassell, 1976). Thus, a basic understanding of the life history processes of these predators is necessary before the dynamics of coral reef ecosystems can be fully understood. Also, because fisheries for elasmobranchs are increasing in many coastal environments and may indeed undergo rapid development in tropical environments such as the Hawaiian islands, information on such life history features as age, growth, and reproduction will be necessary for proper management of these potential emerging fisheries for elasmobranchs.

The determination of age of individual sharks collected from the field is a prominent problem in elasmobranch fisheries research, and only recently has major progress been made. Resolution of age determination will allow growth rates to be calculated and will make it possible to incorporate age-specific parameters such as mortality and production into population dynamics models. Most age determination studies on sharks have utilized rhythmic patterns in their cartilaginous vertebral centra. However, techniques used to determine age in elasmobranchs vary from species to species, and no one technique has proven successful for all species (Cailliet et al., 1981; Cailliet et al., in press). Thus, techniques have to be developed and tested for each new elasmobranch species to be studied.

The gray reef shark, Carcharhinus amblyrhynchos, is one of the more common inhabitants of Hawaiian reef ecosystems (Wass, 1971), and as one of the top predators in these systems, it could greatly influence the functioning of these ecosystems. Indeed, their agonistic behavior has been well documented (Johnson and Nelson, 1973; Nelson, 1981). Their abundance has led some to suggest that they could support a fishery. However, very little is known of the life history of this species (Tinker, 1973; Garrick, 1982), and management of such an emerging fishery would be hindered by the lack of information necessary for understanding their population dynamics. It would be preferable to gather such information before a fishery is started in order to avoid over-exploitation, a common problem typical of other elasmobranch fisheries (Holden, 1977).

To help fill the gap in knowledge of the life history of Hawaiian reef sharks, age, growth, and reproduction of selected species were studied. In this study, concentric bands observed in the vertebral centra of the gray reef shark were utilized to estimate ages and to generate growth characteristics, and energy dispersive x-ray spectrometry was utilized to characterize the chemical nature and periodicity of band formation in this species from the Northwestern Hawaiian Islands.

MATERIALS AND METHODS

Standard longline fishing methods were utilized to collect specimens of the gray reef shark in the Northwestern Hawaiian Islands. The majority (71 percent) of specimens examined for this study were taken from French Frigate Shoals. Upon capture the sharks were measured using total length to the nearest centimeter, and vertebrae were removed from below the first dorsal fin. Each section of vertebrae was then frozen for later study.

Upon defrosting, the vertebrae were separated and their centra were cleaned of all connective tissue following procedures outlined by Cailliet et al. (1981, in press). They were then stored in 70 percent ethanol. One centrum from the vertebral column of each specimen was embedded in epoxy casting resin and a longitudinal section approximately 200 thick was cut from the central area of each embedded centrum using a diamond lapidary saw (S. Smith, National Marine Fisheries Service, Tiburon Laboratory: personal communication). This section was cleaned and polished and then viewed with reflected light at 40X with a dissection microscope. Each section was observed by at least two independent observers, and any disagreements in counts were mediated by a third observer. First, the birth check was located. This was a clear zone occurring approximately 3 to 4 mm from the center of the centrum (Figure 1). Then, assuming the birth occurred prior to or during summer, one complete growth zone was defined as the point at which there were two complete bands -- one opaque and the other translucent. The resultant age estimates were plotted against total length to characterize growth, and a von Bertalanffy growth equation was calculated.

To verify the periodic nature of band formation, calcium and phosphorus concentrations in sectioned centra were analyzed using a Cambax x-ray electron microprobe scanner. For this analysis, a female gray reef shark measuring 1,120-mm TL was collected off Midway Island on August 9, 1980. Its sectioned centrum was embedded in epoxy resin with one side free to form a 1-inch diameter disk. The surface of the disk and the sample were then highly polished in order to prevent analytical errors and diffraction of x-rays. The specimen disks and standards were then coated with carbon to further dampen diffraction of resultant x-rays and to increase electron conductance. Analyses of calcium and phosphorus concentrations were performed at 25-μ intervals with the electron beam focused on a 5-μ^2 area. Calcium and phosphorus concentrations were presented as percentage weight. The pattern of calcium and phosphorus levels across analyzed sections was then compared with band patterns discerned from a separate section of an adjacent centrum which had been prepared and aged using standard techniques.

RESULTS

Preliminary counts of bands in sectioned vertebral centra from 59 gray reef sharks indicated that this species grows

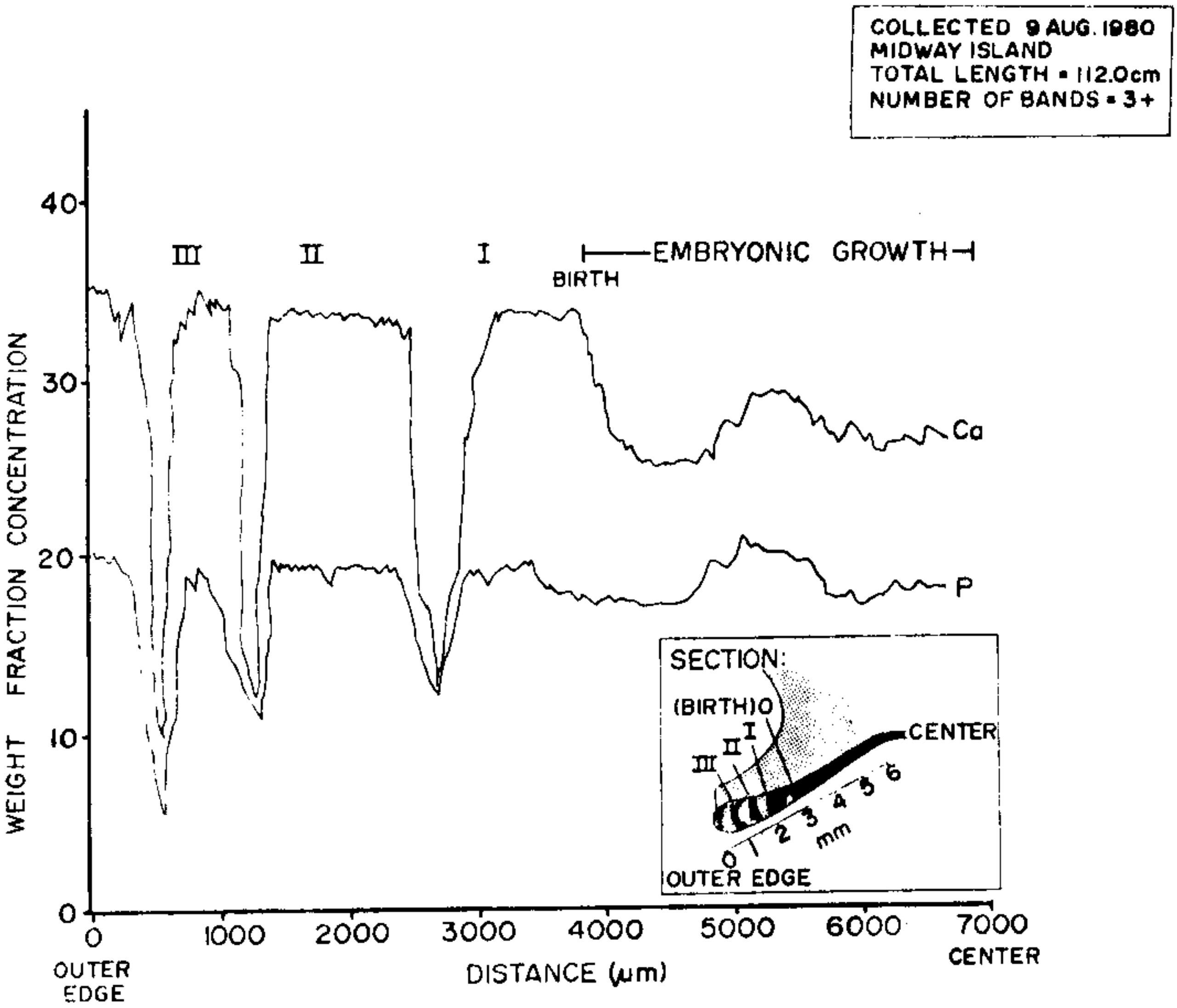

Figure 1. Electron microprobe analysis of calcium-phosphate across the surface of a sectioned vertebral centrum from a gray reef shark, Carcharhinus amblyrhynchos. Inset shows the band pattern discerned from an adjacent centrum, with the darker portion indicating a more opaque zone.

relatively slowly with the oldest estimated age being 12 years for a specimen measuring 1,688-mm TL. Growth was more rapid in smaller individuals (from 735-mm TL) and began to slow down after approximately 1,600-mm TL, which corresponds to 10 bands. The von Bertalanffy growth model fit the data well and predicted an asymptotic length (L) of 1,879-mm TL. The von Bertalanffy curve predicted a size of 600-mm TL at birth. Because specimens over 1,600-mm TL are not represented in the sample of 59 individuals, a growth curve for the species is not presented.

Electron microprobe analysis demonstrated that there were three reduced and four elevated zones of calcium phosphate along the axis of the sectioned centrum examined, and these patterns correspond well to a standard band count of 3 years for this individual (Figure 1). Small disruptive zones were observed from the interior portion of the centrum, presumably formed during the gestation period. The first peak in calcium and phosphorus levels presumably reflects the first summer's growth after birth, with subsequent peaks indicating subsequent summers. The outer edge comprises a portion of a peak and indicates that the specimen, when collected during August 1980, was depositing its fourth summer band. Despite the strong evidence presented here for annual periodicity of opaque and translucent band-pair formation, further work on additional vertebrae is necessary to demonstrate the usefulness of electron microprobe analysis in verifying age estimation procedures.

DISCUSSION

Our results indicate that available techniques for assessing age using vertebral band patterns in elasmobranchs are useful in studying the gray reef shark in Hawaiian waters. The bands seen in sectioned centra provide reasonable estimates of age and add another species to the list of elasmobranchs for which age is known (Cailliet et al., 1981; in press).

The resultant growth curve for this species agrees with Holden (1977), indicating that they are long-lived and grow relatively slowly. Since specimens which are considerably smaller than the largest reported, from 2,400-mm TL (Kato et al., 1967) up to 2,540-mm TL (Garrick, 1982) were studied, the conclusion regarding longevity will probably be modified by further analysis of additional data.

The question of temporal periodicity involved in the centrum band formation was clarified by electron microprobe analysis, which supported the hypothesis that one opaque and one translucent band are deposited each year, presumably in the summer and winter months, respectively. The correspondence, when measured in detail along the axis of the section, is quite good, but certainly not perfect. This could be due to the fact that different vertebrae were used for microprobe analysis than for band counting, and that perhaps different wings of the section might have been counted. Nevertheless, the correspondence is sufficient to suggest further microprobe work on this and other species to add evidence about the periodic nature of band deposition in elasmobranch vertebral centra.

It is obvious that the microscopic structure of the elasmobranch centrum is conducive to electron microprobe analysis, and that the resultant calcium and phosphorus levels indicate areas of calcium-phosphate deposition as bone apatites. Our results agree quite well with the study of Jones and Geen (1977), who, using similar x-ray spectrometry procedures, demonstrated the potential of this method to detect growth bands in vertebrae of the spiny dogfish, *Squalus acanthias*. This analytical tool will undoubtedly prove valuable to further studies on growth in elasmobranch fishes.

The minor deflections detected by microprobe analysis in the internal portion of the centrum most likely are related to in utero growth processes. Because gray reef sharks are estimated to have a 1-year long gestation period (Wass, 1971), the length of this portion of the centrum should be equivalent to 1 year's growth. It is interesting that the presumed in utero portion of the centrum has no major peaks and depressions in either calcium or phosphorus levels, and that these peaks and depressions occurred only after birth, when the shark is more susceptible to such external factors as temperature and food availability.

Besides longevity, another life history feature which could make a species susceptible to over-exploitation is age at reproductive maturity. Holden (1977) proposed that maturity occurs relatively late in life in elasmobranchs. Garrick (1982) suggested that gray reef sharks mature at approximately 1,300 and 1,350-mm TL, corresponding to an age of about 6 to 8 years old. If gray reef sharks reach 2,540-mm TL, they may become mature at approximately 53 percent of their maximum size. However, if gray reef sharks live to be only 12 to 13 years old, as our largest specimens indicate, then maturity occurs relatively late in life. Samples in this study do not include the largest individuals recorded; hence, the estimate of longevity will probably increase. Extrapolating from the von Bertalanffy growth model derived for 59 specimens, it would take approximately 18 years to reach asymptotic length. Assuming this to be an accurate estimate of longevity, the gray reef shark becomes mature between 33 percent and 44 percent of its lifespan. Further work on reproduction in this species is certainly needed.

In conclusion, the results of this study on age, growth, and reproduction of the gray reef shark agree well with Holden's (1977) generalizations concerning elasmobranchs. They appear to grow slowly, have long gestation periods, and reproduce relatively late in life. Should a fishery for this or any other reef shark species be initiated, these parameters should be carefully considered. Hopefully, this preliminary information, coupled with more sophisticated and thorough research in the future, will allow intelligent management of this or any other shark fishery in Hawaiian waters.

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SPAWNING AND GONADAL MATURATION OF THE EHU, *ETELIS CARBUNCULUS*, IN THE NORTHWESTERN HAWAIIAN ISLANDS

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ABSTRACT

Ehu, *Etelis carbunculus*, ovaries were collected from various banks throughout the Northwestern Hawaiian Islands during 1977-81. Ovaries were microscopically examined to determine the most advanced developmental stage. Mean monthly gonadal somatic indices indicated that maturation began in May and spawning occurred from July to September. Ehu were found to be serial spawners, i.e., they spawned multiple batches of ova during the season. Most females spawned by the time they reached 35 to 40-cm fork length and older (>45 cm) fish were found to remain in spawning condition longer. The overall sex ratio in a pooled sample of 833 ehu was in favor of females by 2:1. Females also predominated in the larger size ranges (45 to 65-cm fork length) and during certain times of the year, indicating possibly that they live longer or aggregate during spawning. Fecundity of ehu 38.3 to 50.8 cm was estimated at 349,500 to 1,325,600 ova.

ehu
ova
sex ratio
maturation
spawning
fecundity

INTRODUCTION

In 1976, following the enactment of the Magnuson Fishery Conservation and Management Act (FCMA), the Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service (NMFS), in cooperation with the U.S. Fish and Wildlife Service (FWS) and the Division of Aquatic Resources (DAR), Hawaii Department of Land and Natural Resources (DLNR), initiated a 5-year assessment of the marine and terrestrial resources in the

Northwestern Hawaiian Islands (NWHI). An important goal of this study was to describe the distribution and abundance of commercially valuable deepwater snapper. Ehu or red snapper, *Etelis carbunculus* Cuvier, was the bottomfish species most frequently caught (in numbers) during this period. It ranked third in total weight. Little is known about reproduction in Hawaiian deepwater snappers and there has been nothing reported on the spawning and maturation of ehu. To better understand the recruitment of this species into the fishery, a study was initiated to determine the ehu's spawning season, fecundity, and other important aspects of its reproductive potential.

The range of ehu is limited to the Indo-western Pacific, and within this region the distribution is considered discontinuous and is restricted to the Indian Ocean, southern Japan, and Polynesia (Druzhinin, 1970; Forster et al., 1970). Within the Hawaiian Islands ehu is caught on nearly every major bank from the island of Hawaii to Kure Atoll (Figure 1). Their major habitat is the bottom in areas of deep (200 to 350 m) dropoffs around ledges, rock outcrops, and pinnacles (Ralston and Polovina, 1982). During the sampling period they were most abundant in the area northwest of Lisianski bank (see paper in this proceedings by Uchiyama and Tagami), comprising 45 to 86 percent of the total number of bottomfishes caught. Ehu is a very important food fish in Hawaii and is of high commercial value (Uchida et al., 1979).

The major objectives of this study were to determine the spawning season, size at first maturity, and sex ratio of ehu and to determine any differences in these aspects of spawning among banks within the NWHI chain. All of this information is important for any future management of the fishery.

METHODS

Fish were sampled during cruises of the NOAA ship *Townsend Cromwell* over a 5-year period between 1977 and 1981. The majority of fish were caught at bottom handline fishing stations at depths ranging from 200 to 350 m from various banks within the NWHI throughout the year (Figure 1). Hydraulic handline gurdies were used usually with four Nos. 20 or 28 hooks. Stripped squid were used as bait. Of the 935 ehu caught at these stations, 273 (33 percent) were males and 553 (67 percent) were females; 109 fish were not sexed. All fish were weighed to the nearest 0.01 kg and measured to the nearest 0.1 cm. About 300 ovaries collected during fishing operations were either frozen or preserved in 10 percent Formalin. Testes were not saved. Ovarian samples were taken randomly on each cruise and were not necessarily representative of any area, size class, developmental stage, or time of year.

To evaluate differences in ehu reproduction within geographic locations in the NWHI, the area was divided into three different regions. Region I extended from Nihoa to Gardner

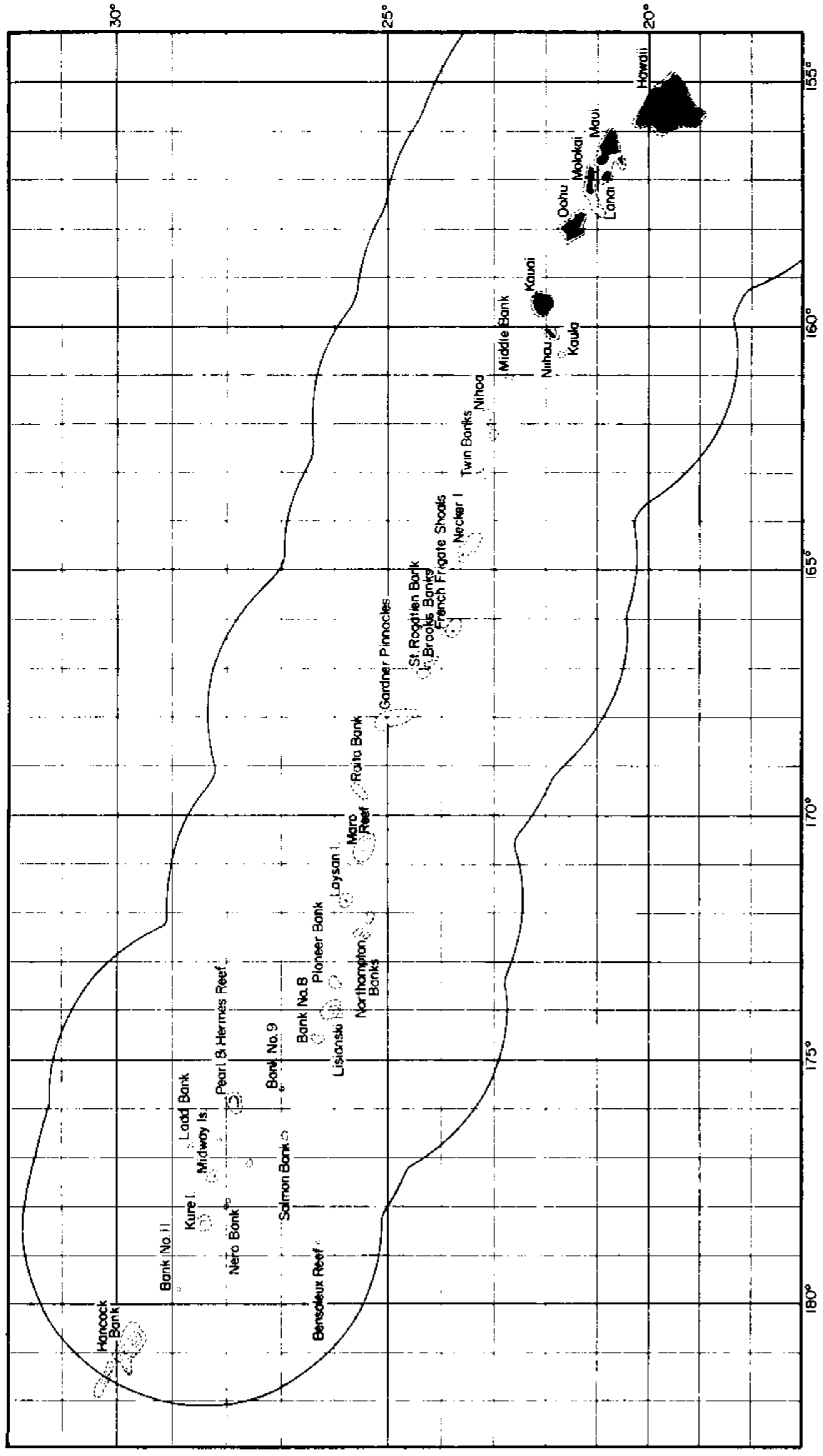

Figure 1. The Hawaiian Islands

Pinnacles, region II from Raita Bank to Lisianski Island, and region III from Pearl and Hermes Atoll to Kure Atoll (Moffitt, 1980).

Various methods have been used to define the spawning season in fishes. The main criterion used in the past has been to monitor the development of the ova, determined by ovum diameters, throughout the year. Each mode in the frequency distribution of ovum diameters was assumed to represent a distinct developmental stage. This technique was used successfully by Clark (1934) for the California sardine, Yuen (1955) for bigeye tuna, and Otsu and Uchida (1959) for albacore. Another method used was to note the developmental stage by microscopically examining the physical characteristics of individual ovum. This can be accomplished by taking a sample from an ovary and teasing out the ova (Uchiyama and Shomura, 1974) or by histologically examining a section of the ovary (Crossland, 1977). The gonadal somatic index (GSI) may also be calculated to assess the fluctuations in ovary weight as a function of body weight during the year (Bagenal and Braum, 1968; Morse, 1980; Goldberg, 1981; Love and Westphal, 1981; Baglin, 1982). A combination of these methods that allowed for a rapid assessment of maturity state and spawning frequency were used.

Each preserved pair of ovaries was blotted dry and weighed to the nearest 0.1 g. To determine stages of development, a dorsoventral sample (completely through the ovary) was taken at the posterior half of the left lobe with a cork borer. The entire sample was teased apart to separate the ova from ovarian connective tissue. All of the ova within the sample were examined under a compound microscope at 40X magnification. The proportion of ova in each development stage and the most advanced stage was noted. Random ovum diameters were measured to determine the size range in each stage, as well as the largest ovum in each sample. The stage of development was classified according to physical characteristics not necessarily dependent on ovum diameters (Uchiyama and Shomura, 1974) (Table 1).

Fecundity was estimated from five ripe-appearing ovaries that were frozen at the time of collection. Thawed samples were placed in modified Gilson's solution (Bagenal and Braum, 1968), until the ova were freed from connective tissue following the procedure described by Kikkawa and Everson (see report in this proceedings). The diameter of 100 randomly selected ova was measured from each ovary (Clark, 1934; Yuen, 1955) to determine the most advanced mode. Ova in this modal group were counted to obtain fecundity estimates since they are most likely to be spawned in a season. These may include ova from maturity stages III to VI. Subsamples were obtained using Van Dalsen's (1977) volumetric technique, modified slightly by Kikkawa and Everson (see report in this proceedings). The ova were placed in a 2,000-ml beaker and initially mixed with a stirring rod. To create a counterflow a magnetic stirrer was then switched on until a homogeneous mixture was obtained. At this time a 5-ml

TABLE 1. DESCRIPTION OF REPRODUCTIVE STAGES OF EHU BASED ON EXTERNAL APPEARANCE OF OVARY AND MICROSCOPIC EXAMINATION OF OVA

Maturity Stage	External Appearance of Ovary
I. Primordial (diameter 0.04 to 0.13 mm)	1. Immature
Oocytes are transparent and irregular in shape with no sign of vitillogenesis. These comprise the oocytes from which smaller numbers of ova mature. Individual ovum are invisible to the naked eye and very difficult to separate from connective tissue.	Ovaries are small and firm in texture and ribbonlike in shape. Very light (white) in color. Sex may be discernible by gross examination. Individual ova are not visible.
II. Early developing (0.10 to 0.16 mm)	
Oocytes are semitransparent and ovoid in shape. A chorian membrane has begun to form around the ovum and yolk granules have started to be deposited within. Barely discernible to the naked eye.	
III. Developing (0.26 to 0.52 mm)	2. Developing
Ova are spherical in shape and have become completely opaque and yellow due to yolk material. They are readily visible within the follicles and can be separated from connective tissue fairly easily.	Ovaries enlarged, elongated, and slightly swollen in girth. Individual ova discernible through the ovarian membrane. Ova, visible to the eye, are small, white, and granular. Ovary appears yellow due to the presence of yolk material.
IV. Advanced developing (0.39 to 0.52 mm)	
A translucent margin bordered by a fertilization membrane is visible. Oil droplets are just starting to form.	
V. Early ripe (0.44 to 0.58 mm)	3. Ripe
Oil droplets have begun to cluster into a single oil globule. The yolk material appears translucent, and ova have become completely round.	Ovary is greatly enlarged reaching its maximum size as it fills the abdominal cavity and hydration takes place. Large ripe ova are discernible through the thin ovarian membrane; ova are easily dislodged from follicles and connective tissue. Ovary is yellow to orange in color.
VI. Ripe (0.5 to 0.78 mm)	
Ova have become almost completely transparent. A single, pronounced yellow oil globule has formed. Ovary wall has become considerably thinner, oil globule (diameter 0.13 to 0.2 mm).	
VII. Residual (atretic)	4. Spent
Ova have become shrunken, wrinkled, and translucent in appearance. Degeneration and resorption in progress.	Ovary empty, flaccid in appearance, and dark gray in color — only primordial ova left. Ovary wall very thick and tough. Residual oocytes may be present.

sample was drawn. This procedure was repeated for each ovary examined. Fecundity estimates were obtained from the formula

$$F = \frac{1}{2} (N_1 + N_2) \left(\frac{V}{5 \text{ ml}}\right)$$

where

F = fecundity
N_1 and N_2 = number of ova in each subsample
V = total volume of the mixture in milliliters

RESULTS

Seasonality of Spawning

Stages of maturity, based on the physical characteristics of the ova, were compared with GSI calculated for ehu captured at various times throughout the year. The GSI increased with advancing stage of maturity and was highest at stage VI (ripe stage). The GSI and stages of maturity were positively correlated ($r = 0.8562$, $N = 286$, $P < 0.01$) (Figure 2). A plot of the mean GSI by month (data for all years pooled) (Figure 3) showed a similar trend when compared with the percentage frequency of maturity stage versus month (Figure 4). The mean GSI values were relatively low from January to April when females were exclusively in stages I and II. In May-June, however, as evidenced by the mean GSI and maturity stages, maturing females were more prominent in the samples. The highest mean GSI's and the most advanced maturity stages were found in July-September. The GSI values decreased and the number of advanced stages declined sharply in October and remained low the rest of the year. Based on these results, the spawning season can be divided into four separate phases: resting phase (January-April), maturing phase (May-June), spawning phase (July-September), and postspawning or recovering phase (October-December). Similar results were obtained when monthly mean GSI's were compared for each individual year from 1977 to 1981.

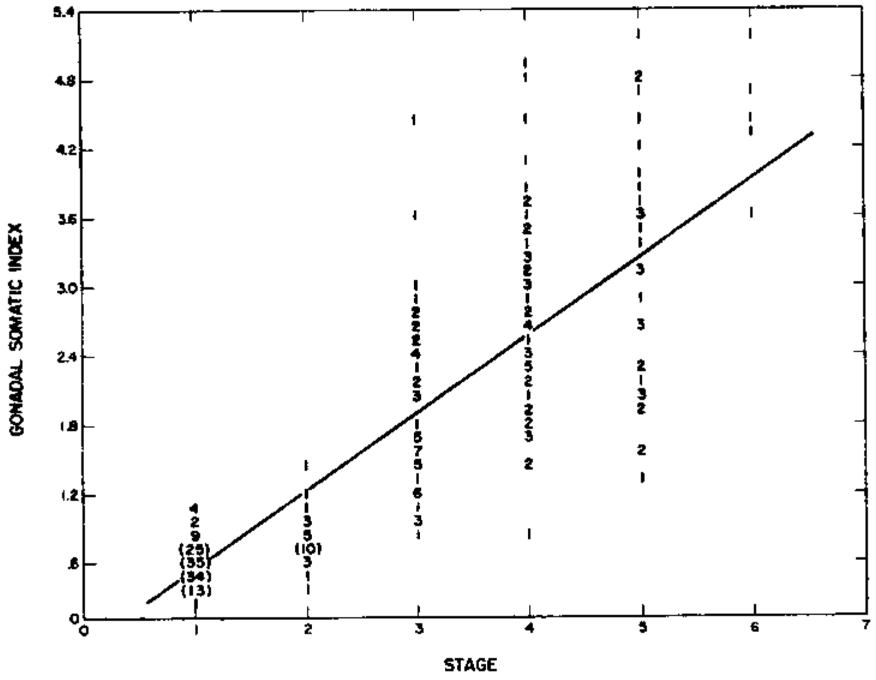

Figure 2. The relationship of gonadal somatic index and maturity stages (I-VI) for 286 ehu ovaries collected between 1977 and 1981.
$Y = 0.67422x - 0.2355$
$r = 0.8562$

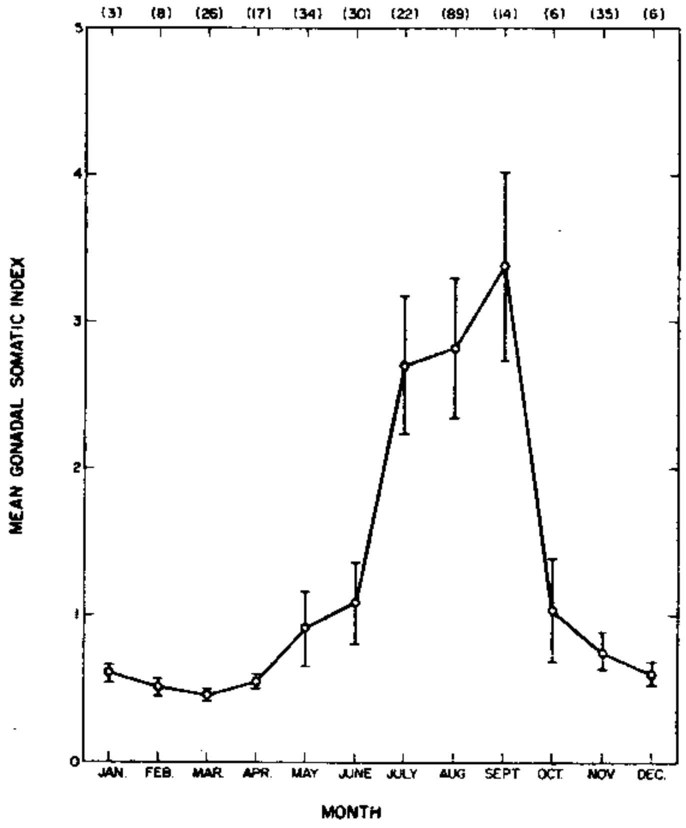

Figure 3. Monthly mean gonadal somatic index for 286 ehu collected between 1977 and 1981. Vertical lines indicate 95 percent confidence limits.
(N) = Number of samples per month

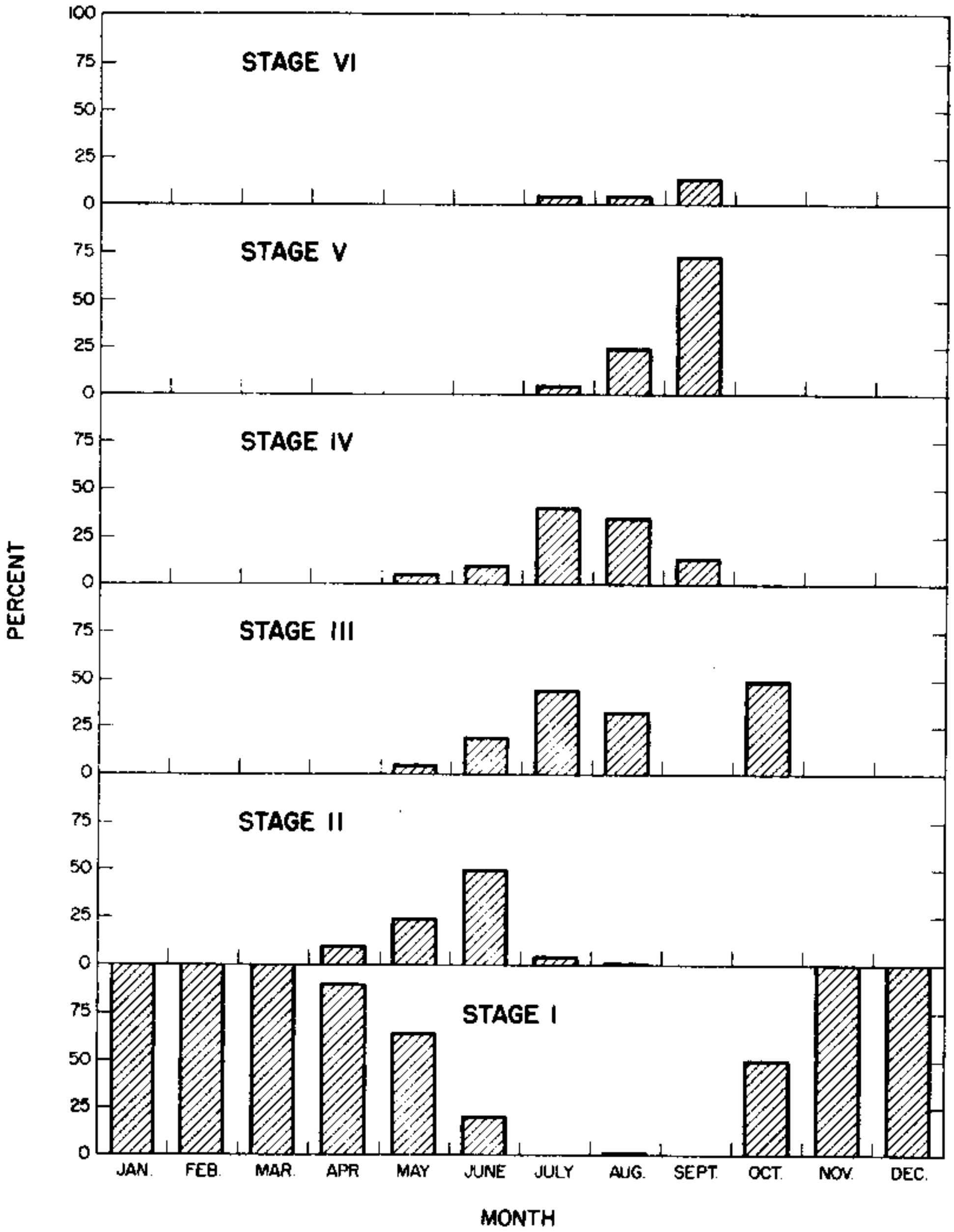

Figure 4. Monthly percentage of ehu ovaries in various stages of maturity, 1977-81

The presence of residual ova (Table 2) was highest (37 percent) in the postspawning phase of maturity and lowest in the maturing phase (3.4 percent).

TABLE 2. OCCURRENCE OF RESIDUAL OVA BY MONTH FOR EHU OVARIES 1977-81. MATURITY STAGES I to V OF DEVELOPING OVA ARE ALSO NOTED FOR EACH OVARY.

Month	Stage	Number	Percent
January	I	1	1.7
February	I	5	8.5
March	I	8	13.6
April	I	7	11.9
May	I	2	3.4
June	--	--	--
July	III	3	5.1
August	III, IV, V	8	13.6
September	--	--	--
October	I	2	3.4
November	I	19	32.2
December	I	2	3.4

Ova diameters were compared with maturity stage for five ovaries in different stages of development. Ova size increased with each advancing stage of development (Figure 5).

The results show that ehu may be multiple spawners and may release several batches of ova during a season. Evidence for multiple spawning is the presence of multiple modes in the ova diameter frequency distribution (Figure 6). Additionally, mature ovaries found during the spawning season contained residual ova (Table 2), and no ehu were found with ovaries that were completely spawned out (containing only stage I ova) until the end of the spawning season.

Maturation

Two separate criteria were evaluated to determine the relationship between maturity and size of fish. In this study, mature fish are defined as those with ovaries that contain developing (stage III) ova and have the potential to spawn during the current season. In contrast, ripe fish are defined as those with ovaries containing ripe (transparent - stages V, VI) ova and are considered imminent spawners with at least one batch spawned during the current season.

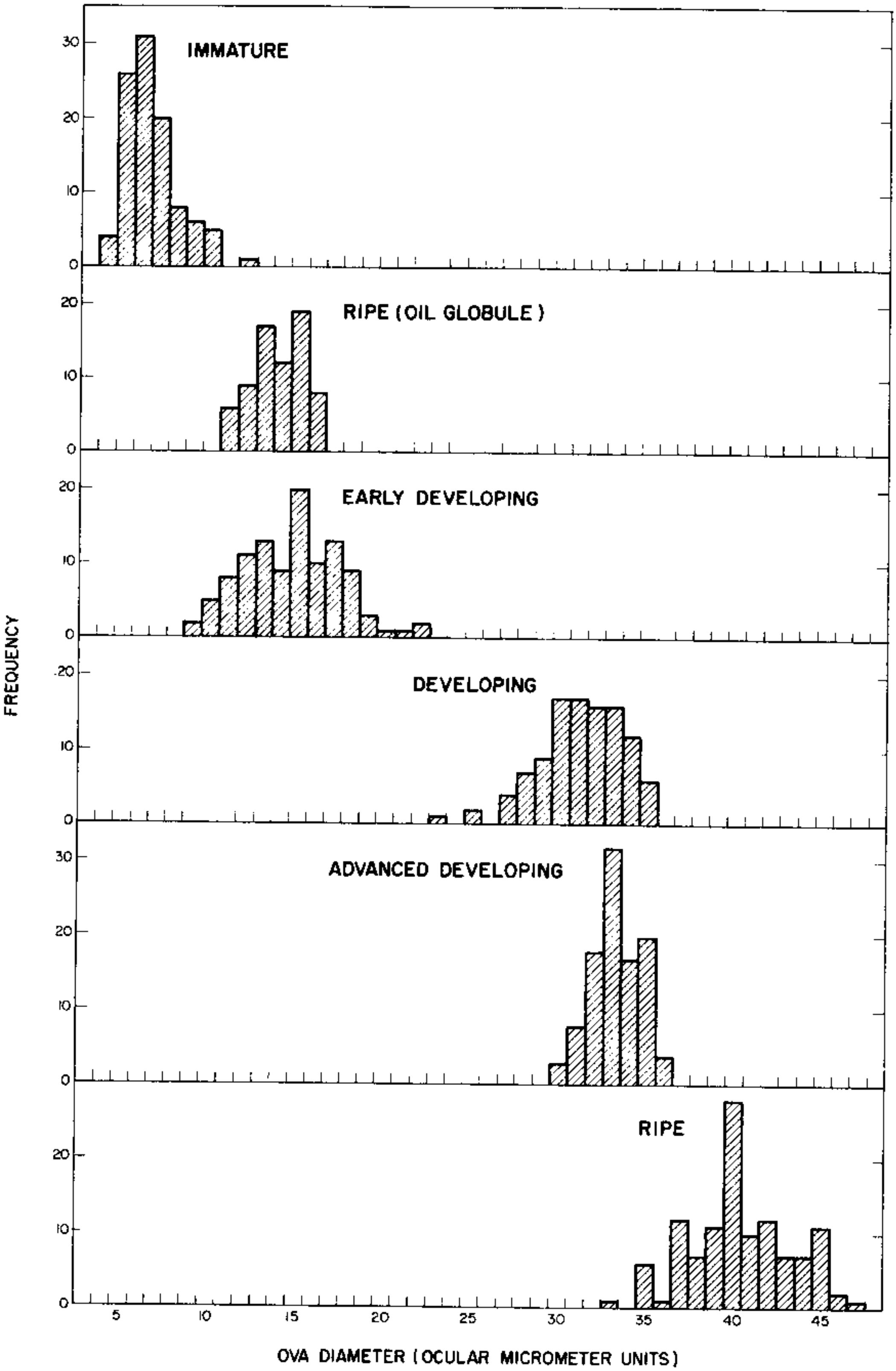

Figure 5. Ova diameter frequency distribution of the most advanced ova for five ehu in various developmental stages. Also shown is the size (diameter) frequency distribution of the oil globule in ripe ova. 1 mm = 72.5 ocular micrometer units

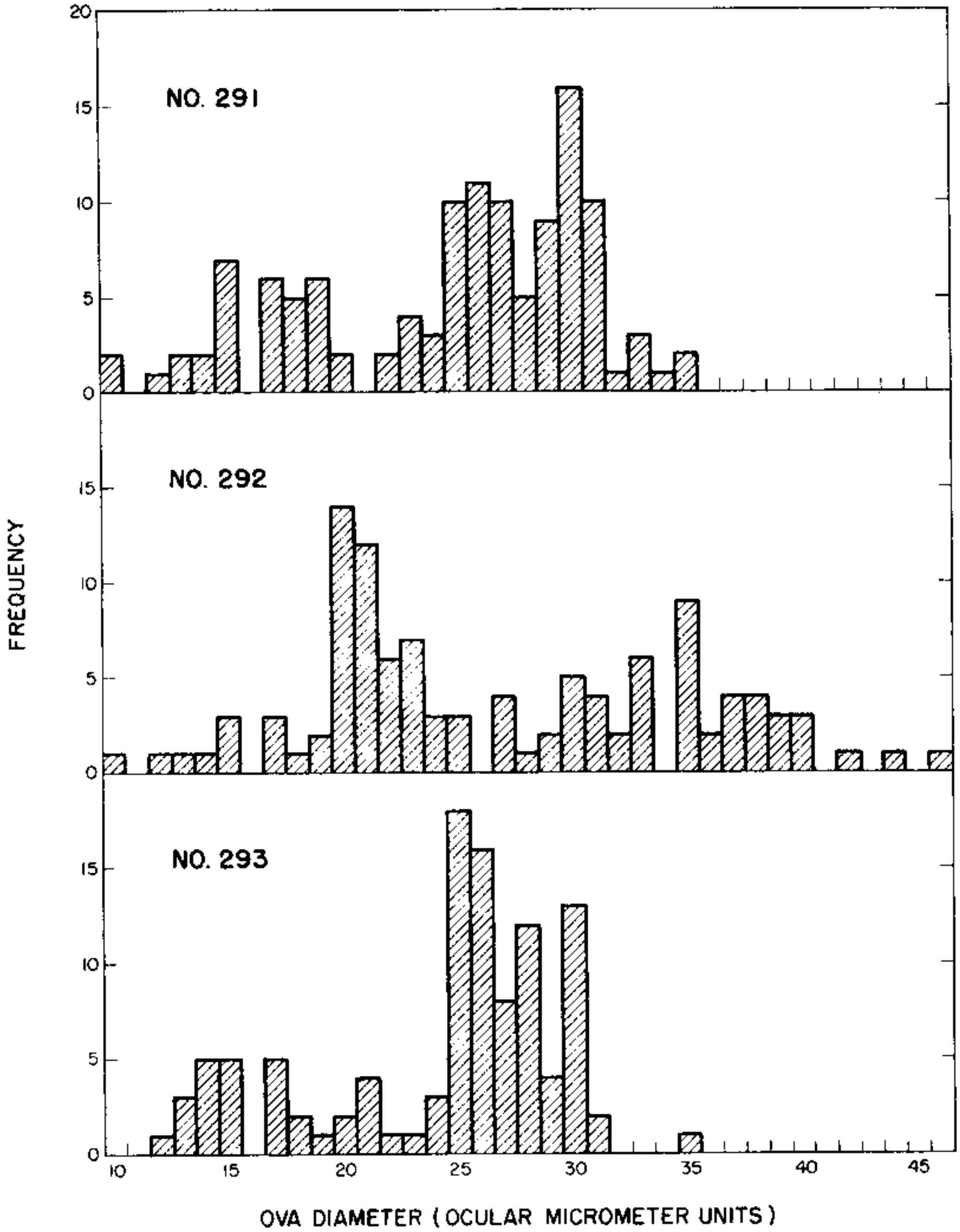

Figure 6. Ova diameter distribution in three ehu ovaries used in fecundity estimates. 1 mm = 72.5 ocular micrometer units

In May, 12 percent of the ehu were mature (Table 3); mature ehu increased to 95 percent by July. The fish captured from May to September ranged from 29.7 to 63.5-cm fork length (FL). Of these, the smallest fish considered mature was 29.8 cm. The proportion of mature fish in each 5-cm size class by month showed that 50 percent were mature in the 25 to 30-cm size class. The proportion increased sharply to 86 percent at 30 to 35 cm, then remained fairly stable through the rest of the size classes.

TABLE 3. THE PERCENTAGE OF MATURE (STAGES III TO VI) AND RIPE (STAGES V TO VI) EHU OVARIES BY FISH SIZE (FL) FOR EACH MONTH OF THE SPAWNING SEASON

Size Class	May	June	July	August	September	Total
25 - 30						
N	1	--	1	--	--	2
% M	0	--	100	--	--	50
% R	0	--	0	--	--	0
30 - 35						
N	--	1	1	5	--	7
% M	--	0	100	100	--	86
% R	--	0	0	33	--	33
35 - 40						
N	3	1	5	13	--	22
% M	0	0	80	100	--	77
% R	0	0	0	23	--	23
40 - 45						
N	7	6	5	19	--	37
% M	0	50	100	90	--	68
% R	0	0	0	26	--	13
45 - 50						
N	12	6	4	21	4	47
% M	17	50	100	90	100	68
% R	0	0	25	24	75	19
50 - 55						
N	4	9	2	21	2	38
% M	0	22	100	100	100	71
% R	0	0	0	24	100	18
55 - 60						
N	6	6	1	7	6	26
% M	33	17	100	100	100	65
% R	0	0	0	43	83	31
60 - 65						
N	--	1	1	--	2	4
% M	--	0	100	--	100	75
% R	--	0	100	--	100	75
Total						
N	33	30	22	86	14	185
% M	12	30	90	98	100	71
% R	0	0	9	27	86	20

Due to the limited number of samples at the lower size classes, it was difficult to determine the smallest size at which ehu reach sexual maturity. The available data indicate that at least some of the females are mature at 25 to 30 cm for age I (Uchiyama et al., in preparation) and that the majority are mature by the time they reach 35 to 40 cm or age II.

Ripeness as an indication of maturity showed a slightly different trend with size (Table 3). There were no ripe fish in the 25 to 30-cm range; the smallest fish with ripe ovaries was 31.8 cm; however, the small sample size at the lower end of the range may bias the data. The 30 to 35-cm range showed a 33 percent increase in the number of ripe fish. In July, 9 percent of the ehu had ripe-appearing ova and no fish <45 cm was ripe. By August, small (<45 cm) ripe fish began to appear and the number of ripe to nonripe increased to 27 percent. In September, 86 percent of all fish caught were ripe, but fish <45 cm were not represented.

Sex Ratio

Sex ratio was determined from a total of 833 ehu collected over a 5-year period. The overall ratio for the period between 1977-81 deviated significantly from the expected 1:1; 557 (66.9 percent) were female and 276 (33.1 percent) were male. Each separate year also showed a significant deviation from 1:1. The sex ratio, calculated for each 5-cm size class, showed that for small ehu (25 to 30 cm), the female to male ratio was 1:1, but among larger (older) fish, there was a gradual increase in the percentage of females. The percentage of females in the 45 to 50-cm class was 65 percent, 84 percent in the 50 to 55-cm class, and 96 percent in the 55 to 60-cm class (Table 4). Contingency table analysis showed that sex ratio and size are not independent (χ^2 $P < 0.05$, d.f. = 7). An analysis of the difference in sex ratio for October and May to test for possible variation due to behavioral factors such as spawning aggregation or female feeding dominance showed no significant difference (Table 5). During the spawning months, however, the percentage of males in the sample dropped from 41 percent in June to 18 percent in August, rose slightly to 26 percent in September, before approaching near normal levels (for this population of ehu) of 38 percent in October. This suggests that sex ratio and season are also dependent (χ^2 $P < 0.01$).

TABLE 4. TEST TO DETERMINE THE DEPARTURE OF THE SEX RATIO OF EHU FROM 1:1 BY 5-CM FL INTERVALS. (DATA POOLED OVER 5 YEARS)

Fork Length (cm)	N	Females (%)	χ^2
25 - 30	12	50.0	0
30 - 35	48	45.8	0.33
35 - 40	114	59.6	4.24*
40 - 45	211	53.6	1.07
45 - 50	199	65.3	18.70*
50 - 55	162	84.0	74.68*
55 - 60	74	96.0	62.48*
60 - 65	10	90.0	6.40*

*$P < 0.05$

TABLE 5. TESTS OF THE HYPOTHESIS THAT SEX RATIO DID NOT VARY SIGNIFICANTLY WITHIN MONTHS OF THE YEAR FROM THAT OF THE ACTUAL POPULATION OF EHU (2:1)

Month	N	Females (%)	Contribution to Total χ^2
January	33	60.6	0.6
February	33	69.7	0.1
March	59	55.9	3.2
April	96	69.8	0.3
May	57	68.4	0
June	176	58.5	5.5
July	50	62.0	0.6
August	138	81.9	14.1
September	57	73.7	1.2
October	21	61.9	0.3
November	96	63.5	0.5
December	17	70.6	0.1

Note: Total $\chi^2 = 26.50$, d.f. = 11, $P < 0.01$

Fecundity

A linear regression using natural log transformed data provided the best fit when fecundity (F) was compared with fork length (FL)in centimeters and total body weight (W) in kilograms. The regression equations were $F = 0.05413\ (FL)^{4.32}$ and

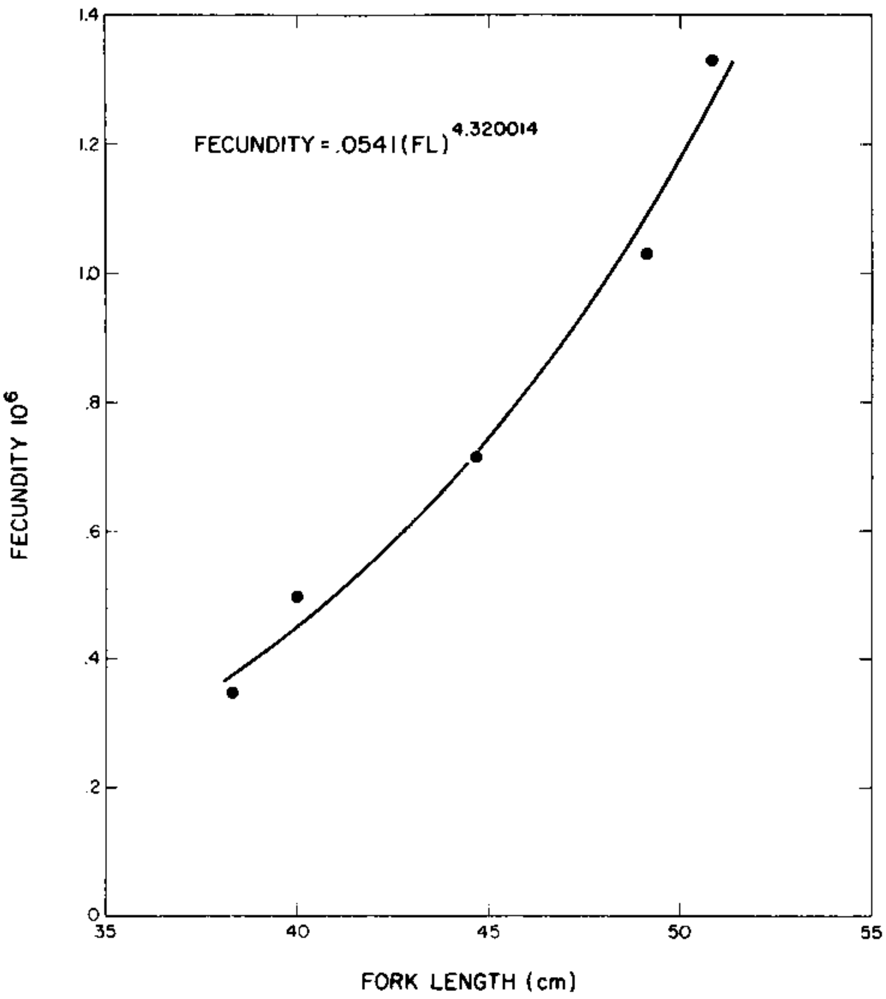

Figure 7. Length-fecundity relationship of ehu

$F = 3.412 \times 10^5 (W)^{1.38}$. This indicated that fecundity increased as a function of both length (r = 0.991) and weight (r = 0.987) (Figure 7). Because of the sample size (N = 5), the estimates of fecundity should be considered tentative, although the correlation for both indicators was quite high. The data did give an approximation of the number of ova spawned by a particular size range of fish. The estimated fecundity ranged from 349,600 to 1,325,600 for ehu between 38.3 and 50.8-cm FL and between 0.97 and 2.49 kg.

Regional Comparisons

To test for differences in spawning season among the three regions within the NWHI, monthly mean GSI versus region was compared. All three regions showed a similar trend of low GSI in January-June, increasing in July-September, then decreasing in October-December. The available data did not show any significant differences in monthly mean GSI among regions.

The sex ratio in regions 1 and 3 did not differ from that of the population ratio (2:1) whereas in region 2 the ratio was slightly skewed in favor of females (2.8:1).

DISCUSSION

Spawning Seasonality

Ehu begin maturing throughout the NWHI in May and spawn in July-September. This corresponds to the time of year when environmental conditions such as temperature and photoperiod are at a peak in this area (Uchida, 1977). Similar observations were made by Grimes and Huntsman (1980) on the vermilion snapper, *Rhomboplites aurorubens*, of North and South Carolina, by Crossland (1977) on the porgy, *Chrysophrys auratus*, in the Hauraki Gulf, and by Ralston (1981) for opakapaka, *Pristipomoides filamentosus*, in Hawaii. All of these investigators found snappers to be summer spawners. Ehu seem to have a shorter, more defined spawning season than many other snappers. Druzhinin (1970) reported that the spawning period of lutjanids may be very protracted, extending over a period of several months. In contrast, ehu in spawning condition were found only during a 3-month period. Spawning ceased in October when GSI values dropped and ovaries containing ripe ova were no longer found. Further degeneration takes place in November-December as indicated by a high percentage of residual ova in the ovaries during this period. Goldberg (1981) found atretic ova near the close of the spawning period when the ova that failed to complete yolk deposition underwent resorption.

Ehu appear to be serial spawners, that is, they release multiple batches of ova during the season. The actual mechanism for this type of spawning varies considerably among different species and depends to a large degree on the environmental conditions. In the Japanese horsemackerel, *Trachurus japonicus*, a dominant egg batch is spawned in the most favorable breeding period, then smaller batches are spawned under less favorable environmental conditions (Chigirinskiy, 1970). Crossland (1977) reported similar results in which serial spawning took place on an annual cycle where successive batches of ripe eggs matured from a stock of developing eggs. Results of this study indicate that a similar pattern occurs with ehu where a developing group of ova matures each year from a core of primary ova and various batches of ova ripen and are spawned each season from this developing stock. Further evidence of serial spawning is that spawned-out ovaries containing mainly primordial ova were not found until the end of the spawning season. This observation was also made for the black croaker, *Cheilotrema saturnum* (Goldberg, 1981). In addition, ehu ovaries contained ova in various stages of development throughout the spawning season, supporting the contention of Grimes and Huntsman (1980) that this may also indicate fractional spawning.

It can be concluded that ehu ovaries develop asynchronously (Wallace and Selman, 1981) throughout the year, but during the maturation phase they develop synchronously and batches of ova ripen and are spawned. The final stage, that is, from ripe to actual spawning, occurs very rapidly (Grimes and Huntsman, 1980), as evidenced by paucity of ripe females and the complete absence of hydrated ovaries in the samples. The absence of fish with ripe or hydrated ova may also be due to behavioral factors, i.e., fish feed less prior to spawning (Reshetnikov and Claro, 1976) or that running ripe fish may shed their eggs when lifted out of the water (Htun-Han, 1978). The latter explanation is very pertinent to ehu since they are caught in deep water and often experience severe stress from the change in pressure as they are brought to the surface.

Investigators have used various criteria to determine the minimum size of sexual maturity. Many feel that the presence of developing (type III) ova indicates that the fish is likely to spawn during the current season (Clark, 1934; Crossland, 1977; DeMartini and Fountain, 1981). For ehu, the presence of ripe (types V and VI) ova gave a better indication of the percentage of fish that will actually spawn in any size class. Ehu with mature (type III) ovaries began appearing in May and were always found in greater proportion than those with ripe ovaries. These fish have the potential to spawn, but many never reach the ripe stage due to environmental conditions (Chigirinskiy, 1970) or age constraints (Clark, 1934). The ova that did not mature would cease development and be resorbed. As with other snappers (Starck and Schroeder, 1971; Grimes and Huntsman, 1980) larger ehu (>45 cm) mature earlier in the season and remained in spawning condition longer than small (<45 cm) fish.

The smallest mature ehu caught was 29.8 cm, and 50 percent of the fish in the 25 to 30-cm size class had mature ovaries. In contrast, the smallest fish that had ripe ovaries was 31.8 cm, and 33 percent in the 30 to 35-cm size class were ripe. Because of the scarcity of small size classes, due possibly to hook selectivity (Ralston, 1982) or other behavioral factors, size at maturity could not be confidently estimated. The data indicated, however, that some ehu spawn during their first year at around 32 cm and that the majority spawn after age II (39 cm).

There appeared to be no differences in spawning season, maturation, and sex ratio for the three regions within the study area. Apparently the change in the environment accompanying the change in latitude from Nihoa to Midway Islands is not significant enough to cause any fluctuation in the spawning within the NWHI.

Sex Ratio

The sex ratio of ehu (all samples pooled) deviated significantly from the expected 1:1 and also by size and season. There was a preponderance of females in nearly every category. A deviation in sex ratio among different size classes was also found in the vermilion snapper (Grimes and Huntsman, 1980). Female vermilion snapper increased to 60 percent of the sample at 25 to 30-cm total length (TL), to 70 percent at 50 to 55 cm, and to 90 percent above 55 cm, suggesting that this anomaly resulted from differential mortality and longevity. The data for ehu show an even greater disproportion of females in the upper size range (Table 5). This implies greater male mortality in the higher (>30 cm) size classes. Age and growth data for ehu are very limited; however, female Lutjanus synagris grow more rapidly and survive to a greater age than males (Reshetnikov and Claro, 1976).

The data for the sex ratio of ehu over the year show that, during the prespawning month of June, the ratio of males increases to about 41 percent then decreases to 18 percent during the peak spawning period in August (Table 4). This suggests behavioral changes during the spawning season such as feeding response and spawning aggregations by females.

Fecundity

Estimates of fecundity for ehu are slightly higher than those for the vermilion snapper. Estimates of the fecundity of vermilion snapper ranged from 8,168 to 1,789,998 ova for 41 females 229 to 557-mm TL (Grimes and Huntsman, 1980). The estimates for ehu ranged from 349,000 to 1,325,600 for fish between 38.3 and 50.8 cm and are based on the total number of eggs that may be spawned under ideal environmental conditions in a given season.

Because ehu is a multiple spawner, the estimates may be less precise since it is difficult to determine the number of spawnings per year and the number of eggs per spawning (Hunter and Goldberg, 1980). Environmental conditions may determine whether some or all of the batches may be spawned (Chigirinskiy, 1970). Also, the relationship among the number of maturing ova in an ovary, the number of ova spawned, and the viable larvae produced are unknown. Therefore, considering all these factors, fecundity estimates for ehu represent an approximation of its reproductive potential.

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MATURATION, SPAWNING, AND FECUNDITY OF OPAKAPAKA, *PRISTIPOMOIDES FILAMENTOSUS*, IN THE NORTHWESTERN HAWAIIAN ISLANDS

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ABSTRACT

The reproductive biology of opakapaka, *Pristipomoides filamentosus*, from the Northwestern Hawaiian Islands was studied. Development of ova within the paired ovaries was heterogeneous, and the stages of maturation, based on the development of ova in the most advanced mode in ova diameter size-frequency distributions, were positively related to the gonadal somatic indices. The data indicated that the spawning season for opakapaka is from June through December, with spawning peaks in August. Fork length appeared to be the best predictor of fecundity. Estimates of annual fecundity ranged from 477,990 ova for a 48.7-cm fish to 1,461,875 ova for a 76.3-cm fish. The species reaches sexual maturity at about 42.5 cm and spawns at 52 cm. The sex ratio (data pooled by years) showed a significant departure from 1:1. More males were observed in January and more females in August. Females predominated in the samples at sizes >70 cm.

fecundity
maturation
sex ratio
Pristipomoides filamentosus
snapper
spawning

INTRODUCTION

In 1978 a tripartite cooperative agreement was signed by the U.S. Fish and Wildlife Service, Hawaii Division of Aquatic Resources, and the Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service (NMFS) to investigate the marine and terrestrial resources in the Northwestern Hawaiian Islands (NWHI). Under this agreement, NMFS was responsible for the survey and assessment of benthic and pelagic fishery resources (Uchida et al., 1979).

Part of the Honolulu Laboratory's work included life history studies of commercially important species such as opakapaka, *Pristipomoides filamentosus* (Cuvier and Valenciennes). Opakapaka have been extensively fished around the main Hawaiian islands for decades. Prized for its good taste and pleasing appearance, opakapaka is one of the most important bottomfish in terms of landed weight and cash value.

In this study the spawning season, size at sexual maturity, sex ratio, and fecundity of the opakapaka was examined.

There is a limited amount of data in the literature on the life history and reproductive biology of this deepwater snapper. Ralston (1981) studied the commercially caught opakapaka in the Hawaiian Archipelago and determined that opakapaka was sexually mature at 38-cm fork length (FL) and spawned from July to November.

MATERIALS AND METHODS

For a major portion of the NWHI resource assessment program, the NOAA ship *Townsend Cromwell* was used to survey the bottomfish resource. The opakapaka, as well as other bottomfishes, were caught on handline gear using four hooks (No. 28 size) per line. Samples were collected from most of the banks and reefs from Necker Island to Northampton Seamount at depths of 73 to 220 m.

Landed fish were measured for fork length (FL) and standard length (SL) in millimeters and weighed to the nearest 10 g. Ovaries from 150 fish were collected and preserved in 4 percent buffered formaldehyde-seawater solution. Ovaries were not examined until 6 or more months had passed and shrinkage had stabilized. The developmental stage of all the ovaries was determined by the physical characteristics of the ova (Table 1).

Homogeneity of Ova Development

A pair of ovaries was examined for homogeneity of ova development. A cork borer with an inside diameter of 10.026 mm was used to sample ovarian tissue from the anterior, middle, and posterior regions of both lobes. Each of the core samples extended from the outer layer of the ovary to the central lumen. Each core sample was sectioned into three equal parts, the outer epithelial layer, middle layer, and inner layer adjacent to the lumen, for a total of 18 subsamples. From each of the subsamples, ova were teased from the connective tissue and 200 randomly selected ova was measured. Diameters of the irregularly shaped ova were measured in a petri dish etched with parallel lines. An ocular micrometer was used to measure the ova following the methods of Clark (1934).

TABLE 1. DEVELOPMENTAL STAGES OF THE OVA

Stage	Description	Size Range (mm)
Primordial	Found in all the ovaries; usually ovoid and transparent.	No measurements taken
Early developing	Ova are transparent to translucent; opaque yolklike material may be present in the ovum. Ova usually ovoid or wedgelike.	0.15-0.39
Developing	Ova are completely opaque and ovoid.	0.16-0.67
Advanced developing	Ova are ovoid and have a translucent margin. The fertilization membrane has formed.	0.39-0.60
Early ripe	Ova are usually round or spherical. Yolk material is translucent and oil globules may be present.	0.47-0.58
Ripe	Ova are transparent and contain oil globules.	No ripe ovary collected
Residual	Ova are degenerating and show signs of degradation.	

Source: Adapted from Uchiyama and Shomura, 1974

Fecundity

Estimates of fecundity for five individual fish were obtained by the gravimetric method (Bagenal and Braum, 1968). Preserved ovaries were dried on paper towels and gently squeezed to expel any liquid within the lumen. An electronic balance was used to weigh each pair of ovaries to the nearest 0.1 mg. A middle core sample was extracted from the left lobe and sectioned into three equal layers and each layer was weighed to the nearest 0.1 mg.

Ova were teased from the connective tissues and a random sample of 300 ova were measured to establish the size range of the ova in the most advanced mode. Ova in the most advanced mode were then counted.

Fecundity was estimated from each subsample by multiplying the number of ova in the most advanced mode by the ratio of the total ovary weight divided by the subsample weight. The mean of these estimates was used to represent the fecundity of the fish.

Relationships of fecundity to fish length and body weight were examined by plotting fecundity estimates against lengths and weights. Regression lines of the form Y = a + bX (where Y = log of the number of ova, X = fish length in centimeters or weight in kilograms) were fitted by the least squares method.

RESULTS

Homogeneity of Development

Because the frequency distributions of the ova diameters (see Table 1) from the 18 subsamples were skewed to the right of the means, a Kruskal-Wallis, nonparametric test (Sokal and Rohlf, 1969) was used to compare the 18 subsamples. The results showed that the variances among the sites were significantly different ($\chi^2 = 191.45$, d.f. = 17, $P < 0.01$), indicating that the ova in opakapaka ovaries developed heterogeneously.

Fecundity

Fecundity estimates ranged from 478,000 for a 48.7 cm fish to 1,462,000 for a 76.3 cm fish. Relationships of the log fecundity to fork length and weight were determined by the least squares method. The relationship between fecundity and fork length gave the best fit ($r^2 = 0.90$) (Figure 1). The relationships of fecundity to length and weight were:

$$\begin{aligned} \log \text{fecundity} &= 4.74 + 0.0187\ \text{FL} \qquad (1) \\ r^2 &= 0.90 \text{ and} \\ \log \text{fecundity} &= 5.43 + 0.108\ \text{wt} \\ r^2 &= 0.87 \end{aligned}$$

where FL is in centimeters and wt in kilograms.

Spawning Seasonality

The gonadal somatic index (GSI) can be used to estimate the spawning season, provided that it can be shown to have a positive relationship with the various stages of ovarian maturity. A test to determine the relationship between fish size and GSI indicated that fish size was positively correlated with GSI ($r = 0.447$, d.f. = 137, $P < 0.01$). A test between fish size and stages of maturity also showed positive correlation ($r = 0.873$, d.f. = 131, $P < 0.01$) (Figure 2). It appeared that as the female developed sexually, the weight of the ovary not only increased faster than that of the total body weight, but also rose and fell in relation to ovary development, spawning, and redevelopment.

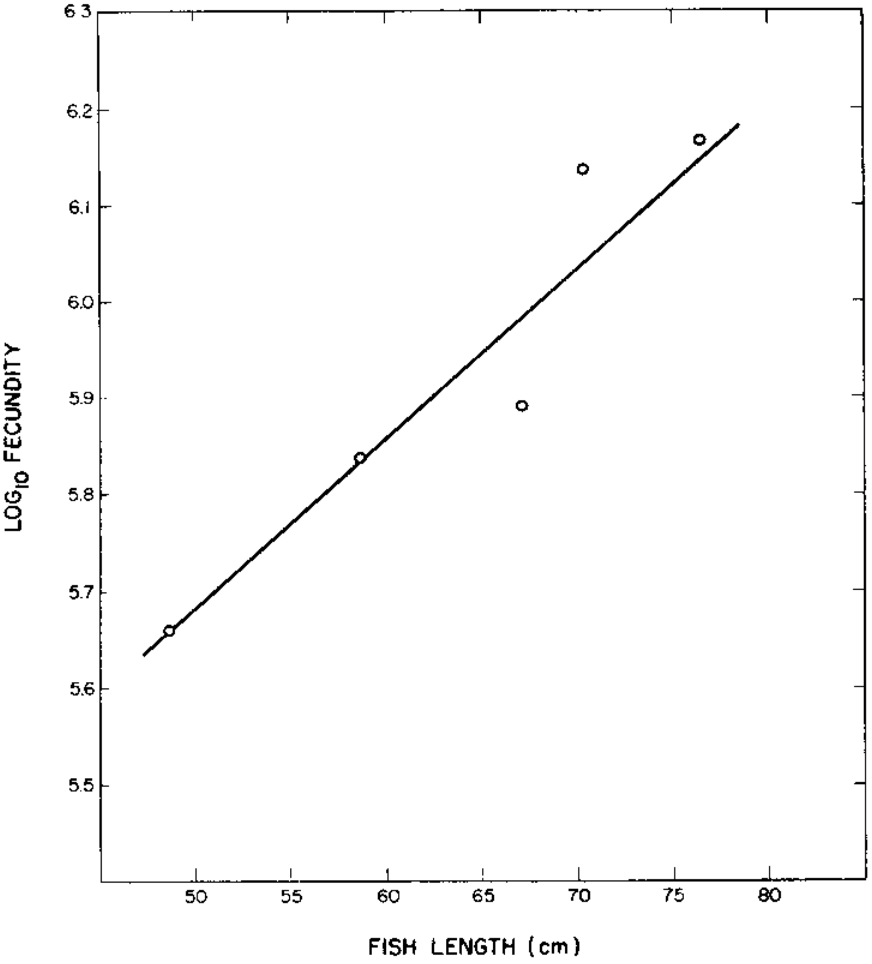

Figure 1. Relationship between the log of fecundity and the fish length (fork length) of opakapaka from the Northwestern Hawaiian Islands

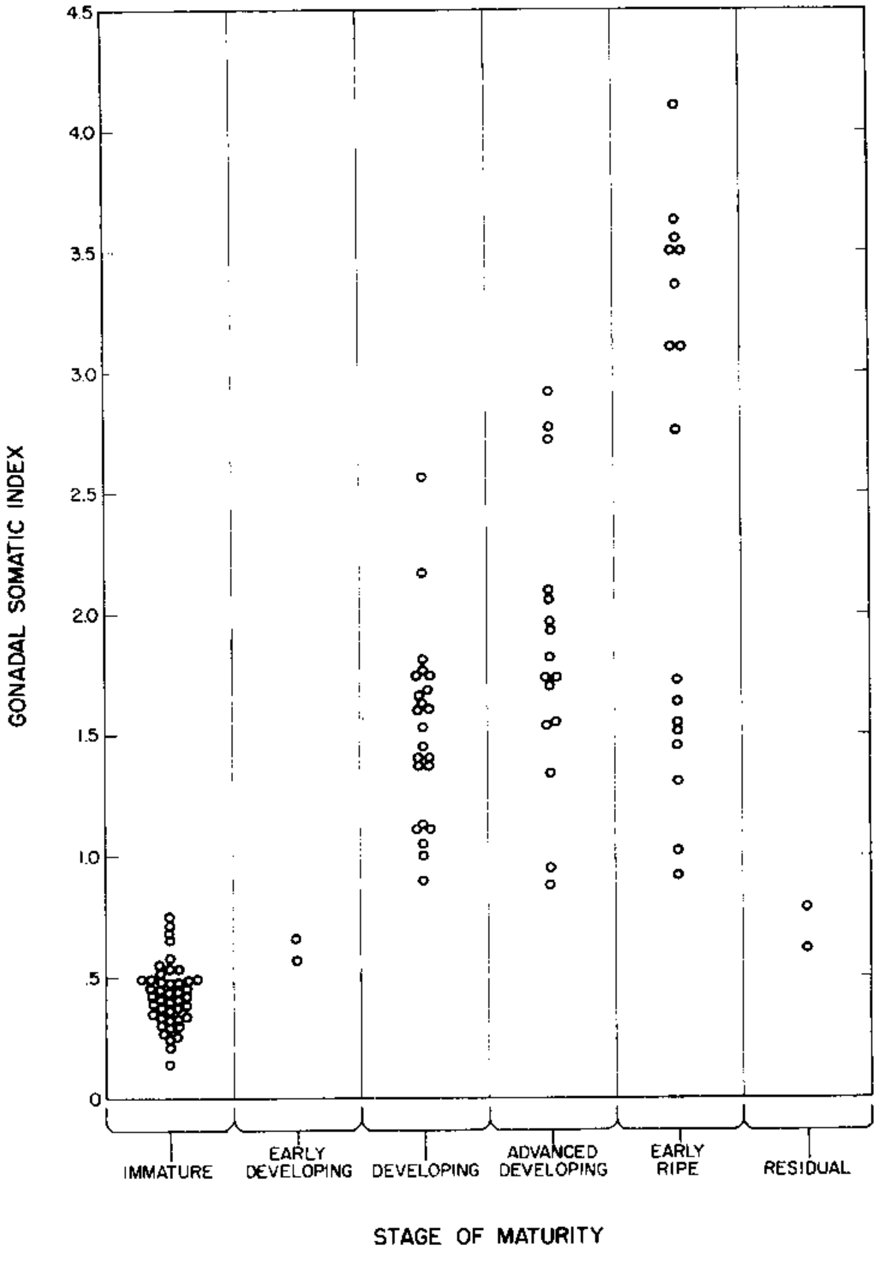

Figure 2. Relationship between stages of maturity and gonadal somatic index in the opakapaka

The spawning cycle of the opakapaka was determined by plotting the GSI against the month of capture (Figure 3). The results showed that spawning commenced in June (GSI = 3.5 percent) and peaked in August (GSI = 4.1 percent). At the conclusion of the spawning season in December, the GSI was 3.1 percent. The lowest GSI was found in January. However, the occurrence of ripening ovaries during this period suggests a protracted spawning season.

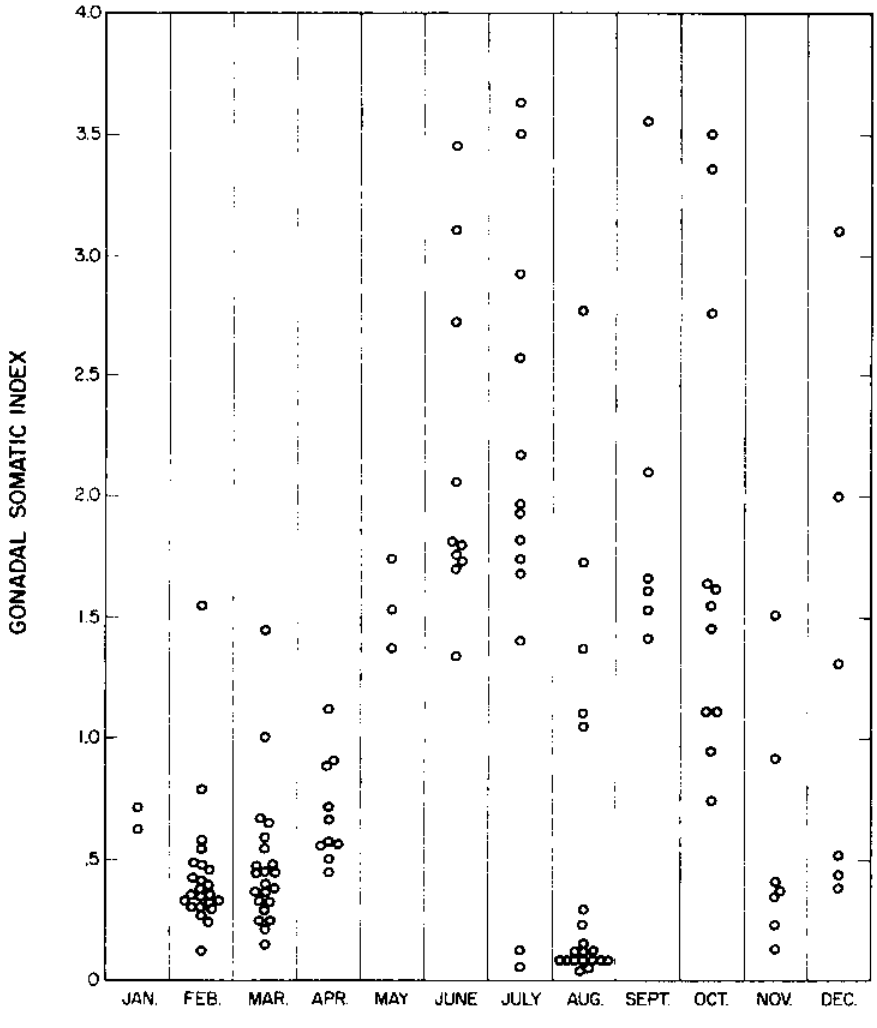

Figure 3. Gonadal somatic index of 135 female opakapaka by month of capture

Size of Maturity

Since it was determined that fish size was closely related to sexual development, size at maturity of the opakapaka was determined by the percentage of change in mean gonad weight at each 5-cm size class (Figure 4). The greatest percentage of increase in gonad weight is expected when a fish matures. For the opakapaka the greatest percentage of increase in gonad weight was observed at the 40 to 50-cm class. The data indicate that opakapaka mature at about 42.5 cm. The smallest mature fish was 42.7 cm. The smallest ripe fish was 37.4 cm and was probably a precocious fish.

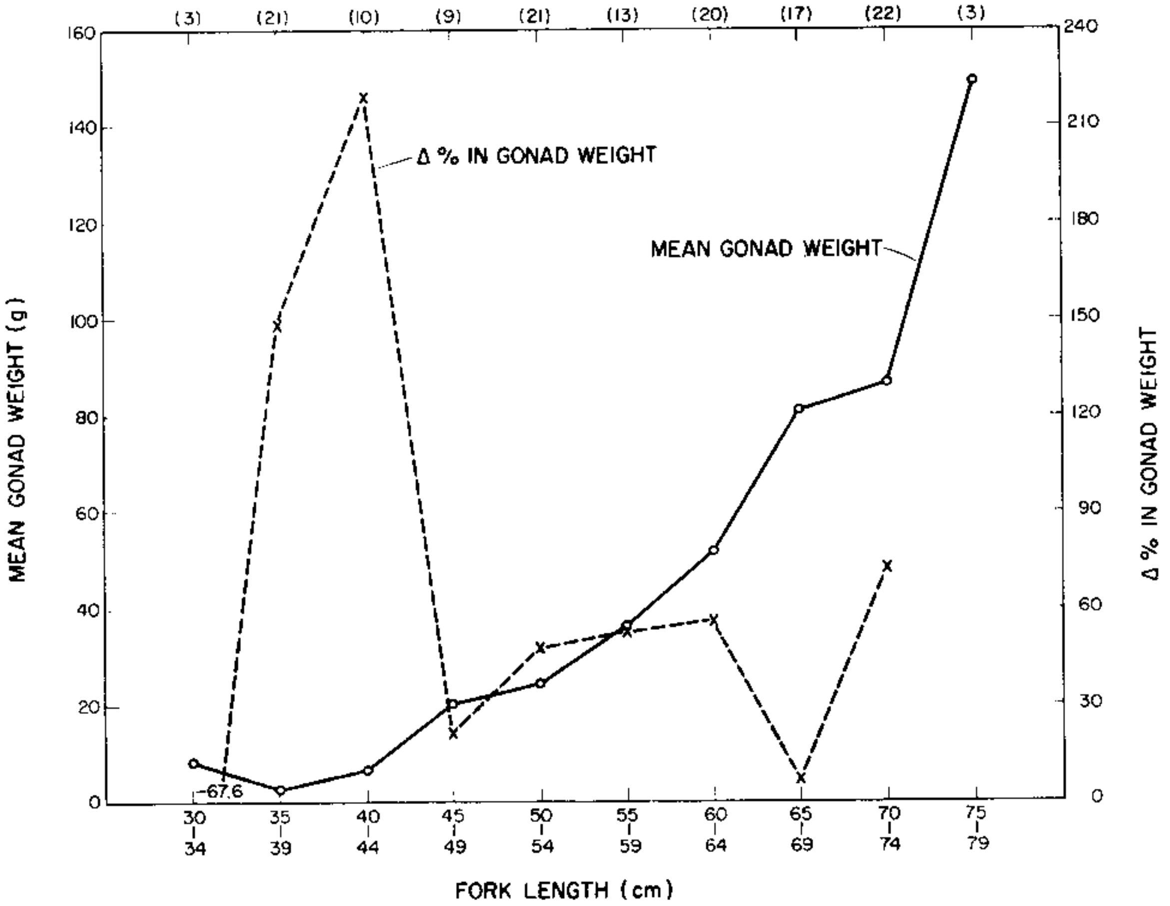

Figure 4. Ovary weight and percent change in ovary weight by 5-cm size classes (sample size in parentheses)

Sex Ratio

Sex data were obtained for 643 opakapaka during the 4 years of the resource assessment program. Because the yearly sex ratios did not deviate significantly from the expected (Table 2), the data for 1978, 1979, 1980, and 1981 were pooled. Females

TABLE 2. NUMBER OF MALE AND FEMALE OPAKAPAKA COLLECTED BY MONTH AND YEARS, 1978 THROUGH 1981

Month	Year				Total	d.f.	χ^2
	1978	1979	1980	1981			
January	61:35	—	—	2:3	63:38	1	6.19*
February	3:8	—	—	11:19	14:27	1	4.12*
March	14:34	—	11:8	0:1	25:43	2	4.76*
April	—	10:9	4:10	4:0	18:19	2	0.03
May	3:5	0:1	—	6:11	9:17	2	2.46
June	12:10	—	9:17	5:11	26:38	2	2.25
July	—	3:5	—	22:21	25:26	1	0.02
August	10:18	—	4:16	9:22	23:56	2	13.78†
September	4:1	1:2	18:12	—	23:15	2	2.19
October	38:34	—	11:5	—	49:39	1	1.14
November	2:3	—	12:12	—	14:15	1	0.03
December	—	4:3	2:6	—	6:9	1	0.60
TOTAL	147:148	18:20	71:86	59:88	295:342		
d.f.	1	1	1	1			
χ^2	0.003	0.11	1.43	5.72*			

Note: The deviation of the male to female ratio from an expected 1:1 was tested by Chi-square.

*$P \leq 0.05$
†$P \leq 0.01$

were more abundant than males. For the pooled sample, the male to female ratio of 1:1.18 significantly differed from the expected 1:1 ($\chi^2 = 4.37$; d.f. = 1; $P = 0.05$).

Monthly sex ratios deviated significantly from 1:1 on four occasions. Larger numbers of males were caught in January and by contrast females were more numerous in February. Also during the peak spawning period in August, females were more predominant than males by 2.43 times.

When size of the fish was considered, the sex ratio deviated from the expected in two size groups. Females were more numerous in the 30 to 39-cm class (1.92:1) and in the largest size class, 70 to 79 cm (1.96:1) (Table 3).

TABLE 3. NUMBER OF MALE AND FEMALE OPAKAPAKA GROUPED IN 10-CM SIZE CATEGORIES

Fork Length (cm)	Males	Females	n	χ^2
20-29	1	5	6	2.67
30-39	36	69	108	10.37*
40-49	59	66	125	0.39
50-59	86	74	160	0.90
60-69	88	83	171	0.15
70-79	25	49	74	7.78*

Note: Deviation of the sex ratio from the expected 1:1 was tested by Chi-square.

*$P < 0.01$

DISCUSSION

The distribution of ova in various stages of development throughout the 18 subsamples indicated that development of the ovary in the opakapaka was heterogeneous. Of the total 18 subsamples from 1 fish, only 6 subsamples had ova in the advanced developing stage and only 2 subsamples had ova in the ripe stage. In the test for homogeneity of location, developing ova were used because of their consistency throughout the 18 subsamples.

It appears likely that opakapaka spawn more than once in the protracted spawning period of 7 months. During the spawning season, only 2 percent of the females of mature size had indices lower than 1 percent which occurred only at the conclusion of the period. Also, all of the sexually mature females during that time exhibited either developing or ripening ovaries and none was found in a spent or resting condition. From the continuous development of the intraovarian ova and the absence of resting ovaries during the spawning period, it is concluded that the opakapaka is probably an intermittent spawner.

Spawning is probably initiated by transient environmental conditions that promote rapid ova development and optimize development and survival of the short planktonic life of the lutjanid larvae (Randall and Brock, 1960).

Occurrence of ripe ovaries substantiated the spawning period indicated by the seasonal distribution of GSI. More sexually developed fish were observed in October: 46 percent of the fish had ripening ovaries. Ralston's 1981 work on commercially caught opakapaka indicated that the fish spawns from July through November.

Although the yearly sex ratios for 1978-81 did not deviate significantly from the expected, the sex ratio for the pooled sample deviated significantly from 1:1 in favor of the females. Kami (1973) observed significantly higher catches of male opakapaka in Guam, whereas Ralston (1981) found no predominance of any sex in his study of *P. filamentosus* caught in Hawaii.

ACKNOWLEDGMENTS

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GONADAL MATURATION, FECUNDITY, AND SPAWNING OF THE GREATER AMBERJACK, *SERIOLA DUMERILI* (RISSO), IN HAWAIIAN WATERS WITH REFERENCES TO CIGUATOXIN INCIDENCES

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ABSTRACT

Reproductive biology of the greater amberjack, *Seriola dumerili*, was investigated to determine relationships with the irregular occurrence of ciguatoxic fish in Hawaiian waters. Incidence of toxic fish was independent of ovary maturity and spawning season. The spawning season is from February through June and peaks in March and April. Incidental spawning occurs year-round. Amberjack appears to be an intermittent spawner with three to four major spawnings in the relatively long protracted spawning season. Size at first maturity was 72-cm fork length and ripe ovaries were first observed in fish 78 cm long. Estimates of fecundity ranged from 1.3 to 4.2 x 10^6 ova for the 83.0 to 118.6-cm size group. Sex ratio was 1.09:1 (males to females); males predominated among fish 60 to 79 cm in length and females among fish 100 cm in length.

ciguatera
fecundity
reproduction
Seriola dumerili
spawning season
greater amberjack

INTRODUCTION

Until May 1980, the greater amberjack, *Seriola dumerili*, comprised a substantial amount of the handline fishery landings in Hawaii, ranking third with an annual average catch of about 33,107 kg (DAR, 1980). Irregular occurrences of ciguatera poisoning (Halstead, 1970) which implicated the amberjack have virtually eliminated commercial sales.

In April 1979, a 2-year program was initiated by the Honolulu Laboratory, Southwest Fisheries Center, National Marine Fisheries Service (NMFS), with the University of Hawaii School of Medicine, and the United Fishing Agency (UFA) to develop a practical method to screen commercial fishes for ciguatera. Due to its history of implication in ciguatera poisoning, the amberjack was employed as a test species.

Previous workers (Hiyama, 1950; Watanabe, 1950; Cooper, 1964) have hypothesized that ciguatera poisoning is directly related to maturity and gonadal ripeness of the fish. A preponderance of toxic fish might occur during the spawning seasons. Banner et al. (1966) have found that elimination of the ciguatoxin in Lutjanus bohar was very slow such that after 30 months there was no detectable drop in toxicity level. They inferred that the incidence of toxicity would be higher in the larger, mature fish.

Of the few studies conducted on the reproductive biology of the greater amberjack, none has examined its relationship with ciguatera levels. Burch (1979) observed that peak spawning in the western Atlantic occurred in March through June with evidence of year-round incidental spawning. Similar fecundity and maturation studies of S. dorsalis off California have demonstrated that multiple spawning occurs from July to October (Baxter, 1960).

In this study, some aspects of reproduction of an exploited fish stock including (1) spawning season, (2) fecundity, (3) size at first maturity, and (4) sex ratio have been determined and compared with the occurrence of ciguatoxin.

MATERIALS AND METHODS

A total of 5,242 amberjack gonads were collected from April 1979 through April 1981 for ciguatera screening. Fish sampled were caught by commercial handline boats in the area between the island of Hawaii and Pearl and Hermes Atoll in the Northwestern Hawaiian Islands.

Fork length (FL), body weight (to the nearest 0.1 kg), date, and location of capture, when available, were recorded. Gonads and stomachs were removed and frozen for laboratory examination. Tissue samples extracted from various parts of the body were collected for ciguatoxin analysis using a radioimmunoassay technique developed by Hokama et al. (1977) at the John A. Burns School of Medicine, University of Hawaii.

Frozen gonads were weighed to the nearest gram and larger more developed ovaries were preserved in modified Gilson's fluid (Simpson, 1951) for fecundity estimates. Other ovaries were preserved in 4 percent formaldehyde solution. Testes were weighed and discarded.

To facilitate the penetrations of the Gilson's fluid, epithelium of the ovary was slit longitudinally on both lobes and inverted, exposing the sinuous germinal tissues. Daily agitations of samples over a 3 to 6-week period enhanced the digestion deterioration of the connective tissues and freeing of the hardened ova. Remaining connective tissue was sufficiently broken down so that any attached ova could be easily freed. Ova were separated from remaining tissue with a 1-mm mesh nylon screen, then collected and washed over a 0.183-mm mesh screen.

Subsamples for fecundity estimates were obtained by a volumetric method (Van Dalsen, 1977) with minor modifications. In place of a reversing magnetic stirrer, ova were initially suspended with a stirring rod. Then, an unidirectional magnetic stirrer was activated to create a counterflow. Prior to the formation of a vortex, two 5-ml aliquots were drawn with a pipette from the lower two-thirds of the mixture, and approximately 2 to 5 cm from the wall of the container.

Estimates of fecundity (F) were obtained by the following formula:

$$F = \frac{\sum^{n} N}{n} \bullet \frac{V}{5\ \text{ml}}$$

where

n = number of subsamples
N = number of ova in each subsample
V = total volume of the mixture in milliliters

Eight ovaries were sampled during the 1980 spawning season for fecundity estimates. Relationships of fecundity with FL, body weight (wt), and gonad weight (gw) were compared using Bartlett's "three-group" method for model II regression (Sokal and Rohlf, 1969; Ricker, 1973). Also from each of the subsamples, 300 randomly selected ova were measured and staged under a microscope (Kikkawa, 1980). Due to the irregular shape of the preserved ova, diameters were measured following the method of Clark (1934).

Earlier workers have customarily used ova diameter frequency distribution in spawning studies (Clark, 1934; Yuen, 1955; Otsu and Uchida, 1959). Although this method provides a good estimate of maturity, the technique is quite laborious. Due to the large number of samples, a simpler method was desirable. Bagenal and Braum (1968) suggested the use of gonad weight as an indicator of reproductive condition. Consequently a percent ratio of gonad weight to body weight (gw/wt x 100), termed the gonadosomatic index (GSI), was employed to represent maturity. For comparative purposes, the developmental stage of ovaries was also determined on the basis of the most advanced ova in the ovaries.

RESULTS

Developmental Stages of the Ovary

Seven stages of ova development could be identified based on physical characteristics: immature, early developing, developing, advanced developing, early ripe, ripe, and residual (Table 1). These stages were similar to those found by Uchiyama and Shomura (1974) in the swordfish, *Xiphias gladius*, and Kikkawa (1980) in the pink snapper, *Pristipomoides filamentosus*.

Ova diameter distributions of ova in various stages of maturity are shown in Figure 1. Primary or primordial cells occurred in all of the ovaries. These rudimentary cells were not measured.

Early developing ova made up the "developing" mode. They were considered unlikely to be released during the next spawning. The "ripening" category included ova in a wide developmental stage from "developing" to "early ripe" (Table 1). No running ripe ova were observed.

The developmental stage assigned to an ovary was based on the most advanced ova. Immature and recently spent females with only primordial cells in the ovaries were considered to have nondeveloping ovaries. Those with ova in the "developing" mode (Figure 1) were classified as developing. Ovaries were classified as "ripening" based on the presence of ova in "advanced developing" mode which included ova in the developing to ripe stage.

TABLE 1. DESCRIPTION OF THE OVARIES OF GREATER AMBERJACK AT VARIOUS STAGES OF DEVELOPMENT

Ova Maturity Stage		GSI Mean (±S.E.)	Physical Description of the Oocytes	Diameter $\mu m \times 10^2$	Ovary Maturity
I.	Primordial	0.940 (0.059)	Oocytes prevalent in all ovaries; oocytes are usually ovoid and consist of uniform transparent gelatinous material.	—	Nondeveloping
II.	Early	0.701 (0.052)	Oocytes are semi-transparent to translucent due to the formation of granular yolk matter. Oocytes are usually ovoid or wedgelike.	2.0-5.1	Developing
III.	Developing	0.701 (0.279)	Oocytes are completely opaque with yolk material.	4.1-6.9	Ripening
IV.	Advanced developing	2.80 (0.099)	Oocytes are usually spherical with uniform opaque yolk granules and encased in a transparent fertilization membrane.	4.6-7.4	Ripening
V.	Early ripe	3.78 (0.55)	Oocytes are usually spherical. The yolk material is translucent; oil globules are present.	5.1-7.6	Ripening
VI.	Ripe	4.86 (0.16)	Oocytes are usually almost transparent; oil globules are present.	—	Ripening
VII.	Residual	3.80	Oocytes show signs of reabsorption. Cells are translucent and greatly reduced.	4.8-7.0	Ripening

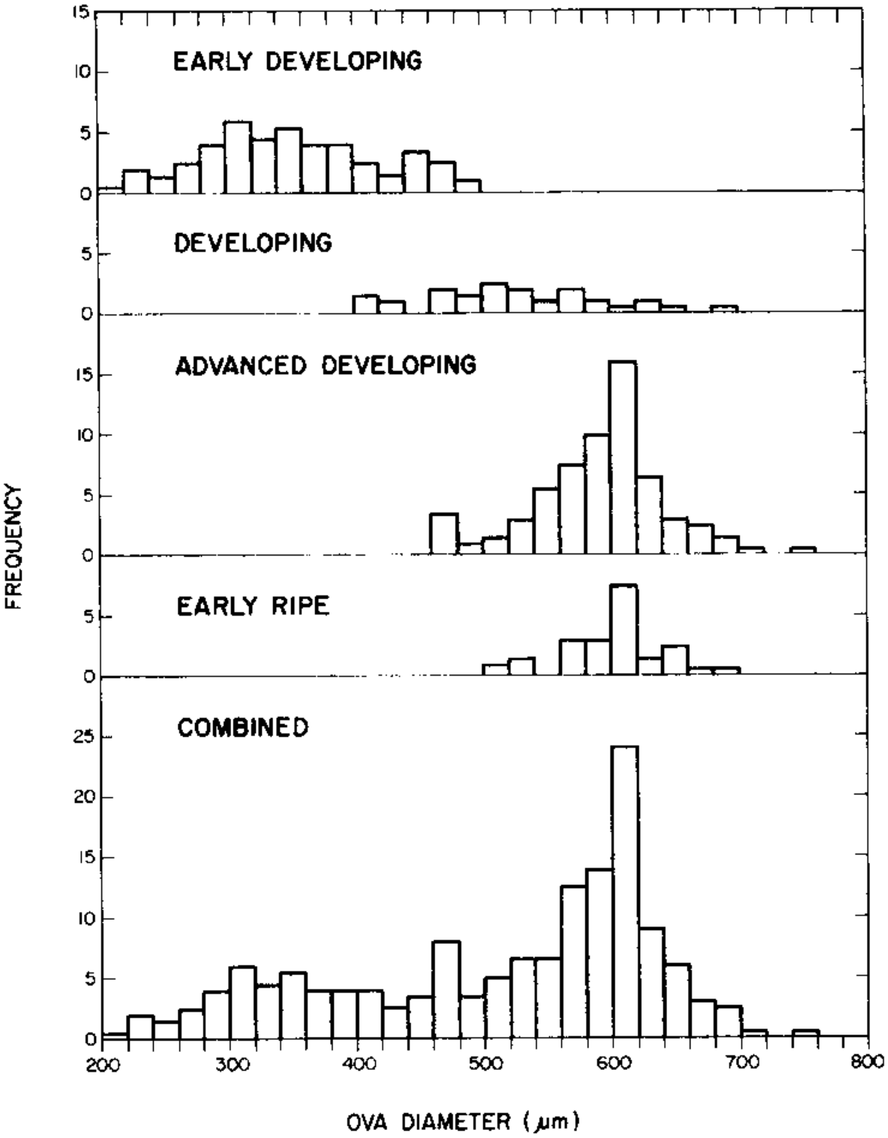

Figure 1. Size-frequency distribution of ova at various stages of maturation

Fecundity

In eight ripening females (83.0 to 118.6-cm FL), fecundity ranged from 1.3 to 4.2 x 10^6 ova. The relationships of fecundity to length, body weight, and gonad weight were linear. Bartlett's method for model II regression was used to describe the relationship:

Relationships	d.f.	Results
Fecundity and length	7	$F = -0.71 + 0.0025\ FL$ $r^* = 0.72$
Fecundity and body weight	7	$F = 0.97 + 0.05\ wt$ $r^* = 0.82$
Fecundity and gonad weight	7	$F = -0.24 + 0.0036\ gw$ $r^* = 0.89$

where

F = fecundity x 10^6
FL = fork length in centimeters
wt = body weight in kilograms
gw = gonad weight in grams
r^* = the unbiased correlation coefficient (Kendall and Stuart, 1967)

All developing and ripening ova in the most advanced mode were used to estimate fecundity. The fecundity was best correlated with gonad weight. Gonad weight, therefore, was considered the best predictor of fecundity.

Ovary maturity and gonadosomatic index

Females that (1) were too small to be sexually mature, (2) had ovaries containing only primordial cells, (3) had ovaries containing early developing oocytes, and (4) were recently spent had indices of about 1 percent. Females with indices 2.0 percent were considered to be sexually active and expected to spawn in the current spawning season. Fish with near ripe ovaries had indices 3.5 percent. The highest index for a female was 4.86 percent.

Spawning season

The seasonal distribution of GSI indicated that spawning began in February, peaked in March and April, and concluded by July (Figure 2). Mean GSI reached 2.5 percent for males and 3.0 percent for females in February and rose to 5 percent for males and 4.5 percent for females in March. At the conclusion of the spawning period, GSI declined to about 1.8 percent for both sexes. The occurrence of a few ripe ovaries and low mean GSI levels throughout the year indicates that incidental year-round spawning may occur.

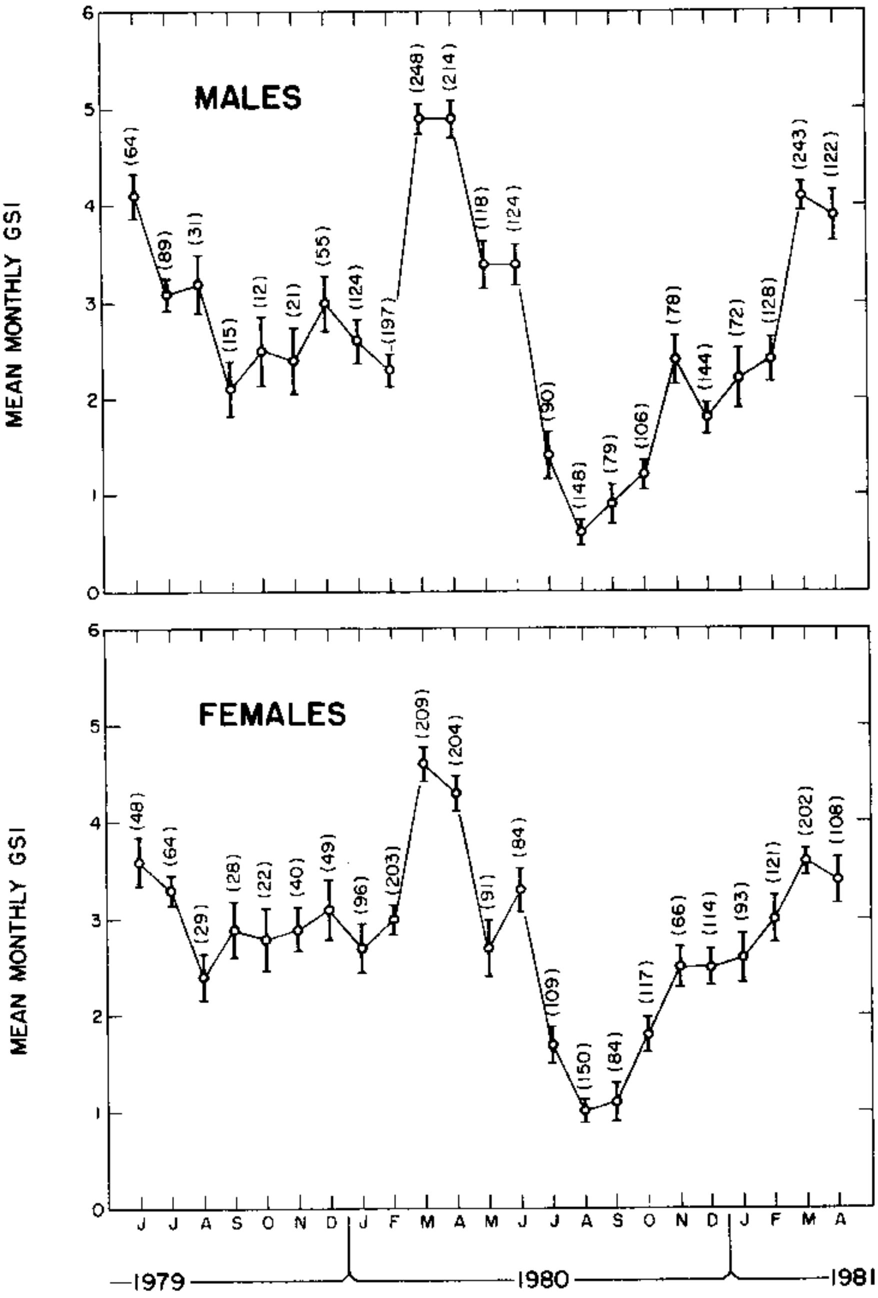

Figure 2. Mean monthly gonadosomatic index (GSI) for the greater amberjack. The vertical lines represent ± standard error of the mean; (N) is sample size.

Size at maturity

The relationship between body length and the development of ovaries was determined from 144 randomly selected ovaries. The percentage of females with nondeveloping, developing, and ripening ovaries was plotted by 2-cm size classes to determine size at maturity. Females with developing ovaries were considered mature and those with nondeveloping ovaries, immature. At 70 cm every female was immature; however, at 72 cm 40 percent had reached maturity. Thus, females were considered likely to reach maturity at 72 cm (Figure 3). The smallest female with ripe ovaries measured 78 cm and was estimated to be 2.5 years old (J.H. Uchiyama, 1983: personal communication).

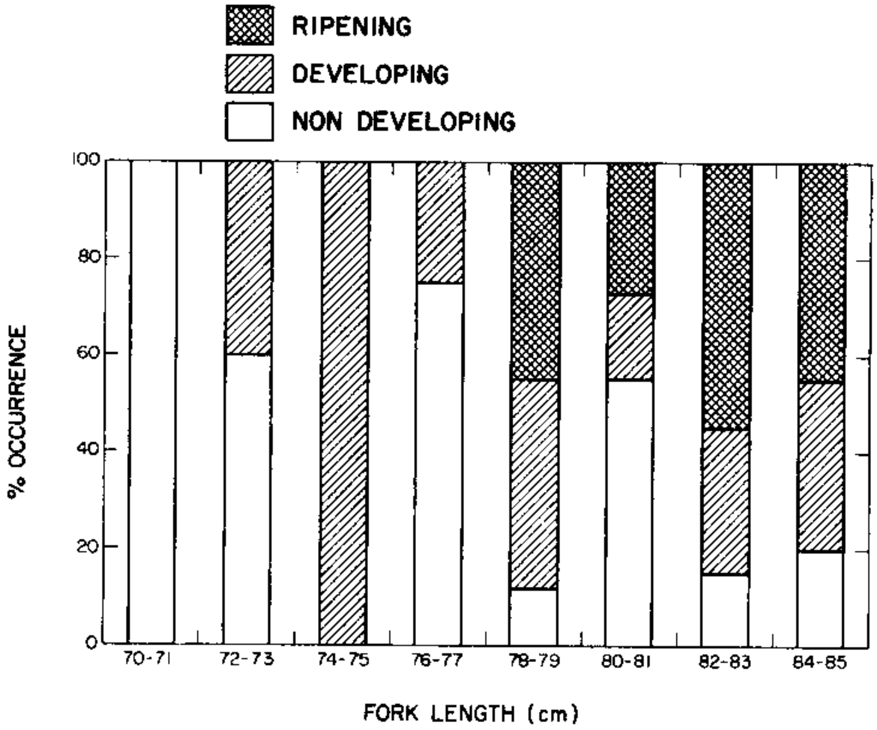

Figure 3. Percentage of distribution of ovaries in various stages of development by fish size

Sex ratio

Males predominated (1.09:1) in the 5,242 fish sampled for this study. Sex ratios by year were: 1979, 1.01:1; 1980, 1.11:1; and 1981, 1.10:1. The sex ratio for 1980 deviated most from the expected 1:1 ratio. Pooled by year, the sex ratio deviated significantly from 1:1 in March, June, and December (Table 2). For the 10-cm length classes, sex ratio deviated from 1:1 for most of the size categories (Table 3). Generally the males predominated in the larger sizes (≤100 cm). Among the smaller sizes (≤60 cm), no significant deviations from the expected were found.

TABLE 2. DEVIATION OF THE MALE TO FEMALE SEX RATIO FROM 1:1 IN GREATER AMBERJACK BY MONTH AND YEAR

Month	Year			Total a	d.f.	χ^2
	1979	1980	1981			
April	29:16	221:221	122:112	372:339	2	1.53
May	43:69	121:94	--	164:163	1	0.003
June	101:72	137:93*	--	238:165	1	13.22†
July	89:64	92:111	--	181:175	1	0.10
August	31:29	150:151	--	181:180	1	0.003
September	15:28	83:87	--	98:115	1	1.36
October	14:26	108:119*	--	122:145	1	1.98
November	23:41	81:69	--	104:110	1	0.17
December	55:50	159:122	--	214:172	1	4.57
January	--	128:97	73:93	201:190	1	0.31
February	--	202:203	129:123	331:326	1	0.04
March	--	265:216	267:208	532:424	1	12.20*
Total b	400:395	1,747:1,583	591:536			
d.f.	8	11	3			
χ^2	0.03	8.08	2.68			

Note: Total a = the sex ratio pooled by month for all years; Total b = the sex ratio for each year

*$P < 0.05$
†$P < 0.01$

Incidence of ciguatoxic fish

Of the 5,227 amberjacks tested, 370 males and 372 females had high levels of ciguatoxin. The percentage of toxic males (13.6 percent) from that of females (14.9 percent) was not significantly different ($t = 1.6934$; d.f. = 5,226; $P > 0.05$).

TABLE 3. DEVIATION OF THE MALE TO FEMALE SEX RATIO FROM 1.09:1 IN GREATER AMBERJACK BY 100-MM SIZE CATEGORIES

Fork Length (mm)	Male	Female	n	χ^2
400	27 (39.7)	41 (60.3)	68	2.88
400-499	104 (46.0)	122 (54.0)	226	1.43
500-599	202 (52.3)	184 (47.7)	386	0.84
600-699	393 (57.4)	292 (42.6)	685	14.89*
700-799	835 (58.1)	601 (41.9)	1,436	38.13*
800-899	815 (54.1)	692 (45.9)	1,507	10.04*
900-999	282 (46.3)	327 (53.7)	609	3.33
1,000-1,099	40 (24.1)	126 (75.9)	166	44.55*
1,100-1,199	7 (13.0)	47 (87.0)	54	29.63*
1,200-1,299	1 (4.4)	22 (95.6)	23	19.17*
1,300	0 (0)	6 (100)	6	--

Note: percentages given in parentheses

*$P < 0.01$

A 2 x 3 contingency table of nontoxic and toxic females against stages of ovary development was constructed to show variations in the occurrence of toxic females by maturity ($\chi^2 = 9.517$; d.f. = 2; $P < 0.01$). A test of independence showed that toxic female amberjacks were most likely to have immature or ripening ovaries ($\chi^2 = 9.668$; d.f. = 2; $P < 0.01$) (Table 4).

TABLE 4. PERCENT DISTRIBUTION OF TOXIC AND NONTOXIC FISH AT VARIOUS DEVELOPMENTAL STAGES

Developmental Stage	Nontoxic	Toxic
Developing	86.0 (3,353)	14.0 (544)
Developing	84.8 (890)	15.2 (159)
Ripe	84.4 (464)	15.6 (86)
TOTAL	100.00 (4,707)	100.00 (789)

Note: Sample size is given in parentheses

No obvious trends in the relationship between the seasonal distribution of toxic fish and spawning could be detected. During 1980, occurrence of ciguatoxic fish peaked in January, March, June, August, and October. The mean percentage was 22 percent of the total month's catch.

DISCUSSION

In this study, fecundity is defined as the number of eggs in the female likely to be extruded at the next spawning (Bagenal and Braum, 1968). Ova in this category were those in the most advanced mode in the ova diameter frequency distribution. It was unlikely that the ova in the secondary mode would develop enough to be released with ova in the most advanced mode. Although the developmental rate of the ova was not determined and the advanced mode included ova in various developmental stages from developing to early ripe, it was assumed that at the time of spawning all of the ova in the most advanced mode would be extruded. Work on the jack mackerel off California demonstrated the occurrence of two major spawnings, i.e., the two modal groups of ova suggested a spawning with each mode.

The seasonal distribution of GSI did not indicate a second peak spawning during the relatively long breeding season, which was estimated to last from February to June, but the possibility of multiple spawning cannot be ignored. It is apparent from the multimodal distribution of ova diameters that the ova in the secondary mode would unlikely develop enough in size and maturity to be released with ova in the most advanced mode. Based on the continuous development of ova, it seems likely that the greater amberjack is a multiple spawner. Although there are no data to determine the number of spawnings per season, higher occurrences of juveniles (fish <45 cm and with sexually indistinguishable undeveloped gonads) in May, July, September, and October (Figure 4) could possibly reflect three or four major spawnings in the spring.

During the off-spawning season, the infrequent catches of ripe fish and a few juveniles indicate that incidental spawning may occur. Spawning would be closely associated with environmental conditions conducive to larval fish survival as was demonstrated for the Japanese horsemackerel, *Trachurus japonicus* (Chigirinskiy, 1970).

The spawning season for greater amberjack off the coast of Florida is from March to June, peaking in April and May. It was inferred from the infrequent catches of ripe fish that the amberjack exhibit low year-round spawning (Burch, 1979). Also, larval fish surveys in the eastern Gulf of Mexico and Straits of Florida tend to support the generalization that year-round spawning is typical of the *Seriola* spp. (Dooley, 1972; Munro et al., 1973; Aprieto, 1974; Fahay, 1975).

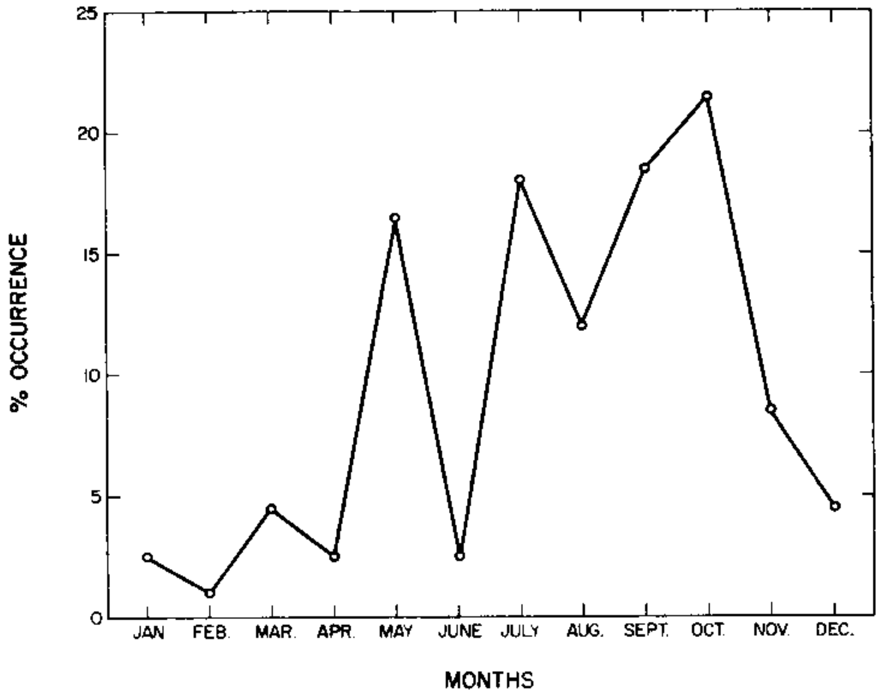

Figure 4. Percentage of distribution of juvenile amberjack ≤ 45 cm throughout the year

The literature on sex ratio provided little assistance in interpreting the significant variations from a 1:1 sex ratio. Deviations from the expected ratio could be due to sexual differences in longevity, growth, mortality, and behavioral patterns, or to sex reversal and migration of one sex out of the sampling area as suggested by Wenner (1972). Of these, only differences in mortality and longevity are supported by available evidence. The number of males in the midsize classes (60 to 90 cm) were significantly greater than the females. Conversely, fish ≥ 100 cm were predominantly females.

The occurrence of 12.2 percent immature and 16.9 percent ripening toxic fish is contradictory to the hypothesis that toxicity is related to spawning period and gonad development (Hiyama, 1950; Watanabe, 1950). No significantly higher number of toxic ripening fish was found. Investigators studying the acquisition and retention of ciguatoxin in the red snapper, _Lutjanus bohar_, have found that toxicity levels remained the same for about 30 months and that elimination of the toxin is very slow (Banner et al., 1966). Due to the persistence of the toxin, one would expect a higher percentage of toxic fish to have reached sexual maturity, but we did not find this to be so. A possible explanation of this anomaly is that at various stages of development, ciguatoxin could be concentrated in different organs. Higher levels of the fat soluble toxin (Scheuer et al., 1967) might be in tissues of high lipid concentrations such as the generative tissues at the onset of spawning. Substantiating work on sardines, herring, and other cluepids have elucidated the increase of fats in the musculature, mesentery, and viscera preceding the onset of spawning (Blaxter and Holliday, 1963; Channon and El Saby, 1932). At the onset of spawning, fat reserves are channeled to the gonads as energy source and nutritive materials in the yolk (Shul'man, 1974). A close association of ciguatoxin with the homologous lipids (Lasker and Theilacker, 1962) might be expected and like the lipids, toxin might be concentrated in different organs due to physiological changes in the fish. During the prespawning period, movement of fat reserves to the reproductive organs would create a lipid and ciguatoxin gradient, thereby increasing the toxicity level in the viscera. Some ciguatera attacks were thought to be caused by the consumption of the more toxic viscera than the musculature (Halstead and Schall, 1958; Cooper, 1964; Helfrich et al., 1968). In immature or resting fish, higher concentrations of toxin would likely be in the musculature due to the rising fat reserves. Because only the musculature was tested by radioimmunoassay, this question remains unresolved.

SUMMARY

1. Greater amberjack gonad samples were collected from the Hawaiian commercial fishery from April 1979 through April 1981 as part of a ciguatera research program.

2. Fecundity estimates, based on counts of all ova in the most advanced mode, ranged from 1.32×10^6 to 4.2×10^6 for fish from 83.0 to 118.6 cm. Relationships of ova count to gonad weight, body weight, and length were best decribed by model II regressions. Gonad weight was the best predictor o fecundity.

3. Spawning season for the amberjack was February through July, peaking in March and April.

4. Infrequent occurrence of ripe ovaries and low mean GSI levels throughout the year indicated year-round incidental spawning.

5. Based on the occurrence of juveniles <45 cm and continuous ripening of the ova during the relatively long spawning period, it appears that the amberjack are intermittent spawners; it is possible that there may be three to four major spawnings in a single season.

6. Size at maturity was estimated to be 72 cm. Some fully ripe individuals were 78 cm.

7. The male to female sex ratio of the 5,242 amberjack sampled was 1.09:1, differing significantly from the expected 1:1 ratio. Males predominated among the midsizes (60 to 79 cm) whereas, females predominated in the larger sizes ($\geq$100 cm).

8. The incidence of ciguatoxic fish was neither related to spawning season nor to sex.

9. There was a slightly higher rate of toxic females in the immature and ripening stages.

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THE FOOD AND FEEDING HABITS OF THE GROUPER, *EPINEPHELUS QUERNUS* SEALE 1901, IN THE NORTHWESTERN HAWAIIAN ISLANDS

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ABSTRACT

Sixty-seven stomach and spew samples of the grouper, *Epinephelus quernus*, from the Northwestern Hawaiian Islands were examined. The study showed that this grouper forages mainly on bottom-associated crustaceans, fishes, and cephalopods.

Shrimp (predominantly of the family Pandalidae) were the most important food item as determined by an index of relative importance (IRI). The IRI incorporates numbers and volumes of the prey and their frequency of occurrence. Of the 22 families of fishes that were represented in the food samples, members of the families Lutjanidae, Emmelichthyidae, and Congridae were the most important. The results suggest that *E. quernus* is a carnivorous, opportunistic bottom feeder.

Epinephelus quernus
Northwestern Hawaiian Islands
feeding

INTRODUCTION

Some of the Hawaiian fishes of highest commercial value are the bottomfishes which comprise the tropical snapper-grouper complex (Uchida et al., 1979). The lone serranid of commercial value within this group is the grouper, *Epinephelus quernus* Seale. Although the maximum size of this species is not known, specimens >105.9 cm total length and weighing 26.5 kg were caught on the resource survey cruises in the Northwestern Hawaiian Islands (NWHI) conducted by the Honolulu Laboratory, National Marine Fisheries Service (NMFS)(Uchida and Uchiyama, in preparation). This species is only recorded from Hawaii and is the only serranid which "contributes significantly to the commercial landings in Hawaii" (Tinker, 1978; Department of Land and Natural Resources, 1979).

The feeding studies on *Epinephelus* thus far have focused upon such species as *E. striatus*, *E. guttatus*, and *E. morio* in the Atlantic (Longley and Hildebrand, 1941; Bardach and Mowbray, 1955; Randall, 1965, 1967; Moe, 1969; Collette and Talbot, 1972) and *E. fuscoguttatus*, *E. merra*, and *E. hexagonatus* in the Indo-Pacific (Hiatt and Strasburg, 1960; Randall and Brock, 1960; Helfrich et al., 1968; Harmelin-Vivien and Bouchon, 1976; Randall, 1980). In general, these groupers are benthic carnivores and primarily feed on fishes and crustaceans. In addition, Randall (1965, 1967), Moe (1969), and Harmelin-Vivien and Bouchon (1976) found that groupers become more piscivorous as they increase in size.

Feeding periodicity of the groupers vary according to the geographical area and the species. Off Florida, *E. morio* feeds indifferently by day or night and *E. striatus* is primarily a diurnal feeder (Longley and Hildebrand, 1941). Serranids in the Caribbean Sea feed day and night and increase foraging activity during the crepuscular periods (Randall, 1967). Serranids in Madagascar also feed during day and night, but more actively at night (Harmelin-Vivien and Bouchon, 1976). In Tahitian waters, groupers are primarily diurnal; however, they may occasionally feed at night, especially in the presence of a bright moon (Randall and Brock, 1960).

These earlier studies have concentrated on groupers captured in nearshore waters. Although *E. quernus* may be found in the shallow, nearshore waters (Hobson, 1980), the food samples for this study were collected from fish captured on the offshore benthic slopes at depths of 128 to 219 m (70 to 120 fathoms).

Kluegel (1921) published the only report on the feeding habits of *E. quernus*. In her study of the diet of food fishes, she found that this grouper was carnivorous. This was based on the contents of 13 stomachs (10 of which were empty) and the presence of scombroid fish among the food items.

The major objective of this study is to quantitatively determine specific forage items of this deep-dwelling species. This study was part of an overall investigation of the life history of this species and other bottomfishes. Together with feeding studies of other species, such as *Pseudocaranx dentex* (see report in this proceedings by Michael P. Seki), occupying the same or comparable habitat, this diet study of the grouper may provide data on competition among species for prey, and thus may lead to a better understanding of trophic relationships.

METHODS

Field Collection of Food Samples

The 67 stomach and spew samples were collected from groupers captured at deep-sea handlining stations aboard cruises to the NWHI from March 1978 to August 1981. Fifty-nine of the samples were collected on the RV *Townsend Cromwell*, whereas four spew samples each were collected aboard commercial vessels, the FV *Easy Rider*, and the FV *Libra*.

The fish (34 females, 2 males, and 31 unsexed) were captured at 21 islands or banks stretching from Nihoa to Kure Atoll. They ranged from 38.7 to 109.3 cm total length and weighed from 1.8 to 22.7 kg. The study material included 14 stomachs removed intact from the fish and 53 spew samples.

The handlined fish were caught primarily on hydraulic-powered gurdies, although a few fish from early cruises may have been hauled by hand or on an electric reel. The terminal rig and gurdy specifications are reported by Uchida and Uchiyama (in preparation). Most of the grouper landed were caught on rigs with four hook lines and Tankichi or Izuo ulua hooks Nos. 26 and 28 baited with stripped squid. At handline stations, the vessel was usually allowed to drift over banks 73 to 219 m (40 to 120 fathoms) deep.

Since the fish were taken from great depths, most of the stomachs were everted due to gas bladder expansion when the fish were brought to the surface and much of the contents were regurgitated. Many food items, however, were caught in the throat or gill rakers and were picked out by long forceps and saved. These were classified as spews. All stomachs and spews were preserved immediately in a 10 percent Formalin-seawater mixture. Data on species, station number, date of capture, total and standard lengths, weight, and sex were noted for each sample.

Laboratory Procedure

The laboratory methods for examination of the samples were similar to those reported in Humphreys (1980) and Harrison et al. (1983). For this study, the analyses of stomach and spew samples were treated similarly. The stomach contents were emptied into a fine mesh strainer, rinsed in running water, and sorted into identifiable groups. The volume of the prey items were measured by water displacement and coded for stage of digestion. The codes ranged from 1 through 4 where code 1 represented an item with no perceptible loss in volume and code 4 an item almost completely digested. When more than one item in the same taxon were present and could not be distinguished as whole individual items, the total number and volume of the items were recorded.

Where possible, lengths of the prey items were determined. The measurements, which included standard length (SL) for fish, mantle length (ML) for cephalopods, and carapace length (CL) for crustaceans, were coded as follows: code 1, totally intact specimen which could be measured precisely, and code 2, inexact measurement of a partially digested specimen. No attempt was made to measure the length of any prey item that was well digested.

Food items were identified to the lowest taxon possible, using the methods reported in Harrison et al. (1983). To identify fish, external characteristics and morphometrics were used whenever possible; however, many fish were in an advanced state of digestion and required clearing and staining in Alizarin S so that vertebral counts and morphological characters could be used for identification purposes. Invertebrates were identified by external morphological features. Thus, many of the crustaceans were identified at least to family since the exoskeletons remained intact despite digestion.

Method of Data Analysis

Traditionally, numerical, volumetric, and frequency of occurrence methods have been used in expressing results of food studies. Reintjes and King (1953) stated that, individually, each method has shortcomings, but food items which ranked high in number, volume, and frequency of occurrence were important foods for the predator at the time and area sampled.

Pinkas et al. (1971) attempted to incorporate the three traditional methods of stomach analysis in the development of an index of relative importance (IRI) expressed as:

$$IRI = (N+V)F$$

where

N = percentage of the total number of prey items
V = percentage of the total aggregate volume of the prey items
F = percentage of the occurrence in the stomach samples

For this study, the importance of each of the forage items was determined by the IRI method. The number, volume, and frequency of occurrence percentages were rounded off to the nearest 10th prior to the IRI calculations.

RESULTS

A list of the food items in the 67 stomach and spew samples is presented in Table 1. The numerical, volumetric, and frequency of occurrence analyses, along with the IRI values, are given for the forage items identified to the lowest taxon.

TABLE 1. NUMBER, FREQUENCY OF OCCURRENCE, VOLUME AND INDEX OF RELATIVE IMPORTANCE (IRI) OF THE FORAGE ITEMS IN 67 *EPINEPHELUS QUERNUS* FOOD SAMPLES

Forage Items	No. of Organisms		Occurrence		Aggregate Total Volume		IRI
	Total	Percent	No.	Percent	ml	Percent	
PHYLUM MOLLUSCA							
Class Cephalopoda	1	0.2	11	1.5	23.0	0.7	1.4
Order Octopoda	4	0.8	3	4.5	239.0	7.6	37.8
PHYLUM ARTHROPODA							
Class Crustacea							
Subclass Malacostraca							
Order Isopoda	1	0.2	1	1.5	0.6	<0.1	0.3
Order Amphipoda							
Family Phronimidae							
Phronima sedentaria	1	0.2	1	1.5	1.0	<0.1	0.3
Order Stomatopoda							
Family Squillidae							
Odontodactylus brevirostris	1	0.2	1	1.5	6.5	0.2	0.6
Order Decapoda							
Suborder Natantia (shrimp)	56	11.5	9	13.4	43.6	1.4	172.9
Superfamily Caridea	27	5.6	5	7.5	17.6	0.6	46.5
Family Pandalidae	308	63.4	16	23.9	212.7	6.8	1,677.8
Plesionika longirostris	5	1.0	2	3.0	14.5	0.5	4.5
"Shrimp remains"	—	—	1	1.5	0.3	<0.1	—
Suborder Reptantia	2	0.4	2	3.0	9.8	0.3	2.1
Tribe Anomura							
Family Galatheidae	1	0.2	1	1.5	2.0	0.1	0.4
Munida sp.	2	0.4	2	3.0	3.5	0.1	1.5
Tribe Brachyura	3	0.6	2	3.0	101.0	3.2	11.4
Family Homolidae	1	0.2	1	1.5	20.0	0.6	1.2
Family Raninidae	1	0.2	1	1.5	27.0	0.9	1.6
PHYLUM ECHINODERMATA							
Class Echinoidea	1	0.2	1	1.5	0.3	<0.1	0.3
PHYLUM CHORDATA							
Subphylum Tunicata							
Family Pyrosomatidae	1	0.2	1	1.5	23.0	0.7	1.4
Superclass Pisces							
Class Osteichthyes							
(unidentified fishes)	3	0.6	3	4.5	101.5	3.2	17.1
Order Anguilliformes	2	0.4	1	1.5	13.7	0.4	1.2
Family Congridae	5	1.0	4	6.0	307.0	9.8	64.8
Family Muraenidae	1	0.2	1	1.5	5.0	0.2	0.6
Order Salmoniformes							
Family Argentinidae	1	0.2	1	1.5	3.5	0.1	0.4

Note: Food items were identified to the lowest taxon possible

TABLE 1. NUMBER, FREQUENCY OF OCCURRENCE, VOLUME AND INDEX OF RELATIVE IMPORTANCE (IRI) OF THE FORAGE ITEMS IN 67 *EPINEPHELUS QUERNUS* FOOD SAMPLES (continued)

Forage Items	No. of Organisms		Occurrence		Aggregate Total Volume		IRI
	Total	Percent	No.	Percent	ml	Percent	
Order Gonorhynchiformes							
Family Gonorhynchidae							
Gonorhynchus gonorhynchus	1	0.2	1	1.5	1.9	0.1	0.4
Order Myctophiformes							
Family Myctophidae	3	0.6	2	3.0	76.1	2.4	9.0
Order Polymixiiformes							
Family Polymixiidae	1	0.2	1	1.5	60.0	1.9	3.2
Polymixia berndti	1	0.2	1	1.5	14.0	0.4	0.9
Order Gadiformes							
Family Ophidiidae							
Brotula multibarbata	1	0.2	1	1.5	32.0	1.0	1.8
Order Beryciformes							
Family Trachichthyidae	2	0.4	2	3.0	2.3	0.1	1.5
Paratrachichthys sp.	3	0.6	2	3.0	13.5	0.4	3.0
Family Holocentridae	1	0.2	1	1.5	4.0	0.1	0.4
Order Scorpaeniformes							
Family Scorpaenidae	1	0.2	1	1.5	24.0	0.8	1.5
Order Perciformes							
Family Serranidae	4	0.8	3	4.5	130.5	4.2	22.5
Family Priacanthidae							
Priacanthus sp.	1	0.2	1	1.5	10.0	0.3	0.8
Family Apogonidae	2	0.4	1	1.5	1.5	<0.1	0.6
Family Echeneidae	4	0.8	4	6.0	307.0	9.8	63.6
Family Carangidae							
Decapterus sp.	1	0.2	1	1.5	1.8	0.1	0.4
Seriola sp.	1	0.2	1	1.5	24.0	0.8	1.5
Family Emmelichthyidae	15	3.1	8	11.9	176.4	5.6	103.5
Family Lutjanidae	1	0.2	1	1.5	136.0	4.3	6.8
Etelis carbunculus	1	0.2	1	1.5	780.0	24.8	37.5
Symphysanodon sp.	4	0.8	3	4.5	7.5	0.2	4.5
Family Mullidae							
Parupeneus sp.	1	0.2	1	1.5	43.0	1.4	2.4
Family Pomacentridae	1	0.2	1	1.5	10.0	0.3	0.8
Family Gempylidae	1	0.2	1	1.5	81.0	2.6	4.2
Order Tetraodontiformes							
Family Monacanthidae	1	0.2	1	1.5	5.5	0.2	0.6
Pervagor spilosoma	1	0.2	1	1.5	7.0	0.2	0.6
Family Tetraodontidae	1	0.2	1	1.5	2.5	0.1	0.4
Unidentified fish remains	—	—	2	3.0	13.7	0.4	—
OTHERS							
Unidentified remains	—	—	1	1.5	1.3	0.1	—
"Coral rubble"	—	—	1	1.5	3.5	<0.1	—

Table 2 presents the analysis of the food items by major classes and groups. The classes are listed in descending order of IRI values for fishes and invertebrates. Primarily, the prey fishes are presented by the families and the invertebrates by class or order. The IRI values and the percentages used in the IRI calculations are given in the table.

Overall, fishes (IRI = 5,384.9) and crustaceans (IRI = 5,009.2) made up the bulk of the forage items. Molluscs (IRI = 54.9), other miscellaneous invertebrates (IRI = 3.3), and unidentifiable remains made up the rest of the food items.

Fishes, representing 22 families, occurred in 59.7 percent of the food samples, comprised 76.2 percent of the total aggregate volume, and represented 14.0 percent of the total number of food items. Lutjanidae (229.5), Emmelichthyidae (103.5), and Congridae (64.8) had the highest IRI. Although unidentified fishes (IRI = 17.1) are significantly represented, the individuals represented various species.

Crustaceans, which made up the majority of the invertebrate forage, appeared in 50.7 percent of the samples and comprised 84.2 percent of the organisms and 14.6 percent of the total aggregate volume. Shrimp (Natantia) represented 96.8 percent of all the crustaceans, and the family Pandalidae represented 79.0 percent of all the shrimp. the lone species of shrimp identifiable beyond the family level was Plesionika longirostris. crabs (Reptantia), stomatopods, amphipods, and isopods made up the rest of the crustaceans in the forage.

Molluscs were present in 5.9 percent of the samples; all but one were octopuses. They comprised 8.3 percent of the total aggregate volume and 1.0 percent of the total number of forage items.

Other invertebrates were not significant contributors to the forage. One tunicate, family Pyrosomatidae, and an echinoid comprised 3.0 percent of the forage and made up 0.7 percent of the total aggregate volume and 0.4 percent of the organism total.

Unidentified remains and coral rubble comprised the remaining items in the samples. The IRI for these classifications and "fish remains" was not computed because it was not possible to determine the number of these items in the samples.

Individual lengths, length ranges, and mean lengths of the prey items are presented in Table 3. The lengths of prey fish ranged from 35 mm (a trachichthyid) to 516 mm (a congrid eel). Among the invertebrates, lengths ranged from 7-mm CL (a pandalid shrimp) to 85 mm ML (an octopod).

TABLE 2. NUMBER, FREQUENCY OF OCCURRENCE, VOLUME, AND INDEX OF RELATIVE IMPORTANCE (IRI) FOR MAJOR CLASSES OF FORAGE ITEMS IN 67 *EPINEPHELUS QUERNUS* FOOD SAMPLES

Forage Classes	No. of Organisms		Occurrence		Aggregate Total Volume		IRI
	Total	Percent	No.	Percent	ml	Percent	
INVERTEBRATES							
Natantia (shrimp)	396	81.5	24	35.8	288.9	9.2	3,247.1
Reptantia	10	2.1	8	11.9	163.3	5.2	86.9
Cephalopoda	5	1.0	4	6.0	262.0	8.3	55.8
Tunicata	1	0.2	1	1.5	23.0	0.7	1.4
Stomatopoda	1	0.2	1	1.5	6.5	0.2	0.6
Amphipoda	1	0.2	1	1.5	1.0	<0.1	0.3
Isopoda	1	0.2	1	1.5	0.6	<0.1	0.3
Echinoidea	1	0.2	1	1.5	0.3	<0.1	0.3
FISHES							
Lutjanidae	6	1.2	5	7.5	923.5	29.4	229.5
Emmelichthyidae	15	3.1	8	11.9	176.4	5.6	103.5
Congridae	5	1.0	4	6.0	307.0	9.8	64.8
Echeneidae	4	0.8	4	6.0	307.0	9.8	63.6
Serranidae	4	0.8	3	4.5	130.5	4.2	22.5
Trachichthyidae	5	1.0	4	6.0	15.8	0.5	9.0
Myctophidae	3	0.6	2	3.0	76.1	2.4	9.0
Polymixiidae	2	0.4	2	3.0	74.0	2.4	8.4
Gempylidae	1	0.2	1	1.5	81.0	2.6	4.2
Carangidae	2	0.4	2	3.0	25.8	0.8	3.6
Monacanthidae	2	0.4	2	3.0	12.5	0.4	2.4
Mullidae	1	0.2	1	1.5	43.0	1.4	2.4
Ophidiidae	1	0.2	1	1.5	32.0	1.0	1.8
Scorpaenidae	1	0.2	1	1.5	24.0	0.8	1.5
Anguilliformes (unidentified eels)	2	0.4	1	1.5	13.7	0.4	1.2
Priacanthidae	1	0.2	1	1.5	10.0	0.3	0.8
Pomacentridae	1	0.2	1	1.5	10.0	0.3	0.8
Apogonidae	2	0.4	1	1.5	1.5	<0.1	0.6
Muraenidae	1	0.2	1	1.5	5.0	0.2	0.6
Holocentridae	1	0.2	1	1.5	4.0	0.1	0.4
Argentinidae	1	0.2	1	1.5	3.5	0.1	0.4
Tetraodontidae	1	0.2	1	1.5	2.5	0.1	0.4
Gonorhynchidae	1	0.2	1	1.5	1.9	0.1	0.4
Unidentified fishes	3	0.6	3	4.5	101.5	3.2	17.1
Fish remains	—	—	2	3.0	13.7	0.4	—
OTHERS							
Unidentified remains	—	—	1	1.5	1.3	0.1	—
"Coral rubble"	—	—	1	1.5	3.5	0.1	—

TABLE 3. LENGTHS AND LENGTH RANGES OF ITEMS FOUND IN 67 *EPINEPHELUS QUERNUS* FOOD SAMPLES

Forage Items	No. of Organisms	Lengths or Range of Length and Mean Length (mm)
INVERTEBRATES		
Cephalopoda		
Octopoda	2	47-85 ($\bar{x}$ = 66.0)
Crustaceans		
Isopoda	1	27
Stomatopoda		
Odontodactylus brevirostris	1	75
Decapoda		
Natantia (shrimp)	2	10-13 ($\bar{x}$ = 11.5)
Caridea	1	12
Pandalidae	98	7-20 ($\bar{x}$ = 11.35)
Plesionika longirostris	5	13-22 ($\bar{x}$ = 16.8)
Reptantia		
Galatheidae	1	45
Munida sp.	2	24-38 ($\bar{x}$ = 36.0)
Brachyura	3	38-39 ($\bar{x}$ = 38.33)
Homolidae	1	43
Raninidae	1	66
FISHES		
Anguilliformes		
(unidentified eels)	1	174
Congridae	4	116-516 ($\bar{x}$ = 297.75)
Argentinidae	1	79
Gonorhynchidae		
Gonorhynchus gonorhynchus	1	78
Myctophidae	2	146-156 ($\bar{x}$ = 151.0)
Polymixiidae	1	161
Polymixia berndti	1	87
Ophidiidae		
Brotula multibarbata	1	158
Trachichtyidae	2	35-37 ($\bar{x}$ = 36.0)
Paratrachichthys sp.	3	50-67 ($\bar{x}$ = 57.33)
Holocentridae	1	63
Serranidae	3	93-197 ($\bar{x}$ = 143.33)
Priacanthidae		
Priacanthus sp.	1	71
Echeneidae	4	179-197 ($\bar{x}$ = 237.5)
Carangidae		
Seriola sp.	1	125
Emmelichthyidae	9	45-126 ($\bar{x}$ = 96.89)

TABLE 3. LENGTHS AND LENGTH RANGES OF ITEMS FOUND IN 67 *EPINEPHELUS QUERNUS* FOOD SAMPLES (continued)

Forage Items	No. of Organisms	Lengths or Range of Length and Mean Length (mm)
Lutjanidae	1	202
Etelis carbunculus	1	377
Symphysanodon sp.	4	53-56 ($\bar{x}$ = 54.25)
Mullidae		
Parupeneus sp.	1	128
Pomacentridae	1	68
Gempylidae	1	267
Monacanthidae	1	67
Pervagor spilosoma	1	66

Note: Means are given in parentheses

DISCUSSION AND CONCLUSION

As mentioned earlier, most of the food samples were spews which were caught in the throat or gill rakers of the groupers when the stomachs everted due to gas bladder expansion. It is possible that the spewed organisms are more likely to be retained due to some morphological structure (such as the antennules and antennae of pandalid shrimps) or perhaps size, and therefore a biased interpretation of the actual feeding habits and diet may result. Thus, it is possible that the results obtained may not completely represent the diet of this species. This problem was also encountered by Kluegel (1921) in the deeper-dwelling food fishes (including *E. quernus*), by Forster et al. (1970) in *Etelis marshi* (= *E. carbunculus*, Anderson (1981)), and by Moe (1969) in the red grouper in the Gulf of Mexico.

The results of this study support the conclusions of other studies on *Epinephelus*, i.e., *E. quernus* is a benthic carnivore. This grouper appears to be primarily piscivorous, although crustaceans and cephalopods also contribute to the forage. As concluded with other species of *Epinephelus* (Bardach and Mowbray, 1955; Hiatt and Strasburg, 1960; Moe, 1969), *E. quernus* appears to be an unspecialized feeder.

The items found in the food samples reflect the bottom-feeding behavior of this grouper. All 22 of the identified fish families contributing to the diet are usually found near the bottom, most being bottom inhabitants. Of particular interest was the occurrence of a red snapper, *E. carbunculus* (377 mm for length), in the stomach of a large (1,059 mm total length) grouper. This snapper is also a bottomfish which belongs to the tropical snapper-grouper complex mentioned earlier.

The invertebrates in the diet were generally small; shrimp were numerous. Shrimp (primarily Pandalidae) appear to be a very important food item for this grouper in the NWHI. Again, it is possible that the abundance of shrimp in the forage may be attributed to the sampling problem and that the long appendages characteristic of the shrimp are responsible for their high representation in the diet. However, 120 shrimp were found in one intact stomach. The lone pandalid shrimp that was identifiable to species was P. longirostris. King (1981) showed that this species was distributed along the benthic slopes in tropical Pacific islands, and our trapping results show this to hold true in the NWHI. This would indicate that the shrimp occupy a similar habitat as E. quernus, and thus their presence in the diet is not surprising. The presence of other invertebrates such as octopuses and galatheid crabs among the forage items further show the opportunistic benthic foraging behavior of E. quernus as well as a potential nocturnal or crepuscular behavior. Time of feeding, however, could not be determined due to lack of sufficient data. This species will take a baited hook both night and day (Moffitt, 1980), so it seems that E. quernus, like its congeners (Longley and Holdebrand, 1941; Randall and Brock, 1960; Randall, 1967; Harmelin-Vivien and Bouchon, 1976), feeds indifferently by day or night but may increase its foraging activities during certain periods of the day.

Trapping data collected on research cruises to the NWHI indicated possible depths of foraging by the grouper (Uchida and Uchiyama, in preparation). Adult E. quernus were caught in depths ranging from 18 to 230 m (10 to 126 fathoms) which includes the depths over which bottom handlining stations were conducted. This suggests that the grouper may forage over a wide range of depths very close to the bottom.

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THE FOOD AND FEEDING HABITS OF THE WHITE TREVALLY, PSEUDOCARANX DENTEX (BLOCH AND SCHNEIDER 1801), IN THE NORTHWESTERN HAWAIIAN ISLANDS

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ABSTRACT

Sixty-four stomach samples of the white trevally, *Psuedocaranx dentex*, caught in the Northwestern Hawaiian Islands were examined to quantitatively determine the items which comprise the diet of this commercially valuable food species.

The results indicated that the white trevally is an opportunistic carnivore. It is primarily piscivorous, although cephalopods and crustaceans are also major contributors to the diet. The findings also strongly indicate that white trevally feeds near the bottom in the deeper waters offshore.

An index of relative importance (IRI) was computed to indicate which forage items were most important to the predators sampled. The IRI incorporates the frequency of occurrence and the percentage in the number and volume of the prey. The IRI showed that members of the families Congridae, Priacanthidae, and Serranidae were the most important fish prey. Cephalopods, crabs, and shrimp had the highest IRI among the invertebrates.

Carangidae *Pseudocaranx dentex*
feeding Northwestern Hawaiian Islands

INTRODUCTION

A food study of commercially important bottomfishes was undertaken as part of a survey and assessment of the benthic slope resources in the Northwestern Hawaiian Islands (NWHI). Among the species that comprise these resources is the white trevally, Pseudocaranx dentex, also known in Hawaii as the thick-lipped jack, butaguchi, or pig ulua. This species has been known as Caranx cheilio Snyder 1904; however, according to Smith-Vaniz and Poss (Department of Ichthyology, The Academy of Natural Sciences of Philadelphia, April, 1982: personal communication), who are working on a revision of the genus Pseudocaranx, C. cheilio is a synonym of P. dentex (Bloch and Schneider 1801). Around Hawaii the species attains a length of 91 cm (3 ft) (Gosline and Brock, 1960).

Outside the NWHI, the Indo-Pacific distribution of P. dentex includes South Africa, Australia, Tasmania, Norfolk Island, New Zealand, Japan, Pitcairn, Rapa, Easter, and the Lord Howe Islands (Randall, 1981). In the NWHI, the white trevally is found mainly on the banks and benthic slope at depths between 73 and 183 m (40 and 100 fathoms). The distribution of this species is not, however, limited to the deep slopes. At Kure Atoll, Okamoto and Kawamoto (1980) observed the white trevally in waters 1.5 m (5 ft) deep, occasionally in large schools of 200 to 300 individuals. Hobson (1980) found the species on his transect lines at Midway in depths of 5 m, and traps set as shallow as 18 m (10 fathoms) during our NWHI studies have captured both juveniles and adults.

Although feeding studies of P. dentex are nonexistent, a few feeding studies on other species of the family Carangidae have been published. Hobson (1974) and Okamoto and Kawamoto (1980) briefly mentioned the foraging habits of the bluefin trevally, C. melampygus, on Hawaiian inshore coral reefs. The same species has been studied on the reefs of the Gilbert Islands (Randall, 1955), the Marshall Islands (Hiatt and Strasburg, 1960; Randall, 1980), and off the east coast of Africa (Williams, 1965). The foraging habits of the giant trevally, C. ignobilis, were studied in the Marshall Islands (Randall, 1980), off East Africa (Williams, 1965), and in the NWHI (Okamoto and Kawamoto, 1980; Parrish et al., 1980). Feeding habits of various other common jacks, such as C. lugubris, have also been covered by Randall (1955, 1967, 1980). In general, the studies have found jacks to be primarily piscivores; however, the time of feeding appeared to vary among the species. Caranx melampygus is a diurnal predator (Williams, 1965; Okamoto and Kawamoto, 1980; Potts, 1980) whereas C. ignobilis is a nocturnal feeder (Okamoto and Kawamoto, 1980). In his examination of stomach contents from five species of Caranx, Randall (1967) noted that although some species were not ordinarily reef residents, many individuals made foraging trips into reef communities.

At the present time, the knowledge of the feeding habits of jacks has been limited to the species which may be easily captured on the nearshore reefs, although C. ignobilis may also be taken in waters as deep as 70 m (40 fathoms). Pseudocaranx dentex is known to inhabit coastal waters about 146 m (80 fathoms) deep with other commercially important food species such as the pink snapper or opakapaka, Pristipomoides filamentosus, and the hapuupuu, Epinephelus quernus (Hawaii Department of Land and Natural Resources, 1979; Ralston, 1981, 1982). The major objective of this study was to quantitatively determine the items constituting the diet of this deep-dwelling species. Together with food studies of other sympatric predators such as E. quernus (see paper on grouper in this proceedings by Seki), this study may provide a better understanding of the trophic relationships among the species of the demersal community in the NWHI.

METHODS

Field Collection of Food Samples

Sixty-four stomach samples of adult white trevally were collected at deep-sea handline stations aboard the RV Townsend Cromwell on resource survey cruises to the NWHI from September 1978 to August 1981. The samples were collected at 11 banks from Nihoa to Kure Atoll (Figure 1).

Fish sampled ranged from 42.7 to 82.2-cm fork length and weighed from 1.35 to 10.73 kg. Thirty-three of the specimens were females, 29 were males, and 2 were unsexed. Sixty of the samples were whole stomachs removed intact from the fish. The remaining four consisted of regurgitated food items removed from the gill rakers. Empty stomachs were not collected.

The fish were caught with hook and line on hydraulic-powered gurdies. The terminal rig and gurdy specifications have been described in a forthcoming publication edited by R.N. Uchida and J.H. Uchiyama. Briefly, the gurdies had a terminal rig with four hooks (Tankichi or Izuo No. 26 and/or No. 28). Each hook was usually baited with stripped squid. Handline stations were conducted with the vessel adrift in depths of 73 to 220 m (40 to 120 fathoms).

When fish were landed, stomachs were removed, examined, and unless empty, preserved in a 10 percent Formalin-seawater solution for later analysis. Regurgitated food items (spew) caught in the gill rakers when the stomachs everted due to gas bladder expansion were also preserved.

Laboratory Procedure

The laboratory methods for examination of the samples were similar to those reported by Humphreys (1980) and Harrison et al. (1983). The stomach contents were emptied into a fine mesh strainer, rinsed in running water, and sorted into identifiable groups. The volume of prey items were measured by water displacement. Where more than one item in the same taxon was present and could not be distinguished as a whole individual, the total volume and number of individuals comprising the volume were recorded. When possible, lengths of the prey were taken, including standard length for fish, mantle length for cephalopods, carapace length for shrimp, carapace width for crabs, and total

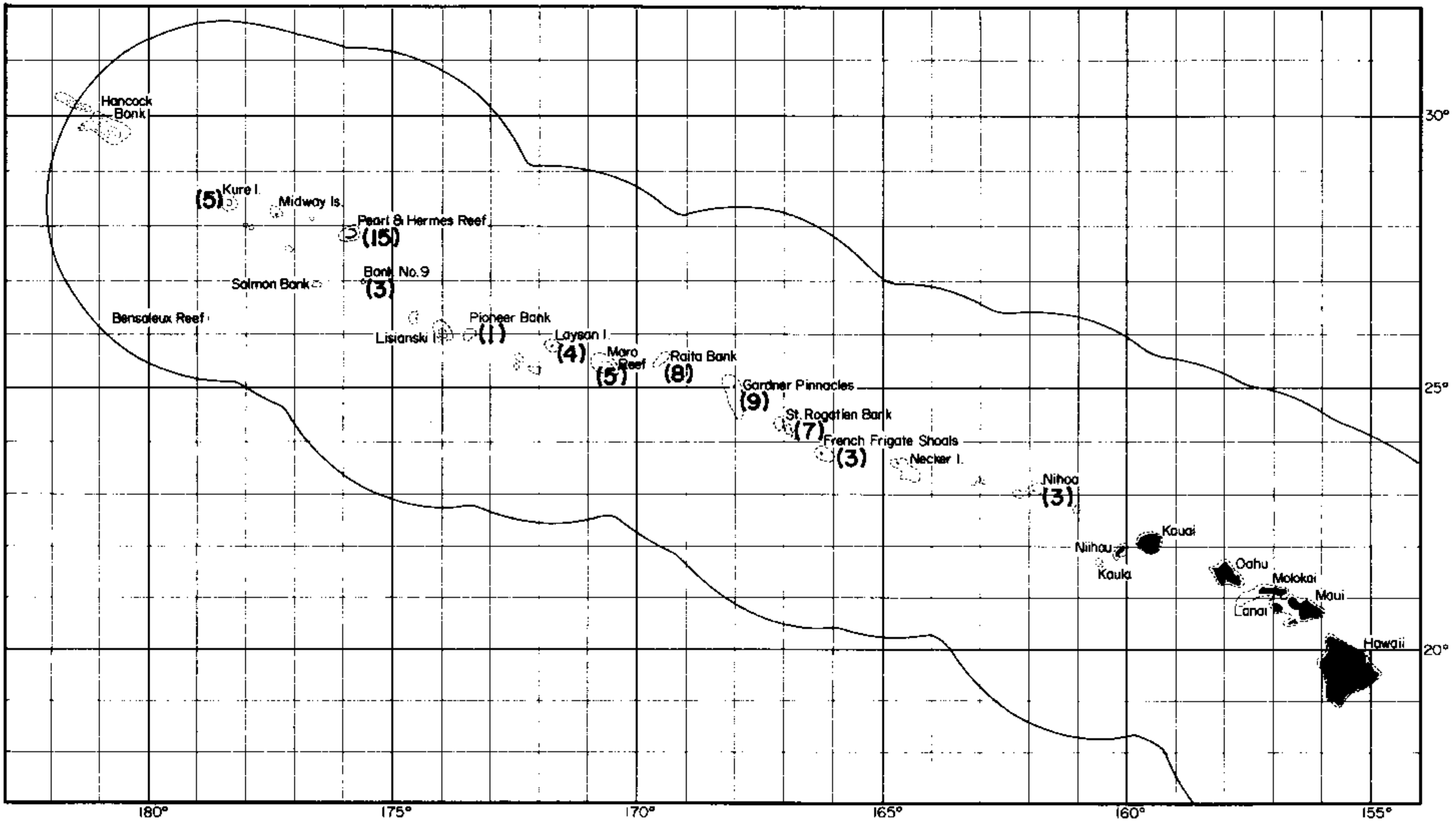

Figure 1. The Northwestern Hawaiian Islands. The number of stomach samples collected at each bank is shown in parentheses.

length for all others. No attempt was made to measure the lengths of any prey items that were well digested.

Food items were identified to the lowest possible taxon using the methods of Harrison et al. (1983). When possible, fish were identified by external characteristics and morphometrics. In most cases, however, the fish were in an advanced stage of digestion and required clearing of the flesh and staining of the vertebrae with Alizarin S. A combination of vertebral counts and morphological characters was then used for identification. Invertebrates were identified by external morphological features; thus many of the crustaceans were identified at least to family since the exoskeletons remained intact or nearly intact despite digestion.

Many samples included bottom sediment and debris (classified as "rubble") which were saved for further identification of small infaunal invertebrates that may be of nutritional value to the predator. The volume of the rubble was determined by water displacement. The volume was also determined for unidentifiable digested remains.

DATA ANALYSIS

The importance of each of the forage items was determined by the method described by Pinkas et al. (1971), who developed the index of relative importance defined as

$$IRI = (N + V)F$$

where

N = Percentage of total aggregate number of a prey item

V = Percentage of total aggregate volume of a prey item

F = Percentage of occurrence of a prey item in the stomach samples

The IRI value provides a basis for ranking the prey items by incorporating the three measures traditionally used in stomach content analysis. Rubble and unidentified remains were not used in determining IRI.

RESULTS

The forage items found in the 64 stomach samples are listed in Table 1. The classification or taxonomic rank, the percent numerical, volumetric and frequency of occurrence, and the IRI values are given for each forage item.

TABLE 1. NUMBER, FREQUENCY OF OCCURRENCE, VOLUME, AND INDEX OF RELATIVE IMPORTANCE VALUES OF THE FORAGE ITEMS IN 64 *PSEUDOCARANX DENTEX* FOOD SAMPLES

Forage Items	No. of Organisms		Occurrence		Aggregate Total Volume		IRI
	Total	Percent	No.	Percent	ml	Percent	
PHYLUM ANNELIDA							
Class Polychaeta	8	1.9	3	4.7	2.3	0.2	9.9
PHYLUM MOLLUSCA							
Class Gastropoda	18	4.3	10	15.6	1.2	0.1	68.6
Class Bivalvia							
Order Mytiloida							
Family Pinnidae							
Pinna muricata	2	0.5	2	3.1	14.0	1.4	5.9
Order Veneroida							
Family Cardiidae							
Nemocardium thaanumi	1	0.2	1	1.6	8.0	0.8	1.6
Class Cephalopoda	12	2.9	10	15.6	8.1	0.8	57.7
Order Octopoda	7	1.7	6	9.4	64.5	6.3	75.2
PHYLUM ARTHROPODA							
Class Crustacea	14	3.4	7	10.9	4.4	0.4	41.4
Subclass Malacostraca							
Order Amphipoda	1	0.2	1	1.6	0.1	<0.1	0.3
Order Stomatopoda	1	0.2	1	1.6	0.1	<0.1	0.3
Family Squillidae							
Lysiosquilla sp.	1	0.2	1	1.6	0.1	<0.1	0.3
Odontodactylus sp.	15	3.6	6	9.4	5.9	0.6	39.5
Pseudosquilla sp.	1	0.2	1	1.6	0.3	<0.1	0.3
Order Decapoda							
Suborder Natantia (shrimp)	14	3.4	5	7.8	3.5	0.3	28.9
Superfamily Caridea	15	3.6	3	4.7	6.0	0.6	19.7
Family Pandalidae	2	0.5	1	1.6	1.0	0.1	1.0
Family Crangonidae	2	0.5	1	1.6	0.4	<0.1	0.8
"Shrimp remains"	1	0.2	1	1.6	0.6	0.1	0.5
Suborder Reptantia							
Tribe Palinura							
Family Palinuridae							
Panulirus sp.	1	0.2	1	1.6	0.1	<0.1	0.3
Tribe Anomura							
Family Paguridae	2	0.5	2	3.1	1.6	0.2	2.2
Family Galatheidae							
Munida sp.	1	0.2	1	1.6	1.0	0.1	0.5
Tribe Brachyura	2	0.5	2	3.1	0.7	0.1	1.9
"Crab"	23	5.5	16	25.0	18.2	1.8	182.5
PHYLUM ECHINODERMATA							
Class Ophiuroidea	2	0.5	2	3.1	0.6	0.1	1.9
Class Echinoidea							
Order Cidaroida							
Family Cidaridae							
Prionocidaris hawaiiensis	1	0.2	1	1.6	5.5	0.5	1.1

TABLE 1. NUMBER, FREQUENCY OF OCCURRENCE, VOLUME, AND INDEX OF RELATIVE IMPORTANCE VALUES OF THE FORAGE ITEMS IN 64 *PSEUDOCARANX DENTEX* FOOD SAMPLES (continued)

Forage Items	No. of Organisms		Occurrence		Aggregate Total Volume		IRI
	Total	Percent	No.	Percent	ml	Percent	
PHYLUM CHORDATA							
Superclass Pisces							
Class Osteichthyes							
(Unidentified fishes)	19	4.6	6	9.4	10.3	1.0	52.6
Order Anguilliformes	5	1.2	4	6.2	61.8	6.1	45.3
Family Congridae	30	7.2	5	7.8	55.7	5.5	99.1
Congrina aequoria	2	0.5	1	1.6	10.0	1.0	2.4
Family Ophichthidae	3	0.7	2	3.1	9.5	0.9	5.0
Muraenichthys cookei	2	0.5	1	1.6	7.0	0.7	1.9
"Leptocephalus larvae"	1	0.2	1	1.6	0.8	0.1	0.5
Order Myctophiformes							
Family Synodontidae	5	1.2	2	3.1	60.1	5.9	21.3
Family Chlorophthalmidae	1	0.2	1	1.6	2.5	0.2	0.6
Family Myctophidae	1	0.2	1	1.6	0.5	<0.1	0.3
Order Gadiformes							
Family Moridae	1	0.2	1	1.6	37.0	3.6	6.1
Family Ophidiidae	27	6.5	3	4.7	7.9	0.8	34.3
Order Lophiiformes							
Family Ogcocephalidae	2	0.5	1	1.6	1.6	0.2	1.1
Halieutaea retifera	1	0.2	1	1.6	3.5	0.3	0.8
Malthopsis sp.	1	0.2	1	1.6	0.3	<0.1	0.3
Order Scorpaeniformes							
Family Scorpaenidae	7	1.7	2	3.1	26.6	2.6	13.3
Order Dactylopteriformes							
Family Dactylopteridae							
Dactyloptena orientalis	1	0.2	1	1.6	1.3	0.1	0.5
Order Pegasiformes							
Family Pegasidae							
Pegasus papilio	2	0.5	2	3.1	0.8	0.1	1.9
Order Perciformes							
Family Serranidae	13	3.1	4	6.2	8.6	0.8	24.2
Anthias sp.	3	0.7	3	4.7	6.4	0.6	6.1
Family Priacanthidae							
Priacanthus sp.	12	2.9	1	1.6	207.0	20.4	37.3
Family Lutjanidae	16	3.9	3	4.7	9.1	0.9	22.5
Symphysanodon sp.	5	1.2	1	1.6	7.7	0.8	3.2
Family Percophididae (= Bembropsidae)	1	0.2	1	1.6	2.3	0.2	0.5
Family Ammodytidae							
Embolichthys sp.	12	2.9	3	4.7	53.9	5.3	38.5
Order Gobiesociformes							
Family Callionymidae	1	0.2	1	1.6	0.8	0.1	0.5
Order Pleuronectiformes							
Family Bothidae	7	1.7	6	9.4	20.8	2.0	34.8
Bothus thompsoni	1	0.2	1	1.6	1.0	0.1	0.5
Order Tetraodontiformes							
Family Monacanthidae	2	0.5	1	1.6	8.0	0.8	2.1
Family Tetraodontidae	18	4.4	5	7.8	18.1	1.8	48.4
Fish remains	—	—	6	9.4	5.3	0.5	—
"Rubble"	—	—	20	31.2	21.9	2.2	—
Unidentified remains	—	—	43	67.2	194.1	19.1	—

Table 2 presents the analysis of food items by major classes and the ranks of the forage items in descending order of IRI values for the invertebrates and fishes. Fish prey were primarily grouped at the family level and the invertebrates primarily at the class or order level.

Fishes, molluscs, and crustaceans formed the bulk of the forage items in the samples. Fish prey yielded a total IRI value of 7,884.5 compared with 1,454.9 for crustaceans and 653.6 for molluscs.

Fishes as a whole occurred in 68.8 percent of the stomach samples and represented 64.2 percent of the total aggregate volume, and 50.4 percent of the total number of forage items. Twenty families of fishes were represented, and families that had high IRI values were Congridae (IRI = 133.5), Priacanthidae (IRI = 74.7), and Serranidae (IRI = 58.9). Unidentified fish (IRI = 52.6) which were also included in the analysis deserve mention only to the extent that individuals which comprised this group were not of the same species, but of various species.

The invertebrate forage included four phyla, with the majority belonging to Arthropoda, class Crustacea. Crustaceans appeared in 53.1 percent of the samples and represented 4.3 percent of the total aggregate volume and 23.1 percent of the total forage items. Among the crustaceans, crabs (suborder Reptantia) ranked the highest (IRI = 277.7), followed by shrimp (suborder Natantia) (IRI = 131.1), of which most were carideans. Stomatopods (primarily _Odontodactylus_ sp.) and an amphipod were also found.

Molluscs were present in 34.4 percent of the samples and comprised 9.4 percent of the total volume and 9.6 percent of the total number of forage organisms. Cephalopods (IRI = 256.2), mainly octopods (IRI = 75.2), were the primary contributor from this phylum appearing in 21.9 percent of the samples and representing 7.1 percent of the total aggregate volume. Gastropods and bivalves were also present.

Other invertebrates were minor contributors to the diet of the white trevally sampled. These included eight polychaetes (IRI = 9.9) and three echinoderms (IRI = 6.1); together they comprised 2.6 percent of the forage items, 0.8 percent of the total aggregate volume, and appeared in 9.4 percent of the samples. Many small invertebrates and limestone fragments were found in the rubble. A list of these organisms (identified through the courtesy of B. Burch, Bishop Museum, Honolulu, Hawaii) and their taxonomic rank are presented in Appendix 1.

To examine differences in diet with respect to location of capture, the islands and banks were divided into three geographical regions as described by Moffitt (1980) (Table 3). Region 1 ranges from Nihoa to Gardner Pinnacles and represents the area in the NWHI fished most by commercial vessels in recent years,

TABLE 2. NUMBER, FREQUENCY OF OCCURRENCE, VOLUME, AND INDEX OF RELATIVE IMPORTANCE VALUES OF MAJOR CLASSES OF FORAGE ITEMS IN 64 *PSEUDOCARANX DENTEX* FOOD SAMPLES

Forage Classes	No. of Organisms		Occurrence		Aggregate Total Volume		IRI
	Total	Percent	No.	Percent	ml	Percent	
INVERTEBRATES							
Reptantia "crabs"	28	6.8	20	31.2	21.5	2.1	277.7
Cephalopoda	19	4.6	14	21.9	72.6	7.1	256.2
Natantia (shrimp)	34	8.2	9	14.1	11.5	1.1	131.1
Stomatopoda	18	4.3	9	14.1	6.4	0.6	69.1
Gastropoda	18	4.3	10	15.6	1.2	0.1	68.6
Crustacea (unidentified)	14	3.4	7	10.9	4.4	0.4	41.4
Bivalvia	3	0.7	3	4.8	22.0	2.2	13.9
Annelida (Polychaeta)	8	1.9	3	4.7	2.3	0.2	9.9
Echinodermata	3	0.7	3	4.7	6.1	0.6	6.1
Amphipoda	1	0.2	1	1.6	0.1	<0.1	0.3
Reptantia "lobsters"	1	0.2	1	1.6	0.1	<0.1	0.3
FISHES							
Congridae	32	7.7	6	9.4	65.7	6.5	133.5
Priacanthidae	13	3.1	2	3.1	213.6	21.0	74.7
Serranidae	16	3.9	7	10.9	15.0	1.5	58.9
Osteichthyes (Unidentified fishes)	19	4.6	6	9.4	10.3	1.0	52.6
Tetraodontidae	18	4.3	5	7.8	18.1	1.8	47.6
Anguilliformes (Unidentified eels)	5	1.2	4	6.2	61.8	6.1	45.3
Bothidae	8	1.9	7	10.9	21.8	2.1	43.6
Lutjanidae	21	5.1	4	6.2	16.8	1.6	41.5
Ammodytidae	12	2.9	3	4.7	53.9	5.3	38.5
Ophidiidae	27	6.5	3	4.7	7.9	0.8	34.3
Synodontidae	5	1.2	2	3.1	60.1	5.9	22.0
Scorpaenidae	7	1.7	2	3.1	26.6	2.6	13.3
Ophichthidae	5	1.2	2	3.1	16.5	1.6	8.7
Moridae	1	0.2	1	1.6	37.0	3.6	6.1
Ogcocephalidae	4	1.0	2	3.1	5.4	0.5	4.6
Monacanthidae	2	0.5	1	1.6	8.0	0.8	2.1
Pegasidae	2	0.5	2	3.1	0.8	0.1	1.9
Chlorophthalmidae	1	0.2	1	1.6	2.5	0.2	0.6
Percophididae (= Bembropsidae)	1	0.2	1	1.6	2.3	0.2	0.6
Dactylopteridae	1	0.2	1	1.6	1.3	0.1	0.5
Leptocephalus larvae	1	0.2	1	1.6	0.8	0.1	0.5
Callionymidae	1	0.2	1	1.6	0.8	0.1	0.5
Myctophidae	1	0.2	1	1.6	0.5	<0.1	0.3
Fish remains	—	—	6	9.4	5.3	0.5	—
OTHERS							
"Rubble"	—	—	20	31.2	21.9	2.2	—
Unidentified remains	—	—	43	67.2	194.1	19.1	—

TABLE 3. RANKS AND INDEX OF RELATIVE IMPORTANCE VALUES OF THE MAJOR FORAGE CLASSES OF PREY ITEMS BY REGION

Forage Classes	Region 1 (n = 22)		Region 2 (n = 18)		Region 3 (n = 23)	
	Rank	IRI	Rank	IRI	Rank	IRI
INVERTEBRATES						
Annelida (Polychaeta)	12	1.6	11	2.6	—	—
Gastropoda	9	4.6	9	4.7	5*	15.5
Bivalvia	7	5.8	—	—	15	1.6
Cephalopoda	—	—	5*	14.4	6	15.0
Octopoda	2*	58.6	—	—	—	—
Crustacea (unidentified)	17	0.4	12	2.4	4*	17.2
Amphipoda	—	—	21	0.4	—	—
Stomatopoda	17	0.4	20	0.4	2*	48.5
Natantia (shrimp)	1*	77.7	—	—	11	4.9
Reptantia "lobsters"	—	—	—	—	22	0.4
Reptantia "crabs"	3*	37.6	7	7.4	1*	59.3
Echinodermata	11	3.2	—	—	21	0.4
FISHES						
Osteichthyes (Unidentified fishes)	6	6.2	13	1.9	9	9.5
Anguilliformes (Unidentified eels)	—	—	21	0.4	12	2.9
Congridae	—	—	1*	132.9	—	—
Ophichthidae	10	3.4	18	1.0	—	—
"Leptocephalus larvae"	—	—	—	—	20	0.5
Synodontidae	—	—	19	0.9	8	10.2
Chlorophthalmidae	—	—	—	—	17	0.8
Myctophidae	16	0.4	—	—	—	—
Moridae	—	—	8	6.0	—	—
Ophidiidae	—	—	10	4.3	7	14.2
Ogcocephalidae	—	—	17	1.0	16	1.3
Scorpaenidae	5*	13.5	—	—	—	—
Dactylopteridae	—	—	—	—	19	0.6
Pegasidae	—	—	15	1.8	—	—
Serranidae	8	5.7	16	1.1	3*	17.5
Priacanthidae	13	1.4	2*	36.2	—	—
Lutjanidae	4*	25.9	14	1.9	—	—
Percophididae	15	0.7	—	—	—	—
Ammodytidae	—	—	3*	24.4	18	0.6
Callionymidae	—	—	—	—	20	0.5
Bothidae	—	—	6	13.3	10	9.0
Monacanthidae	—	—	—	—	13	2.0
Tetraodontidae	14	1.1	4*	15.1	14	1.8

*Highest ranked classes for each region

Region 2 is from Raita Bank to Lisianski Island, and Region 3 is from Pearl and Hermes Reef to Kure Atoll. The latter two regions are separated by a natural break in the chain. The IRI values of the prey classes for each region were used to rank the importance of the classes in the three regions. The highest value was given the rank of 1. The top ranked classes in Regions 1 and 3 were invertebrates, primarily crustaceans. The top classes in Region 2 were fishes (Congridae, Priacanthidae, Ammodytidae, and Tetraodontidae).

The lengths of fish prey ranged from 14 mm (*Pegasus papilio*) to 306 mm (an ophichthid eel). Lengths of invertebrate forage items ranged from 5 mm (a crangon shrimp) to 42 mm (a stomatopod, *Odontodactylus* sp.). Measurements, ranges, and mean lengths of prey items are presented in Table 4.

DISCUSSION

The results of this diet study indicate that as in other carangids previously studied, the white trevally is a high-level opportunistic carnivore. The species is primarily piscivorous, although cephalopods and crustaceans are also major contributors to their diet. The results also strongly indicate that this species is a bottom feeder. By comparison, Randall (1967) noted small amounts of sand in a few stomachs of *Caranx ruber*, indicating that at times they were feeding on prey directly off the bottom. The presence of some coral tissue and algae provided evidence that *C. ignobilis* also forage occasionally on the bottom (Williams, 1965). In this study, the presence of rubble in about 31 percent of the samples shows that the white trevally feeds on the bottom to an even greater degree.

Nineteen of the 20 fish families found in the forage can be classified as benthic, the exception being myctophids, which although inhabiting the water column, may approach the bank slopes during their vertical migrations. Nearly half of the fish families represented in the diet of white trevally were also represented in the food of another bottom feeder, *E. quernus* (see paper on grouper in this proceedings by Seki). Fishes of the Congridae and Serranidae families, which were two of the most important groups in the diet of the white trevally, were also among the most important fishes in the *E. quernus* stomach samples.

The bottom feeding behavior of white trevally is also reflected in the invertebrate forage. The invertebrates with the highest IRI ranking were crabs, octopi, and gastropods, all bottom dwellers. The occurrence of other invertebrates such as echinoderms, bivalves, and shrimp (even if taken infrequently) in the forage composition reflects the probable browsing behavior of the species. It is noteworthy that among the outstanding morphological features of white trevally are the thick, fleshy lips on a mouth that features an inferior jaw, uncharacteristic of most other carangids. This morphology would appear to facilitate bottom browsing.

TABLE 4. LENGTHS OR RANGE OF LENGTHS OF THE ITEMS FOUND IN 64 *PSEUDOCARANX DENTEX* FOOD SAMPLES

Forage Items	No. of Organisms	Lengths or Range of Lengths and Means	
		mm	
INVERTEBRATES			
Polychaeta	6	10-29	($\bar{x}$ = 15.0)
Gastropoda	8	5-8	($\bar{x}$ = 6.5)
Crustacea			
Amphipoda	1	7	
Stomatopoda			
Odontodactylus sp.	7	30-42	($\bar{x}$ = 33.9)
Pseudosquilla sp.	1	33	
Lysiosquilla sp.	1	13	
Decapoda			
Natantia (shrimp)	7	6-16	($\bar{x}$ = 10.3)
Caridea	14	11-12	($\bar{x}$ = 8.4)
Pandalidae	2	11-11	($\bar{x}$ = 11.0)
Crangonidae	2	5-6	($\bar{x}$ = 5.5)
Reptantia - "crab"	4	6-11	($\bar{x}$ = 9.2)
Anomura			
Paguridea	1	14	
Galatheidae			
Munida sp.	1	14	
Brachyura	1	9	
Ophiuroidea	1	6	
FISHES			
Anguilliformes			
(unidentified eels)	3	73-162	($\bar{x}$ = 108.0)
Congridae	11	80-135	($\bar{x}$ = 114.0)
Congrina aequoria	2	120-148	($\bar{x}$ = 134.0)
Ophichthidae	1	306	
Muraenichthys cookei	2	167-196	($\bar{x}$ = 181.5)
Synodontidae	2	40-75	($\bar{x}$ = 57.5)
Chlorophthalmidae	1	62	
Moridae	1	152	
Ophidiidae	14	45-54	($\bar{x}$ = 49.7)
Ogcocephalidae	2	38-38	($\bar{x}$ = 38.0)
Halieutaea retifera	1	52	
Malthopsis sp.	1	22	
Scorpaenidae	5	27-69	($\bar{x}$ = 52.6)
Dactylopteridae			
Dactyloptena orientalis	1	30	

Note: Means are given in parentheses

TABLE 4. LENGTHS OR RANGE OF LENGTHS OF THE ITEMS FOUND IN 64 *PSEUDOCARANX DENTEX* FOOD SAMPLES (continued)

Forage Items	No. of Organisms	Lengths or Range of Lengths and Means	
		mm	
Pegasidae			
Pegasus papilio	2	14-24	($\bar{x}$ = 19.0)
Serranidae	7	21-43	($\bar{x}$ = 32.0)
Anthias sp.	2	32-39	($\bar{x}$ = 35.5)
Priacanthidae			
Priacanthus sp.	10	82-94	($\bar{x}$ = 89.1)
Lutjanidae	6	28-61	($\bar{x}$ = 39.2)
Symphysanodon sp.	3	50-57	($\bar{x}$ = 53.7)
Ammodytidae			
Embolichthys sp.	6	93-100	($\bar{x}$ = 96.5)
Callionymidae	1	52	
Bothidae	2	70-70	($\bar{x}$ = 70.0)
Bothus thompsoni	1	37	
Monacanthidae	2	60-71	($\bar{x}$ = 65.5)
Tetraodontidae	15	22-45	($\bar{x}$ = 37.7)
Unidentified fishes	3	24-87	($\bar{x}$ = 45.7)

Unlike the other species of jacks which feed on reef fishes (Randall, 1955, 1980; Williams, 1965; Hobson, 1974; Okamoto and Kawamoto, 1980; Parrish et al., 1980), the white trevally feeds on fishes found in the deeper waters offshore. Most of the species such as *Halieutaea retifera* and *Bothus thompsoni* in the diet of white trevally have been captured in bottom trawls between 55 and 92 cm (30 and 50 fathoms) (Uchida and Uchiyama, in preparation). The trap catch data collected during the NWHI resource survey also provide a relative indication to the feeding grounds of this species. Although food samples were not collected from trap-caught fish, the data provided depths of capture and thus information on foraging depths. Adult white trevally were captured in traps set in waters 18 to 124 m (10 to 68 fathoms) deep, suggesting a fairly wide range of foraging depths. This diet study concentrated on adults; however, it is worth noting that large numbers of juveniles (100 to 252 individuals per trap) were caught in traps set in water 60 to 64 m (33 to 35 fathoms) deep.

The wide variety of forage organisms and the absence of any dominant prey in the gut contents suggests opportunistic feeding. This is consistent with the results of the studies by Major (1978) and Potts (1980), where *C. ignobilis* and *C. melampygus* exhibited opportunistic feeding habits; however, it may be that the number of stomach samples was inadequate to demonstrate possible selective feeding or other trends.

A small sample size also prohibited an investigation of the extent stomach contents are influenced by seasonal effects. Although sampling was conducted throughout the year, 37 (58 percent) of the stomachs were collected in the summer. For the other seasons, 15 (23 percent) were collected in the spring, 9 (14 percent) in the fall, and 3 (5 percent) in the winter.

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APPENDIX A.

Components of rubble found in *Pseudocaranx dentex* stomachs. (Identified through the courtesy of B. Burch, Bishop Museum, Honolulu, Hawaii)

- Limestone "rubble"
- Phylum Protozoa
  - Order Foraminifera
    - Family Nummulitidae
      - *Heterostegina depressa*
    - Family Homotrematidae
      - *Miniacina miniacea*
    - Family Amphisteginidae
      - *Amphistigina* cf. *bicirculata*
    - Family Soritidae
      - *Marginopora vertebralis*

- Phylum Coelenterata
  - Order Scleractinia
    - Family Fungiidae (coral)
      - *Cycloseris fragilis*

- Phylum Echinodermata
  - Class Echinoidea
    - Family Cidaroidae
    - Family Fibulariidae
      - *Echinocyamus elongatus*
  - Class Ophiuroidea

- Phylum Mollusca
  - Class Gastropoda
    - Family Strombidae
      - *Strombus helli*
    - Family Eulimidae
    - Family Atyidae
    - Family Naticidae (Natica)
    - Family Cerithiidae
    - Family Littorinidae
      - ?*Peasiella tautilla*
    - Family Epitoniidae
    - Family Hipponicidae
      - *Sabia conica*
    - Family Xenophoridae
      - *Xenophora peroniana*
    - Family Triphoridae
      - *Triphora* cf. *tubularis*
    - Family Columbellidae
    - Family Pteropoda
    - Family Bursidae
      - *Gyrineum pusillum*
    - Family Turbinidae
      - *Gibbula marmorea*
    - Family Rissoidae
      - *Zebina tridentata*
    - Family Turridae
  - Class Bivalvia
    - Family Ostreidacea
    - Family Cardiidae
      - *Nematocardium thaanumi*
    - Family Spondylidae
      - *Spondylus linguafelis*
    - Family Carditidae
      - *Carditella* sp.
    - Family Mytilidae
      - *Brachidontes crebrestriatus*
    - Family Arcidae
    - Family Pectinidae
    - Family Pinnidae
  - Class Scaphopoda
    - Family Dentalidae

- Phylum Arthropoda
  - Class Crustacea
  - Order Amphipoda
    - Family Gammaridae
  - Tribe Brachyura
    - Family Xanthidae
    - Family Portunidae
    - Family Leucosiidae
  - Tribe Anomura
    - Family Paguridea

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LENGTH-WEIGHT AND STANDARD LENGTH-FORK LENGTH RELATIONSHIPS OF DEEPSEA HANDLINE FISHES OF THE NORTHWESTERN HAWAIIAN ISLANDS

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ABSTRACT

Predictive and functional length-weight and standard length-fork (or total) length relationships were calculated from lengths and weights of eight major deepsea species caught by handline in the Northwestern Hawaiian Islands (NWHI). Data collected on RV *Townsend Cromwell* cruises from August 1978 to September 1981 were grouped by sex, cruise, and location of capture. Differences in slopes of regression lines between sexes, tested by ANCOVA for six species, were not significant. There were, however, significant differences among cruises for *Epinephelus quernus* and *Pristipomoides filamentosus*, the two most important species in the handline fishery. Among locations, differences in slopes were also not significant except for *E. quernus*. Pooling of data to calculate a single relationship representative of the whole population for each species, regardless of sex, cruise, or location of capture appeared justified. In this paper, length-weight relationships are given for eight major deepsea species caught by handline in the NWHI. These data represent conversion factors that should prove to be useful in the development of fishery management plans for the Hawaiian handline fishery.

bottomfish
length-weight
standard length-fork length
Northwestern Hawaiian Islands

INTRODUCTION

A deepsea handline fishery has been in existence in the Northwestern Hawaiian Islands since the mid-1940s. In 1976, the Magnuson Fishery Conservation and Management Act was enacted to extend U.S. jurisdiction over fishery resources out to 200 nautical miles from shoreline, and a management plan for the handline fishery resource in Hawaii was undertaken by the Western Pacific Regional Fishery Management Council. Between October 1976 and September 1981, the National Marine Fisheries Service (NMFS) conducted a series of resource survey and assessment cruises on the RV *Townsend Cromwell* and occasionally on a chartered commercial fishing vessel to collect data.

The catch of the deepsea handline fishery consisted primarily of eight species: greater amberjack, *Seriola dumerili*, pig ulua, *Pseudocaranx dentex* (= *Caranx cheilio*) (W.F. Smith-Vaniz, The Academy of Natural Sciences, 1981: personal communication), opakapaka, *Pristipomoides filamentosus* (= *P. microlepis*) (revised by Kami, 1973), kalekale, *P. sieboldii*, gindai, *P. zonatus* (= *Rooseveltia brighami*) (W.D. Anderson, College of Charleston, 1981: personal communication), ehu or ulaula, *Etelis carbunculus* (= *E. marshi*) (revised by Anderson, 1981), onaga, *E. coruscans* (= *E. carbunculus*) (revised by Anderson, 1981), and hapuupuu, *Epinephelus quernus*. These fishes were caught at the edge of banks between depths of 73 and 274 m.

There is no published life history information on any of these fishes from the NWHI and very little from elsewhere in the world. This report provides length-weight and standard length-fork length relationships of the eight major fish species caught on handline gear in the NWHI.

MATERIALS AND METHODS

Fork length (FL) or total length, standard length, weight, and sex were recorded for all fishes (Osteichthyes) caught at deepsea handline stations on the *Townsend Cromwell* survey cruises 78-03, 78-04, 79-02, 80-02, 80-03, 80-04, 80-05, 81-01, 81-02, 81-03, and 81-04 to the NWHI. Fork, total, and standard lengths were measured to the nearest millimeter with 1-m fish calipers according to Ricker (1980). Since the hapuupuu has a rounded tail, its total length was measured. The other fishes have forked tails. Although only fork length is mentioned in the balance of this manuscript, total length was used in place of fork length for hapuupuu. Weights were taken on a Maco (model 25) platform beam scale to the nearest 10 g. Prior to August 1978, weights were taken by spring scales and considered less accurate; these were not used in this study. Sex was determined by examining the gonads.

The length-weight data were examined for possible differences or changes due to sexual dimorphism, time of year (cruise), and area of capture (banks). For each species, the length-weight data were grouped by sex, cruise, and area of capture, and the slopes of the length-weight relationships for these groupings were compared by an analysis of covariance (ANCOVA) to test for equality of slopes among groups. When the group size was very small, <3, the data were not used. Computer program P1V from BMDP Statistical Software (Dixon, 1981) was used to perform the analyses. The decision to pool all data of the same species was made partially on the results of these tests. The relationship of weight to length is described by a power function of the form

$$W = aL^b$$

where

W = weight in kilograms
a = a constant (the Y-intercept)
L = fork length in millimeters
b = a constant (the regression coefficient or slope)

To fit a least square regression to the linear form of the length-weight power function, common log transformation of lengths and weights was required.

The predictive length-weight and standard length-fork length relationships were calculated by the BMDP computer program P6D (Dixon, 1981). The parameters for the functional length-weight, and standard length-fork length regression were calculated using the slopes of the predictive regression equations (Ricker, 1973).

RESULTS

Results of the ANCOVA comparing slopes and a tabulation of slopes for individual groups of six species of fish are listed by sex in Table 1, seven species by cruise in Table 2, and seven species by bank in Table 3. On the basis of these tests, all data were pooled for each species, so that single length-weight relationships would be representative of the whole NWHI population.

Parameters for the predictive and geometric mean (GM) functional length-weight regressions, sample size, correlation coefficients, and range of fork lengths for each species are tabulated in Table 4. Parameters for the predictive and GM functional standard length-fork length regressions are tabulated in Table 5. Functional length-weight curves for the eight deepsea fishes are illustrated in Figures 1 through 8.

TABLE 1. ANCOVA COMPARING EQUALITY OF SLOPES BETWEEN MALE AND FEMALE LENGTH-WEIGHT RELATIONSHIPS OF DEEPSEA HANDLINE FISHES

		Seriola dumerili	*Pseudocaranx dentex*	*Pristipomoides filamentosus*	*Pristipomoides sieboldii*	*Pristipomoides zonatus*	*Etelis carbunculus*
Males	Slope (b)	2.8539	2.9905	2.8340	3.1804	3.0732	2.9922
	Number (n)	106	128	194	27	34	238
Females	b	2.9577	2.9583	2.8727	3.0850	2.9657	3.0023
	n	71	132	240	89	45	496
All pooled	b	2.8986	2.9737	2.8584	3.1118	3.0121	2.9992
	n	177	260	434	116	79	734
	F value	1.7622	0.2621	1.6642	0.1295	0.2060	0.0326
	d.f.	1, 173	1, 256	1, 430	1, 112	1, 75	1, 730

TABLE 2. ANCOVA COMPARING EQUALITY OF SLOPES AMONG LENGTH-WEIGHT RELATIONSHIPS OF DEEPSEA FISHES GROUPED BY CRUISE

Cruise No.		*Seriola dumerili*	*Pseudocaranx dentex*	*Pristipomoides filamentosus*	*Pristipomoides sieboldii*	*Pristipomoides zonatus*	*Etelis carbunculus*	*Epinephelus quernus*
TC-78-03	Slope (b)	2.7759	2.9172	2.6880	2.4019	2.8394	2.9476	3.1833
	Number (n)	33	30	33	8	22	114	103
TC-78-04	b	2.9806	3.0941	2.7609	3.0276	—	2.3839	3.1245
	n	20	46	77	16	—	7	20
TC-79-02	b	—	2.1621	2.7696	3.2071	2.9855	3.0710	3.0748
	n	—	4	21	9	8	41	24
TC-80-02	b	3.2340	2.7391	2.8600	2.8953	2.7987	3.0275	3.0903
	n	9	15	43	15	6	98	75
TC-80-03	b	3.0348	2.6629	2.9790	3.6220	2.7675	3.0245	3.3476
	n	11	28	26	23	5	175	59
TC-80-04	b	2.9700	3.0016	2.7965	2.8786	3.5380	3.1853	2.9405
	n	12	22	71	11	7	22	45
TC-80-05	b	2.7615	2.8003	2.9636	3.3239	2.9335	3.0145	3.1002
	n	33	39	40	8	11	103	57
TC-81-01	b	3.1423	2.8631	2.8294	3.2541	—	3.0380	2.8785
	n	11	6	35	9	—	16	15
TC-81-02	b	2.8147	2.8850	2.8570	2.9673	2.1396	2.8549	3.0123
	n	11	9	5	3	3	57	38
TC-81-03	b	3.2171	2.8495	2.9983	4.7342	2.8351	3.4360	3.0373
	n	6	11	45	3	3	9	32
TC-81-04	b	2.8019	2.9873	2.7917	3.3846	3.0530	3.0465	2.9848
	n	35	57	75	23	19	112	79
All pooled	b	2.8626	2.9519	2.8281	3.1344	3.0000	3.0215	3.0662
	N	181	267	471	128	84	754	547
	F value	1.3214	1.2750	3.0654*	1.0638	0.4988	1.6198	3.3421*
	d.f.	9, 161	10, 245	10, 449	10, 106	8, 66	10, 732	10, 525

*$P \leq 0.001$

TABLE 3. ANCOVA COMPARING THE SLOPES OF LENGTH-WEIGHT RELATIONSHIPS OF DEEPSEA FISHES GROUPED BY AREA OF CAPTURE

Location		*Seriola dumerili*	*Pseudocaranx dentex*	*Pristipomoides filamentosus*	*Pristipomoides sieboldii*	*Pristipomoides zonatus*	*Etelis carbunculus*	*Epinephelus quernus*
Nihoa	Slope (b)	2.0632	2.9491	2.7190	3.3226	2.8226	2.7018	3.1117
	Number (n)	6	17	6	11	4	9	11
Twin Banks	b	3.5030			—		—	2.4642
	n	4			2		2	3
Necker Island	b	3.1249	2.8444	2.8820	3.1665	3.3738	3.0851	2.9346
	n	27	23	138	23	8	62	25
French Frigate Shoals	b	3.0290	2.8800	2.8474	2.5694	2.9584	3.1620	3.0196
	n	10	29	189	25	11	27	70
Brooks Banks	b	—		2.5652				—
	n	1		7				1
St. Rogatien Bank	b	2.6158	2.9327	2.8740	4.2627	—	3.0025	2.7741
	n	4	12	16	3	2	17	21
Gardner Pinnacles	b	2.8590	3.0331	2.9417	3.0694	2.9069	3.0645	3.2203
	n	30	47	24	4	5	19	19
Raita Bank	b	3.0471	3.2211	2.7278	3.7351	3.1793	3.1094	3.0638
	n	15	23	17	16	8	24	47
Maro Reef	b	2.7612	2.9672	2.5130	—	2.6892	2.8013	3.0421
	n	19	29	35	2	9	24	53
Laysan Island	b	3.0085	3.1059	2.5450	3.5621	3.1261	3.0501	3.2619
	n	20	31	25	6	8	50	54
Northampton Seamounts	b		—	—	—	1.0547	2.4400	—
	n		1	1	2	6	6	2
Pioneer Bank	b							4.4152
	n							5

TABLE 3. ANCOVA COMPARING THE SLOPES OF LENGTH-WEIGHT RELATIONSHIPS OF DEEPSEA FISHES GROUPED BY AREA OF CAPTURE (continued)

Location		*Seriola dumerili*	*Pseudocaranx dentex*	*Pristipomoides filamentosus*	*Pristipomoides sieboldii*	*Pristipomoides zonatus*	*Etelis carbunculus*	*Epinephelus quernus*
Lisianski Island	b	3.0457	—	2.7858	—	—	2.9101	2.8368
	n	4	1	3	1	2	19	16
Bank No. 8	b	2.8226				2.5721	2.9802	3.3047
	n	6				12	46	15
Bank No. 9	b	2.6286	1.4618	—	3.2199	1.5433	2.9547	2.9476
	n	10	3	1	6	3	41	25
Pearl and Hermes Atoll	b	2.8353	2.9894	—	3.0234	2.4107	2.9689	3.0459
	n	19	46	2	12	7	212	111
Salmon Bank	b				2.7487	—	3.0449	—
	n				7	1	38	2
Ladd Seamount	b		-6.3426		0.5139		3.0938	3.5369
	n		3		6		55	18
Midway Islands	b	—	—				2.8397	2.9011
	n	2	1				17	8
Nero Seamount	b	1.0460	—	—	—		2.9148	2.8623
	n	3	1	2	1		77	10
Kure Atoll	b				—		3.3064	3.1142
	n				1		9	20
Bank No. 11	b							3.0171
	n							9
Group	b	2.9109	2.9868	2.8479	3.0656	2.9777	3.0135	3.0624
	n	177	263	460	119	81	752	540
	F value	1.5026	1.8598	1.8689	1.7048	0.9770	1.2153	3.4280*
	d.f.	13, 149	10, 241	9, 440	10, 97	10, 59	17, 716	18, 502

*$P \leq 0.001$

TABLE 4. LENGTH-WEIGHT RELATIONSHIPS OF FISHES COMMONLY CAUGHT IN THE DEEPSEA HANDLINE FISHERY IN THE NORTHWESTERN HAWAIIAN ISLANDS

Species	Equation*	Y-axis Intercept	Regression Coefficient	N	Correlation Coefficient	Fork Length	
						Max. (mm)	Min. (mm)
Seriola dumerili	1	2.6069	0.3349	181	0.985	1,138	499
	2	-7.5280	2.8971				
	3	2.6026	0.3400				
	4	-7.6551	2.9412				
Pseudocaranx dentex	1	2.5860	0.3283	267	0.987	890	333
	2	-7.6624	2.9694				
	3	2.5832	0.3325				
	4	-7.7686	3.0074				
Pristipomoides filamentosus	1	2.5852	0.3455	471	0.995	779	234
	2	-7.4085	2.8670				
	3	2.5846	0.3471				
	4	-7.4453	2.8806				
Pristipomoides sieboldii	1	2.5741	0.2758	128	0.929	435	245
	2	-8.0845	3.1327				
	3	2.5772	0.2967				
	4	-8.6857	3.3702				
Pristipomoides zonatus	1	2.5580	0.3026	86	0.965	489	263
	2	-7.8524	3.0751				
	3	2.5559	0.3137				
	4	-8.1477	3.1878				
Etelis carbunculus	1	2.5864	0.3192	754	0.981	635	260
	2	-7.7930	3.0163				
	3	2.5850	0.3253				
	4	-7.9464	3.0740				
Etelis coruscans	1	2.5993	0.3376	44	0.979	880	480
	2	-7.3542	2.8399				
	3	2.5945	0.3448				
	4	-7.5248	2.9003				
Epinephelus quernus	1	2.5912	0.3187	547	0.989	1,106^{+}	238
	2	-7.9342	3.0683				
	3	2.5886	0.3223				
	4	-8.0318	3.1028				

*Predictive equation 1: $\log X = \log a + b \log Y$
Predictive equation 2: $\log Y = \log c + d \log X$
Functional equation 3: $\log X = \log u + v \log Y$
Functional equation 4: $\log Y = \log w + x \log X$

where X = fork length (mm)
Y = weight (kg)
Y-intercept: a, c, u, w
regression coefficient: b, d, v, x

$^{+}$Total length

TABLE 5. STANDARD LENGTH-FORK LENGTH RELATIONSHIPS OF FISHES COMMONLY CAUGHT IN THE DEEP-SEA HANDLINE FISHERY IN THE NORTHWESTERN HAWAIIAN ISLANDS

Species	Equation*	Y-axis Intercept	Regression Coefficient	N	Correlation	Range of Fork Length		Range of Standard Length	
						Max. (mm)	Min. (mm)	Max. (mm)	Min. (mm)
Seriola dumerili	1	3.5344	0.9391	74	0.996	1,494	524	1,367	504
	2	2.1377	1.0572						
	3	0.7493	0.9425						
	4	-0.7889	1.0610						
Pseudocaranx dentex	1	-0.1104	0.9448	129	0.997	830	464	772	431
	2	4.6975	1.0510						
	3	-2.2639	0.9481						
	4	2.4134	1.0547						
Pristipomoides filamentosus	1	2.5515	0.9012	200	0.997	779	268	723	242
	2	0.5081	1.1034						
	3	1.0884	0.9037						
	4	-1.1713	1.1065						
Pristipomoides sieboldii	1	4.2166	0.8983	70	0.987	435	245	403	225
	2	4.0474	1.0853						
	3	0.0356	0.9098						
	4	-0.0218	1.0992						

*Prediction equation 1: $X = a + b Y$
Prediction equation 2: $Y = c + d X$
Functional equation 3: $X = u + v Y$
Functional equation 4: $Y = w + y X$

where X = standard length
Y = fork length
Y-intercept: a, c, u, w
regression coefficient: b, d, v, y

TABLE 5. STANDARD LENGTH-FORK LENGTH RELATIONSHIPS OF FISHES COMMONLY CAUGHT IN THE DEEP-SEA HANDLINE FISHERY IN THE NORTHWESTERN HAWAIIAN ISLANDS (continued)

Species	Equation	Y-axis Intercept	Regression Coefficient	N	Correlation	Range of Fork Length		Range of Standard Length	
						Max. (mm)	Min. (mm)	Max. (mm)	Min. (mm)
Pristipomoides zonatus	1	-13.888	0.9506	42	0.985	489	282	452	256
	2	26.825	1.0207						
	3	-20.0176	0.9650						
	4	20.7707	1.0362						
Etelis carbunculus	1	-2.8201	0.9185	434	0.993	629	269	581	241
	2	9.8694	1.0728						
	3	-6.0045	0.9253						
	4	6.5023	1.0807						
Etelis coruscans	1	-0.5400	0.9169	40	0.998	480	876	440	810
	2	3.4976	1.0859						
	3	-1.8766	0.9189						
	4	2.0160	1.0883						
Epinephelus quernus	1	-13.152	0.8630	289	0.997	21,100	235	956	181
	2	18.896	1.1525						
	3	-14.758	0.8653						
	4	17.096	1.1556						

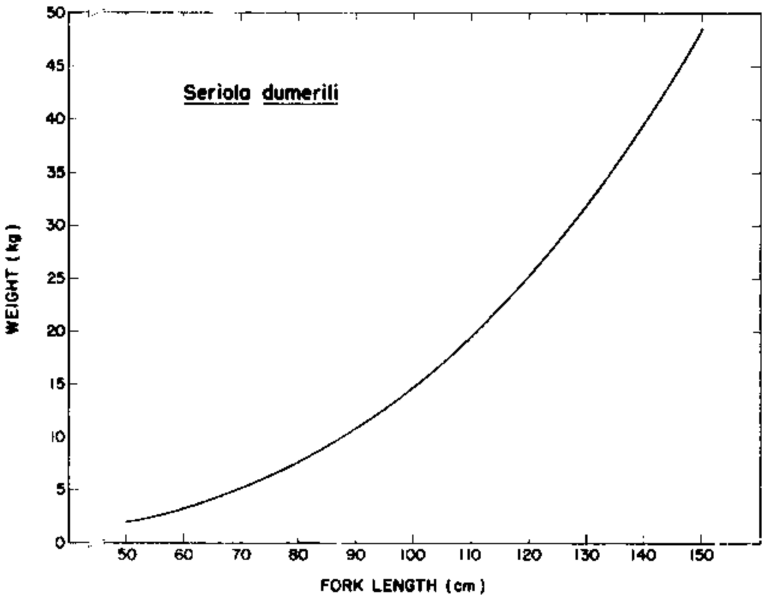

Figure 1. Functional length-weight relationship of the greater amberjack from the Northwestern Hawaiian Islands

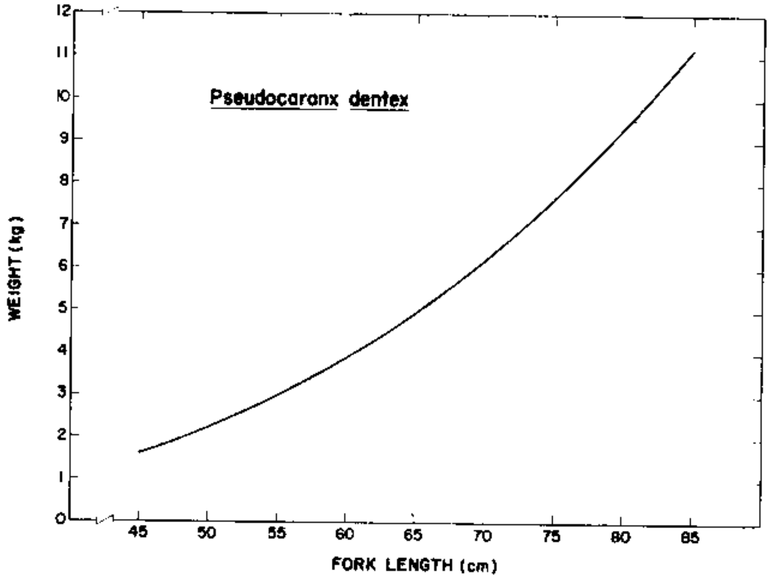

Figure 2. Functional length-weight relationship of pig ulua from the Northwestern Hawaiian Islands

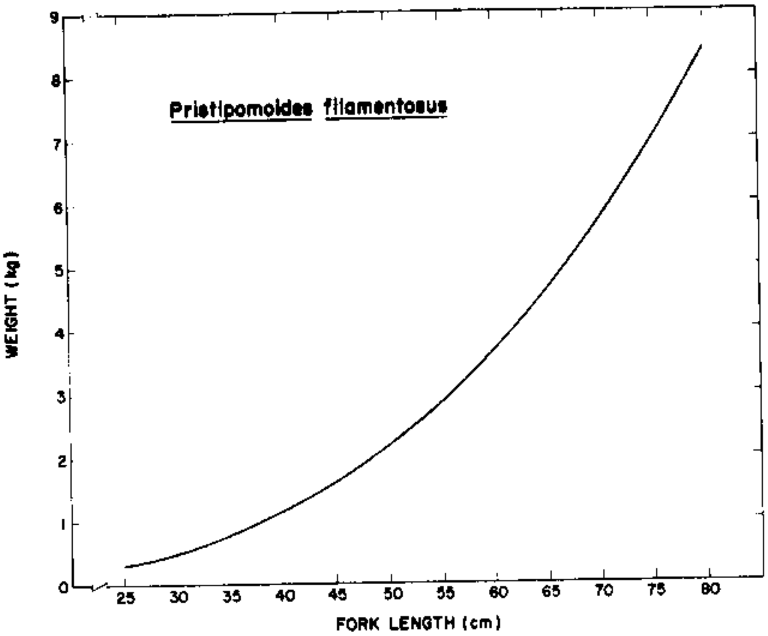

Figure 3. Functional length-weight relationship of opakapaka from the Northwestern Hawaiian Islands

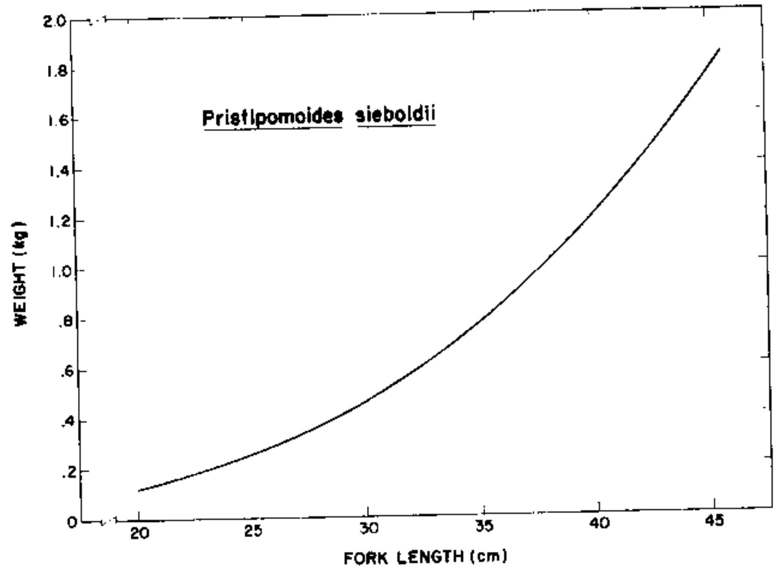

Figure 4. Functional length-weight relationship of kalekale from the Northwestern Hawaiian Islands

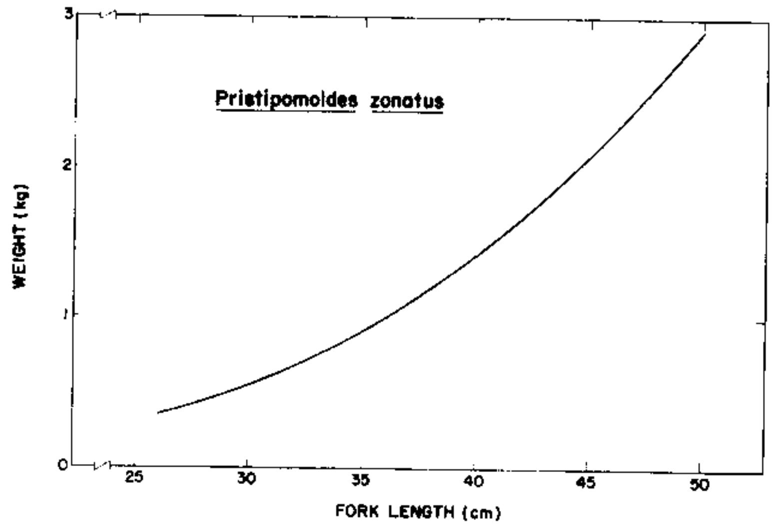

Figure 5. Functional length-weight relationship of gindai from the Northwestern Hawaiian Islands

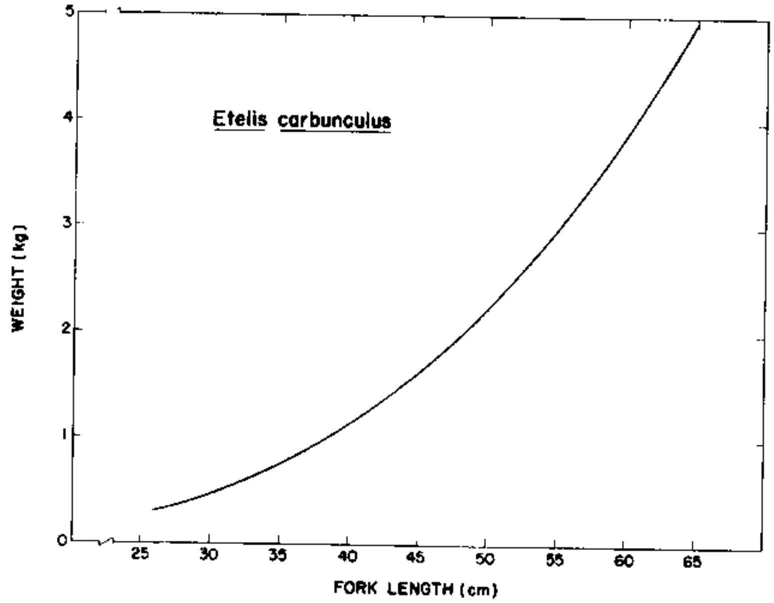

Figure 6. Functional length-weight relationship of ehu from the Northwestern Hawaiian Islands

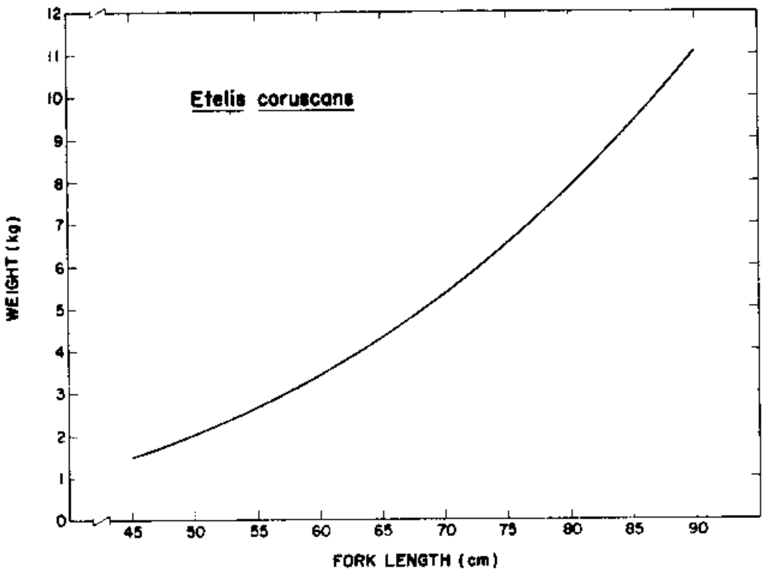

Figure 7. Functional length-weight relationship of onaga from the Northwestern Hawaiian Islands

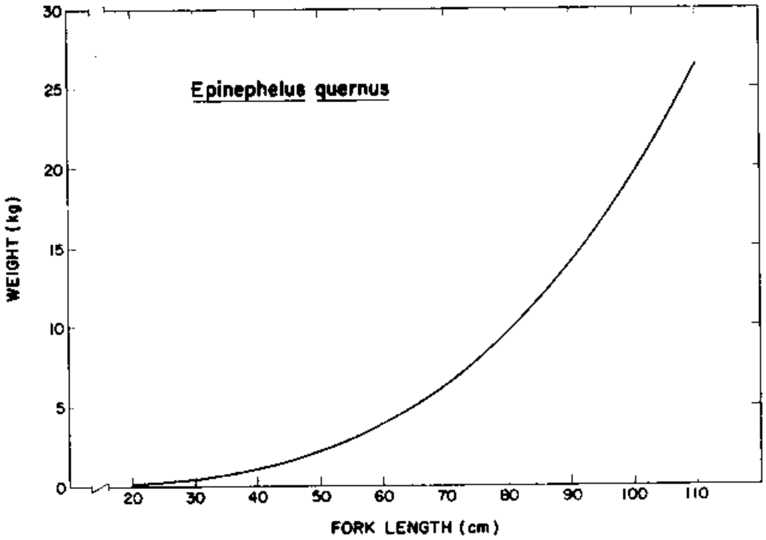

Figure 8. Functional length-weight relationship of hapuupuu from the Northwestern Hawaiian Islands

DISCUSSION

The slopes of length-weight regressions were compared among groups by ANCOVA to test for equality of slopes in the data. There were no significant differences between the slopes of male and female groups for any species (Table 1). Sex comparison for hapuupuu was not conducted due to the small sample size for males. No significant differences occurred in the comparison of slopes among cruises except for opakapaka and hapuupuu (Table 2). Large opakapaka caught on cruises 78-03 and 80-03 and small opakapaka caught on cruise 81-03 appeared to have been responsible for the significant difference. The slope of the length-weight regression of opakapaka of cruise 78-03 was lower than the rest of the cruises and the slopes for cruises 80-03 and 81-03 were higher than the other cruises. Likewise, large hapuupuu caught on cruise 80-03 appeared to be responsible for the significant difference among cruises. These cruises occurred during different months of the year, so the nonsignificance may also have implied that there were no significant seasonal differences in their length-weight relations. No significant differences were found in the comparison of slopes among banks for all species except hapuupuu (Table 3). Hapuupuu has a stout body compared with the more elongated body type of the snappers and greater amberjack or the laterally compressed body of pig ulua, and its length-weight relations may reflect changes in size structure in its population more than the other bottomfishes.

Forster et al. (1970) estimated the length-weight relationship of ehu from the western Indian Ocean. They found that females grew larger than males, calculated the length-weight relationship separately for males and females, and provided 95 percent confidence limits of the exponent of L (length). Although most of the Indian Ocean specimens were larger than Hawaiian forms (largest: 111 cm in the Indian Ocean, 63 cm in the NWHI), the estimates of the exponent of L for the two areas agreed well for males (3.07) and were well within the confidence limits ($P = 0.05$) of the exponent of L for females. Female fish in Hawaii also grew slightly larger, but the difference was not statistically significant.

Ralston (1981) calculated the length-weight relationship of opakapaka from the NWHI, from data collected on a commercial fishing vessel using a spring scale to weigh the fish. The parameters could not be directly compared, so curves derived from the parameters were compared and found to be only slightly different. Weights estimated for lengths <70 cm FL were slightly larger by Ralston's parameters.

Burch (1979) calculated the length-weight relationship of the greatest amberjack caught by sport fishing boats at Miami, Florida. Hawaii data could not be compared directly because different units of measurements were used, so curves derived from the parameters were compared and found to be slightly different. Weights estimated by Burch's formula tended to be lower than Hawaiian estimates, with the difference increasing as length increased. The weight difference estimated for a 130-cm FL fish by the two formulae was about 2.5 kg. The difference in length-weight relationships may have been due to unequal fish sizes in the two studies. The catch in the NWHI consisted mostly of fish under 100-cm FL, whereas the catch in Florida consisted primarily of fish greater than 100-cm FL. Other possible reasons for the difference in length-weight relationships may have been real morphometric differences between populations in different geographical areas or unequal dehydration due to sampling methods. Burch weighed his samples at the dock after a day's fishing trip, whereas Hawaiian samples were weighed within 2 hours after being caught.

SUMMARY

Length-weight data for each species except onaga were separated into groups by sex, cruise, and area of capture. The slope of length-weight relationship of a group was compared with others within their grouping by ANCOVA to test for heterogeneity in the data. Results of the tests appeared to justify the pooling of all data for each species.

Parameters of both the functional and predictive equations of length-weight relationship and standard length-fork length relationship were calculated for greater amberjack, pig ulua, opakapaka, kalekale, gindai, ehu, and onaga. For hapuupuu, the parameters for standard length-total length and length-weight relationships were calculated. In this paper, length-weight relationships are given for eight major deepsea species caught by handline in the NWHI. These data represent conversion factors that should prove to be useful in the development of fishery management plans for the Hawaiian handline fishery.

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RADIOIMMUNOASSAY RESULTS OF CIGUATERA ANALYSIS OF FISHES IN THE NORTHWESTERN HAWAIIAN ISLANDS, 1980-81

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ABSTRACT

As part of the Northwestern Hawaiian Islands (NWHI) survey and assessment investigation, tissues of various nearshore and offshore fish species were analyzed by radioimmunoassay (RIA) to evaluate the distribution of ciguatoxic fishes. From 1980 through 1981, the Honolulu Laboratory of the Southwest Fisheries Center, National Marine Fisheries Service (NMFS) sampled 43 different offshore species for a total of 1,831 tissue samples. A total of 962 samples representing 76 different nearshore species were collected by the Division of Aquatic Resources (DAR) of the Hawaii Department of Land and Natural Resources from 1980 through 1982. When analyzed by the RIA method, 2,292 (82 percent) of the samples from NMFS and DAR were negative, 278 (10 percent) were borderline, and 223 (8 percent) were positive. The results were similar to those of the 1977-79 surveys and show that commercially valuable species, especially those in the snapper-grouper complex from various NWHI locations, had moderate to high frequencies of borderline and positive RIA results. Of the nearshore species, _Cheilinus unifasciatus_ (= _C. rhodochrous_) had the highest rejection rate (percentage of samples with RIA borderline and positive results). Although not previously implicated in ciguatera, _Pontinus macrocephalus_ had the highest rejection rate among the offshore species, followed by _Epinephelus quernus_. Recent studies suggest that species having high rejection rates and not previously implicated in ciguatera may contain polyether compounds which are similar in chemical reactivity to ciguatoxin but of lower toxicity.

ciguatera radioimmunoassay
rejection rate Northwestern Hawaiian Islands

INTRODUCTION

Ciguatera is a disease caused by the ingestion of a variety of fish contaminated with ciguatoxin, a lipid originating in the dinoflagellate, *Gambierdiscus toxicus* (Yasumoto et al., 1977). Characterized by neurological and gastrointestinal symptoms, ciguatera has been a health problem as well as a deterrent to fisheries development and utilization in the oceanic islands of the Pacific.

As part of the Northwestern Hawaiian Islands survey and assessment investigation, various nearshore and offshore species of fish were sampled to determine the occurrence and distribution of ciguatoxic fishes. From 1977 until 1982, commercially important as well as other less valuable species were sampled through the cooperative efforts of the Division of Aquatic Resources (formerly the Division of Fish and Game) of the Hawaii Department of Land and Natural Resources and the Honolulu Laboratory of the Southwest Fisheries Center, National Marine Fisheries Service. Fish tissues were tested for the presence of ciguatoxin by a radioimmunoassay procedure developed at the University of Hawaii (Hokama et al., 1977).

Radioimmunoassay results of fish surveys conducted between 1977 and 1979 were reported previously (Ito and Uchida, 1980) and indicated that ciguatoxic fish occurred throughout the NWHI from Nihoa to Kure Atoll. Species among the snapper-grouper complex, including *Caranx ignobilis*, *Pseudocaranx dentex* (= *C. cheilio*), *Seriola dumerili*, *Epinephelus quernus*, *Etelis carbunculus*, *Lutjanus kasmira*, and *Pristipomoides filamentosus*, had high frequencies of borderline and positive RIA results for ciguatoxin. Among the nearshore species tested, *Kuhlia sandvicensis* and *Cheilinus unifasciatus* (= *C. rhodochrous*) had high frequencies of ciguatoxic fish.

The RIA results of nearshore and offshore surveys done from 1980 until 1982 are presented in this report. The data are similar to those of the 1977-79 surveys and show that some commercially valuable species from various NWHI locations had moderate to high frequencies of borderline and positive RIA results.

METHODS

DAR sampled fish from the nearshore areas and NMFS concentrated on sampling offshore species although some nearshore species were sampled during refueling and rest stops. Shortly after capture, each fish was weighed and measured before tissue samples were taken. Tissues collected by DAR were obtained from the anterior dorsal musculature (A); tissues collected by NMFS were taken from site A as well as from the anterior ventral abdominal musculature (B) and the posterior ventral musculature (E). Each tissue sample was placed in a plastic vial or bag and kept frozen until analyzed by the RIA method.

The RIA procedure was carried out according to the method of Hokama et al. (1977) with modifications described by Kimura et al. (1982). In the assay, precisely weighed tissue samples were incubated for 3 hours with ^{125}I - sheep anti-ciguatoxin antibody, washed, and then placed in a gamma counter to determine the radioactive counts per minute per gram of tissue. Based on studies of fish involved in clinically evaluated cases of ciguatera, and on mouse and mongoose toxicity tests, levels of toxicity were established as follows:

Counts per minute per gram	Toxicity level
<350,000	Negative
350,000 to 399,999	Borderline
>399,999	Positive

For all samples analyzed, tests were conducted "blind," i.e., samples were identified only by the original numbers assigned at the time of collection. Species identification and location of capture were revealed by NMFS and DAR only when all samples from a survey had been analyzed.

RESULTS

Approximately 18 percent of all fish sampled by NMFS and DAR showed either a positive or borderline ciguatoxin level when tested by the RIA method. Of the fish tested, 2,292 were negative, 278 were borderline, and 223 were positive.

From DAR surveys of 1980 through 1982 a total of 76 different species accounting for 962 samples were tested. Of these samples, 873 (90 percent) were negative, 53 (6 percent) were borderline, and 36 (4 percent) were positive. Table 1 shows the RIA results for the nearshore fishes and includes only those species for which a total of 10 or more samples were tested over the 3-year period. The species having the highest rejection rate (50 percent) was C. unifasciatus followed by Polydactylus sexfilis (32 percent), Myripristis murdjan (27 percent), Mulloidichthys flaviolineatus (24 percent), and Bodianus bilunulatus (13 percent). The rejection rates for NWHI samples in Table 1 varied from 5 percent in the summer of 1980, to 16 percent in the fall of 1980, and to 12 percent in the fall of 1981. In the summer of 1982, samples from Kure Atoll had a 2 percent rejection rate.

TABLE 1. NUMBER OF NEGATIVE (N), BORDERLINE (B), AND POSITIVE (P) REACTIONS OBTAINED WITH THE RADIOIMMUNOASSAY TEST ON FISHES CAUGHT DURING THE NORTHWESTERN HAWAIIAN ISLANDS NEARSHORE SURVEYS CONDUCTED BY THE HAWAII DIVISION OF AQUATIC RESOURCES IN 1980-82

Species*	1980 Summer	1980 Fall†	1981 Fall	1982 Spring-Summer§	Rejection# (%)
	N-B-P	N-B-P	N-B-P	N-B-P	
Acanthurus nigroris	--	--	2-0-0	9-0-0	0
A. triostegus	45-1-3	17-3-0	48-0-2	25-0-0	6
Bodianus bilunulatus	12-1-2	14-5-1	34-0-0	2-0-0	13
Carangoides ferdau	--	--	10-0-0	1-0-0	0
Caranx ignobilis	10-0-0	1-0-0	4-0-0	1-0-0	0
C. melampygus	5-0-0	4-0-0	5-1-1	--	12
Cheilinus unifasciatus	--	2-4-1	4-0-1	--	50
Kuhlia sandvicensis	51-1-0	19-0-0	38-5-0	37-2-0	5
Kyphosus bigibbus	22-0-0	13-3-2	--	25-0-0	8
Mulloidichthys flaviolineatus	1-0-0	10-6-1	11-0-0	--	24
Myripristis amaenus	14-1-1	--	8-0-0	10-0-0	6
M. murdjan	--	6-0-1	10-2-3	--	27
Parupeneus multifasciatus	--	--	13-1-0	--	7
P. porphyreus	5-0-0	27-1-1	3-1-2	1-0-0	12
Priacanthus sp.	--	7-0-0	--	7-0-0	0
Polydactylus sexfilis	--	--	19-1-8	--	32
Pseudocaranx dentex	--	13-0-0	--	1-0-0	0
Thalassoma duperreyi	--	19-1-0	--	--	5
Selar crumenophthalmus	30-0-0	--	--	--	0
TOTAL	195-4-6	153-23-7	209-11-17	119-2-0	

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*Only species of which 10 or more samples were collected are included.

†Fishes were collected only from Midway and Kure Atoll.

§Fishes were collected only from Kure Atoll.

#Percent rejection = number borderline + positive fish/total number tested x 100.

From the NMFS surveys of 1980 through 1981, a total of 43 different species accounting for 1,831 samples were tested. Of these samples, 1,419 (78 percent) were negative, 225 (12 percent) were borderline, and 187 (10 percent) were positive. Table 2 shows the RIA results for species that had a sample size of at least 10 during this period. Although only 16 samples of *Pontinus macrocephalus* were analyzed from 6 locations, this species had a rejection rate of 50 percent, the highest among all species examined. *Epinephelus quernus*, the only serranid sampled, had the next highest rejection rate of 39 percent, based upon 308 fish from 19 locations. Among the carangids, *Pseudocaranx dentex* had the highest rejection rate (22 percent), followed by *Caranx ignobilis* (18 percent) and *Seriola dumerili* (10 percent). Among the snappers, *Pristipomoides zonatus* had a rejection rate of 36 percent, followed by *P. filamentosus* (26 percent), *Etelis carbunculus* (22 percent), and *P. sieboldii* (10 percent). Samples collected only from Midway gave moderate to high rejection rates: *Acanthurus triostegus* (25 percent), *Selar crumenophthalmus* (14 percent), and *K. sandvicensis* (10 percent).

For the NMFS surveys, comparison of rejection rates according to locations of capture indicates that Lisianski (44 percent) and Raita Bank (43 percent) had the highest rates of rejection. The following locations also showed high rates of rejection: Kure Atoll (33 percent), Laysan Island (28 percent), Pearl and Hermes Atoll (27 percent), French Frigate Shoals (26 percent), Maro Reef (23 percent), Necker Island (23 percent), Nihoa (21 percent), and Gardner Pinnacles (17 percent).

DISCUSSIONS AND CONCLUSIONS

The results of the NMFS and DAR surveys for ciguatoxic fish during 1980 through 1982 are similar to those obtained in the 1977-79 surveys (Ito and Uchida, 1980). Fish having borderline or positive RIA results were found among many of the species examined and appeared to be distributed throughout the NWHI. The results are in agreement with those of Sylvester et al. (1977) who reported that members of the family Carangidae, followed by snappers and groupers, were the species most likely to be ciguatoxic in the Virgin Islands.

A comparison of the data obtained by DAR and NMFS shows that higher rejection rates were found in the NMFS surveys: 22 percent vs 9 percent. A possible explanation for the difference is that the DAR rejection rates were based on only one tissue sampling site (A) for each fish whereas the NMFS rejection rates were based on results from three tissue sites (A, B, and E). No consistent relationship has been found between toxicity as determined by the RIA method and tissue sampling site. Therefore, the higher rejection rates for the NMFS samples may have resulted from the greater chance of detecting ciguatoxin since tissues from three sites rather than one were tested.

TABLE 2. NUMBER OF NEGATIVE (N), BORDERLINE (B), AND POSITIVE (P) REACTIONS OBTAINED WITH THE RADIOIMMUNOASSAY ATEST ON FISHES CAUGHT DURING THE NATIONAL MARINE FISHERIES SERVICE SURVEY CRUISES TO THE NORTHWESTERN HAWAIIAN ISLANDS IN 1980-81

Species	Nihoa	Twin Banks	Necker	French Frigate Shoals	Brooks Banks	St. Rogatien	Gardner Pinnacles	Raita Bank
	N-B-P	N-B-P	N-B-P	N-B-P	N-B-P	N-B-P	N-B-P	N-B-P
Acanthuridae								
Acanthurus triostegus								
Carangidae								
Caranx ignobilis			0-0-1	1-1-0			1-0-0	
Pseudocaranx dentex	1-0-0		8-3-2	9-3-3		12-0-0	22-2-2	11-4-0
Seriola dumerili	3-0-0	4-0-0	15-1-0	12-0-0	1-0-0	3-0-0	21-5-1	12-1-0
Selar crumenophthalmus								
Kuhliidae								
Kuhlia sandvicensis								
Kyphosidae								
Kyphosus bigibbus								
Lutjanidae								
Etelis coruscans		1-0-0				1-0-0	4-0-0	
E. carbunculus	2-0-0	2-0-0	13-3-4	6-2-2		8-2-0	9-0-2	2-0-0
Pristipomoides filamentosus	1-0-0		59-10-8	48-7-6	2-0-0	11-3-1	15-2-0	3-6-3
P. sieboldii	0-1-0	2-0-0	8-0-0	1-1-0		2-0-0	2-0-0	1-0-1
P. zonatus			3-1-0	1-3-0			4-0-0	1-0-0
Mullidae								
Mulloidichthys flaviolineatus								
Priacanthidae								
Priacanthus meeki								
Scombridae								
Acanthocybium solandri	1-0-0		8-0-0		1-0-0		1-0-0	2-0-0
Euthynnus affinis	2-0-1		12-0-0			1-0-0		
Scorpaenidae								
Pontinus macrocephalus								
Serranidae								
Epinephelus quernus	1-1-0	3-0-0	9-6-2	25-5-3		13-1-0	11-1-1	9-8-8
TOTAL	11-2-1	12-0-0	135-24-17	103-22-14	4-0-0	51-6-1	90-10-6	41-19-12

TABLE 2. NUMBER OF NEGATIVE (N), BORDERLINE (B), AND POSITIVE (P) REACTIONS OBTAINED WITH THE RADIOIMMUNOASSAY TEST ON FISHES CAUGHT DURING THE NATIONAL MARINE FISHERIES SERVICE SURVEY CRUISES TO THE NORTHWESTERN HAWAIIAN ISLANDS IN 1980-81 (continued)

Species	Maro Reef	Laysan	Northampton Seamount	Lisianski	Bank No. 9	Pearl and Hermes Reef	Grass	Salmon Bank
	N-B-P	N-B-P	N-B-P	N-B-P	N-B-P	N-B-P	N-B-P	N-B-P
Acanthuridae								
Acanthurus triostegus								
Carangidae								
Caranx ignobilis	2-0-0			2-1-0		25-4-0		
Pseudocaranx dentex	3-1-1	13-2-2		2-0-0	1-0-1	33-4-2		
Seriola dumerili	11-0-0	12-3-0		3-0-0	3-1-0	13-0-0		
Selar crumenophthalmus								
Kuhliidae								
Kuhlia sandvicensis								
Kyphosidae								
Kyphosus bigibbus								
Lutjanidae								
Etelis coruscans		1-0-0			1-0-0	4-0-0		
E. carbunculus	4-0-1	23-3-6	11-0-2		13-1-0	90-14-18	4-0-0	26-1-0
Pristipomoides filamentosus	7-4-0	3-1-0	1-0-0	1-1-0	1-0-0	2-0-0		
P. sieboldii		8-0-0	1-0-0		2-0-0	6-0-0	2-0-0	6-0-0
P. zonatus	2-0-0	8-0-4	5-0-0		1-0-0	2-1-1		1-0-0
Mullidae								
Mulloidichthys flaviolineatus								
Priacanthidae								
Priacanthus meeki								
Scombridae								
Acanthocybium solandri	3-0-0	1-0-0						
Euthynnus affinis		4-1-0		0-1-0				
Scorpaenidae								
Pontinus macrocephalus		0-0-1		2-0-1		2-2-2		1-0-0
Serranidae								
Epinephelus quernus	8-4-1	27-12-0	3-0-0	5-4-4	13-3-1	39-10-23		1-1-0
TOTAL	40-9-3	97-22-13	21-0-2	15-7-5	35-5-2	216-35-46	6-0-0	35-2-0

TABLE 2. NUMBER OF NEGATIVE (N), BORDERLINE (B), AND POSITIVE (P) REACTIONS OBTAINED WITH THE RADIOIMMUNOASSAY TEST ON FISHES CAUGHT DURING THE NATIONAL MARINE FISHERIES SERVICE SURVEY CRUISES TO THE NORTHWESTERN HAWAIIAN ISLANDS IN 1980-81 (continued)

Species	Ladd Bank	Midway	Eastern	Nero and Pogy	Kure Atoll	Bank No. 11	Total All Banks	Rejection (%)
	N-B-P	N-B-P	N-B-P	N-B-P	N-B-P	N-B-P	N-B-P	
Acanthuridae								
Acanthurus triostegus		51-10-8	2-0-0				53-10-8	25
Carangidae								
Caranx ignobilis		1-0-0					32-6-1	18
Pseudocaranx dentex	2-1-0	1-0-0		1-0-0	2-1-0		121-21-13	22
Seriola dumerili		0-1-0	1-0-0	3-0-0			117-12-1	10
Selar crumenophthalmus		24-3-1					24-3-1	14
Kuhliidae								
Kuhlia sandvicensis		223-14-11					223-14-11	10
Kyphosidae								
Kyphosus bigibbus		19-0-0					19-0-0	0
Lutjanidae								
Etelis coruscans							12-0-0	0
E. carbunculus	17-3-4	1-0-0		12-1-2	9-1-0		252-31-41	22
Pristipomoides filamentosus				0-1-1			154-35-19	26
P. sieboldii	2-2-0			1-0-0	1-0-0		45-4-1	10
P. zonatus							28-5-5	36
Mullidae								
Mulloidichthys flaviolineatus		13-0-0					13-0-0	0
Priacanthidae								
Priacanthus meeki		12-1-1					12-1-1	14
Scombridae								
Acanthocybium solandri					1-0-0		18-0-0	0
Euthynnus affinis					0-0-1		19-2-2	17
Scorpaenidae								
Pontinus macrocephalus				1-0-0	2-2-0		8-4-4	50
Serranidae								
Epinephelus quernus	7-0-6	1-0-0		5-1-4	7-5-1	1-2-2	188-64-56	39
TOTAL	28-6-10	346-29-21	3-0-0	23-3-7	22-9-2	1-2-2		

Similar to the results of earlier surveys, the nearshore species showing the highest rejection rate was Cheilinus unifasciatus which has been frequently implicated in ciguatera. Of the offshore species Pontinus macrocephalus had the highest rejection rate. However, this species has not been implicated in ciguatera in the past. Another offshore species having a high rejection rate was Epinephelus quernus, a member of the grouper family which has been implicated in ciguatera.

Results of surveys from 1977 through 1982 indicate that certain species (such as P. macrocephalus and Pristipomoides sp.), which have not been implicated in ciguatera, have high rejection rates based on the RIA. Recent studies describing the existence of compounds with structures similar to ciguatoxin suggested the possibility that the sheep anti-ciguatoxin antibody may also react with these compounds. Tachibana et al. (1981) reported that two marine sponges (genus Halichondria) contained okadaic acid, a cytotoxic polyether compound having close structural similarity to ciguatoxin. Murakami et al. (1982) identified okadaic acid as the toxic component in Prorocentrum lima, a benthic marine dinoflagellate, and found close similarity between okadaic acid and ciguatoxin in terms of chromatographic and ionophoric properties, and oxygenated polyether structure. Another marine toxin, brevetoxin B, from the red tide dinoflagellate Ptychodiscus brevis, also has a polyether structure similar to ciguatoxin (Lin et al., 1981).

Preliminary studies indicate that purified okadaic acid and brevetoxin partially inhibit the binding of sheep anti-ciguatoxin to toxic fish tissues, although at concentrations greater than those required for similar inhibition by purified ciguatoxin (unpublished observations). The presence of these ciguatoxinlike compounds in fish tissues may give positive RIA results and yet may not cause toxic symptoms because they are inherently less toxic than ciguatoxin. The LD_{99} of highly purified ciguatoxin is 0.45 μg/kg when given intraperitoneally to mice (Tachibana, 1980) whereas the LD_{99} of okadaic acid is 200 μg/kg (Murakami et al., 1982) and that of brevetoxin T34 is between 150 and 270 μg/kg (Baden et al., 1981).

In conclusion, results of the DAR and NMFS surveys of the nearshore and offshore waters of the NWHI indicate that approximately 18 percent of the fishes examined gave borderline or positive results by the RIA method. Offshore species that belong to the snapper-grouper complex showed a high degree of rejection. Among nearshore species, C. unifasciatus showed high rejection rates. More recent studies suggest that species with high rejection rates but not previously implicated in ciguatera may contain polyether compounds similar to ciguatoxin but of lower toxicity. Further studies are needed to examine this possibility, especially in view of the recent availability of techniques to develop monoclonal antibodies which could be used instead of the polyclonal sheep anti-ciguatoxin.

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CIGUATERA AND THE FEEDING HABITS OF THE GREATER AMBERJACK, SERIOLA DUMERILI, IN THE HAWAIIAN ARCHIPELAGO

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ABSTRACT

Stomach contents collected from those greater amberjack, *Seriola dumerili*, tested for ciguatoxicity, were (1) examined to determine whether a relationship exists between feeding habits and incidence of toxicity, and (2) analyzed to determine the extent of geographic variability in the diet. Amberjack were classified into two weight groups. Large fish caught in the main Hawaiian islands fed predominantly on *Decapterus* regardless of their level of ciguatoxicity. For small amberjack, *Decap-terus* again predominated in the diet with these exceptions: those determined as being ciguatoxic and those caught in the Northwestern Hawaiian Islands. These two groups, plus the large nonciguatoxic amberjack of the Northwestern Hawaiian Islands fed more on bottom-associated fauna than all other groups studied. A series of hypotheses were generated from these results to explain the observed dietary differences.

ciguatera	Hawaiian Archipelago
amberjack	feeding habits

INTRODUCTION

Ciguatera is a toxin-related malady caused by the consumption of certain reef fishes of the tropics and subtropics. The symptoms include a variety of gastrointestinal and neurological disorders which occasionally cause death. The reef fishes involved are primarily algal and detrital feeders and higher reef predators, including some neritic predators which range into the reef environment. Virtually no evidence of toxicity exists for reef planktivores and pelagic fishes (Withers, 1982).

A source of the toxic agent, ciguatoxin, has been identified as a benthic dinoflagellate, Gambierdiscus toxicus, from surveys conducted by Yasumoto et al. (1977a, 1977b) of reef areas around the Gambier Islands, French Polynesia. This dinoflagellate has also been identified from Oahu, Hawaii by Taylor (1979) and found to be toxicologically similar to the Gambier Islands population (Shimizu et al., 1982).

The linkage of ciguatoxin production to G. toxicus supports a theory proposed by Randall (1958) which, in part, suggests that the toxin originates in the benthic reef environment. Additionally, Randall (1958) suggests that the toxin is transmitted via the food chain to fishes of higher trophic levels. The latter is supported by identification of the dinoflagellate among the gut contents of a ciguatoxic acanthurid, Naso unicornis, from studies by Yasumoto et al. (1977a). Although this is the only such finding to date, studies on two ciguatoxic acanthurids, Ctenochaetus strigatus and Acanthurus lineatus (Yasumoto et al., 1971), and on the ciguatoxic scarid, Scarus gibbus (Yasumoto et al., 1977c), revealed gut contents containing ciguatoxin. These species all belong to the lower reef trophic levels and are herbivores or detrital feeders. Fishes at these trophic levels are considered the initial accumulators of ciguatoxin; later, as prey they transmit the toxin to fishes in higher trophic levels. This pattern of transmission agrees well with documented accounts of a ciguatera outbreak at Hao Atoll, Tuamotus in 1966-68 (Banner, 1976).

Among the higher reef predators prone to be ciguatoxic is the amberjack, Seriola dumerili, whose distribution is worldwide in tropical and subtropical waters. In Hawaii, amberjack is found throughout the archipelago in the inner reef and outer reef slope environments. The adults are primarily found near the bottom, although they are capable of considerable vertical mobility ranging from the surface to depths of 240 m.

Dietary studies on amberjack are few and do not include any from Hawaii. Valdes-Munoz (1980) examined the stomachs (9 empty) of 21 amberjack from Cuban waters as part of a food study on 6 species implicated in ciguatera poisonings. The pomadasyid, Haemulon sciurus, and lutjanid, Lutjanus synagris, occurred most frequently in the stomachs. Randall (1967) examined 8 stomachs (2 empty) from the West Indies and found only fish as prey items including Calamus sp., Caranx ruber, H. aurolineatum, and Priacanthus arenatus. In a study of the biology and fishery of amberjack in southern Florida, Burch (1979) described the contents of 135 stomachs. Prey items occurring most frequently were lutjanids, carangids, portunids, and loligids.

Since these studies did not determine ciguatoxin levels in the amberjack sampled, little information is available on the identity of the prey species involved in ciguatoxin transmission. The opportunity to conduct such a study in Hawaii arose after a 1979 outbreak of ciguatera which implicated amberjack. This incident, coupled with previously reported cases from Hawaii and adjacent Pacific areas (Kubota, 1981) and amberjack's commercial importance in Hawaii, led to the initiation of a ciguatoxin testing program.

In this program -- involving the Southwest Fisheries Center Honolulu Laboratory of the National Marine Fisheries Service, the fishing industry, the University of Hawaii Department of Pathology, and state agencies -- flesh samples were tested for ciguatoxin levels from all amberjack delivered for sale to the United Fishing Agency (UFA) fish auction in Honolulu. Concurrently, an investigation was begun into possible dietary differences between the ciguatoxic (CTC) and non-ciguatoxic (non-CTC) amberjack. This report also includes geographical dietary comparisons among non-CTC amberjack.

METHODS

Weight, fork length, sex, and usually catch location were recorded for amberjack samples at the UFA fish auction. Only fish caught in the fishery around Penguin Bank, Kahoolawe, Lanai, Maui, and Hawaii in the lower main Hawaiian islands (LMHI) and those caught from Gardner Pinnacles to Necker bank in the Northwestern Hawaiian Islands (NWHI) were examined. These two general areas are separated by some 645 km (Figure 1). Commercial amberjack fishing was conducted primarily in depths ranging from 55 to 110 m in both areas.

Flesh samples were tested for ciguatoxin at the University of Hawaii John A. Burns School of Medicine, Pathology Department, by a radioimmunoassay (RIA) technique (Hokama et al., 1977). The toxicity levels of the fish tissues were determined from gamma radiation counts per minute per gram tissue (cpm/g) and were classified as follows: <350,000 cpm/g tissue -- negative; 350,000 to 399,999 cpm/g tissue -- borderline; and ≥400,000 cpm/g tissue -- positive. All borderline cases were considered ciguatoxic.

Stomachs from CTC and non-CTC amberjack caught in the LMHI were collected during February 1980 to February 1981 and July 1979 to March 1980, respectively. Samples from non-CTC amberjack in the NWHI were collected during June to July 1979 and June to October 1980. No stomach samples of CTC amberjack from the NWHI were available.

Stomachs were sampled and preserved in 10 percent Formalin at the auction market. Because there was a lapse of 1 to 10 days between capture and the time the fish were brought to auction, the condition of stomach contents was often poor.

In the laboratory, stomach contents were sorted into identifiable groups. Stomachs containing only unidentifiable remains were discarded and not utilized in the study. Bait could be identified by its appearance and state of digestion. Bait and

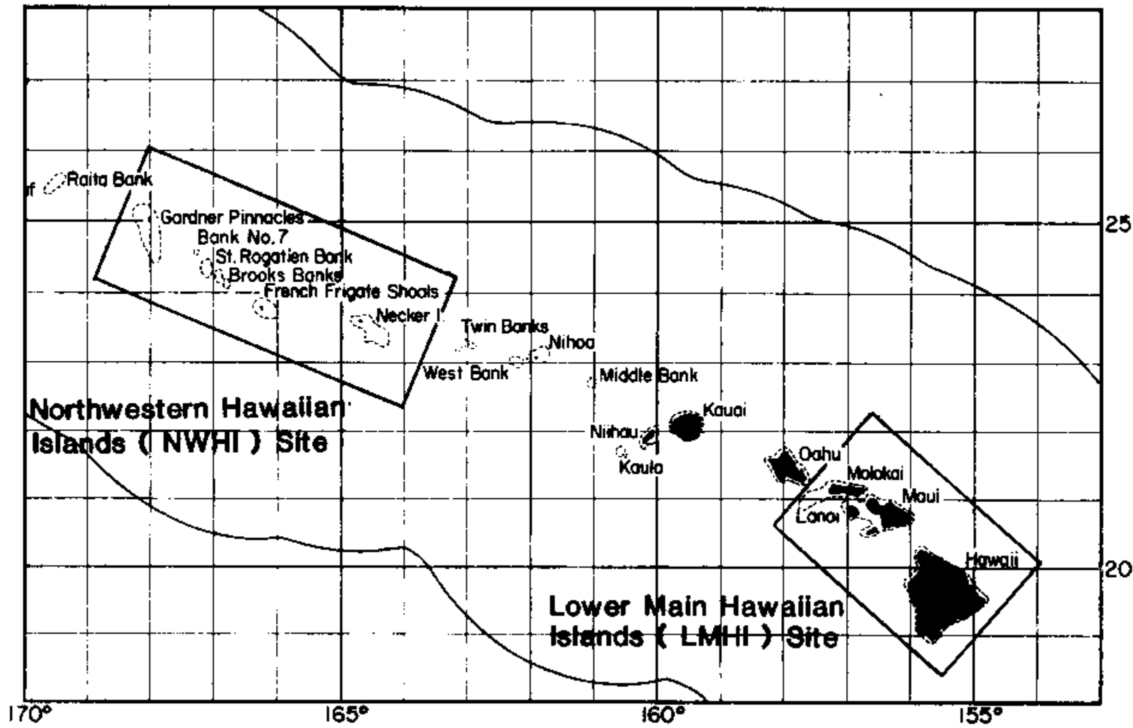

Figure 1. The two study areas of the fishery for amberjack in the Hawaiian Archipelago

parasites were recorded but not considered as food items. The volume of each food item was measured by water displacement.

Prey items were identified to lowest possible taxon. Invertebrates were digested rapidly, and frequently could be identified only to suborder. Fishes were usually identifiable to family and sometimes to species. Exceptions were the eels and flatfishes which were only identified to order. Fish in an advanced state of digestion were cleaned of flesh, stained in alizarin, and identified by vertebral count and bone morphology.

The total number (N), frequency of occurrence (F), and aggregate total volume (V) were converted to percentages to the nearest 0.1 percent for all prey taxa, and the index of relative importance (IRI) (Pinkas et al., 1971) was computed as follows:

$$IRI = \%F \times (\%N + \%V) .$$

The IRI values were rounded off to the nearest whole number. The IRI's of 0.6 to 0.9 were rounded off to 1 whereas values 0.5 and less were represented as <1. The IRI values ≥100 were considered to represent major food items.

Prey comparisons were made among class taxa and the lower identified taxa. Class comparisons offered information on the general animal types in the diet whereas lower taxa comparisons yield more specific information on the prey and diet. Prey identifiable only to class (i.e., unidentified fish, crustaceans, and cephalopods) were treated as separate entities and included in the lower taxa comparisons.

Diet was also analyzed by ecological habitat with respect to available information on the spatial distribution of prey within the Hawaiian Archipelago. The objective was to indirectly determine whether amberjack feed preferentially on bottom or midwater fauna. Three arbitrary categories were used: (1) benthic and demersal, (2) midwater and surface, and (3) combination of both habitats. This latter category includes prey which are known or suspected of inhabiting both environments equally (Natantia) and those which change habitat during larva, juvenile, or adult stage (Mullidae, Zeidae, and Tetraodontidae). Unidentified carangids, cephalopods, crustaceans, and fish were excluded from the habitat comparison.

To reduce the possibility of an artifact in dietary differences due to amberjack size alone, CTC and non-CTC amberjack were divided into two weight groups: 4.00 to 8.99 kg (small) and those >8.99 kg (large). Small amberjack were most commonly encountered during the study. Large amberjack were much less abundant but corresponded to the size commonly thought (in Hawaii) to be more frequently CTC.

RESULTS

A dietary comparison between CTC and non-CTC amberjack was investigated only within the LMHI. Among small amberjack of both these groups, the predominate class taxon in the diet was fish; crustaceans and cephalopods contributed little to the diet (Tables 1 and 2). Decapterus spp. were the most important (IRI = 457) among lower taxa in the CTC group. Other major lower taxa were Teuthoidea (IRI = 246), Symphysanodon maunaloae (IRI = 232), crustaceans (IRI = 169), Natantia (IRI = 167), Synodontidae (IRI = 139), and Myctophidae (IRI = 118) (Figure 2, Table 1). In the non-CTC group, Decapterus spp. were also the greatest contributor (IRI = 2,421) followed by Natantia (IRI = 466) and S. maunaloae (IRI = 188) (Figure 3, Table 2).

In the diet of large amberjack, fish again predominated in both CTC and non-CTC groups with minor contributions of crustaceans and cephalopods (Tables 3 and 4). In the CTC group, Decapterus spp. dominated (IRI = 1,429) among lower taxa followed by Teuthoidea (IRI = 727), Myctophidae (IRI = 177), and Engraulidae (IRI = 101) (Figure 4, Table 3). In the non-CTC group, Decapterus spp. also ranked highest (IRI = 1,894) followed Auxis thazard (IRI = 119) (Figure 5, Table 4).

TABLE 1. PREY ITEMS OF SMALL CTC AMBERJACK FROM THE LOWER MAIN HAWAIIAN ISLANDS (N = 88) LISTED IN DECREASING IMPORTANCE BY TAXA. TAXA OF LESSER PREY (THOSE WITH IRI VALUES BELOW 100) ARE LISTED WITH THEIR RESPECTIVE IRI VALUES ONLY.

	%N	%F	%V	IRI
Taxa of prey				
Fishes	44.0	88.6	91.8	12,032
Crustaceans	38.9	29.6	4.6	1,288
Cephalopods	17.1	21.6	3.6	447
Major lower taxa prey				
Decapterus spp.	3.3	13.6	30.3	457
Teuthoidea	14.6	14.8	2.0	246
Symphysanodon maunaloae	9.0	15.9	5.6	232
Crustaceans	10.2	15.9	0.4	169
Natantia	15.1	10.2	1.3	167
Synodontidae	5.9	12.5	5.2	139
Myctophidae	5.4	18.2	1.1	118
Taxa of lesser prey				
Fish				86
Caridea				44
Octopoda				13
Pontinus macrocephala				12
Priacanthidae				12
Pomacentridae				11
Heterocarpus ensifer				8
Lutjanidae				8
Pristipomoides sp.				8
Serranidae				8
Anthias sp.				7
Auxis thazard				7
Labridae				7
Xanthichthys mento				7
Scorpaenidae				5
Mullidae				4
Reptantia				4
Selar crumenophthalmus				4
Carangidae				3
Cephalopod				3
Emmelichthyidae				2
Percophididae				2
Pleuronectiformes				2
Symphysanodon typus				2
Ammodytidae				1
Antigonia steindachneri				1
Chaetodontidae				1
Dactylopteridae				1
Grammatonotus laysanus				1
Munida sp.				1
Penaeidea				1
Plesionika longirostris				1
Plesionika sp.				1
Portunidae				1
Tetraodontidae				1
Anguilliformes				<1
Balistidae				<1
Bleekeria gilli				<1
Congridae				<1
Embolichthys sp.				<1
Engraulidae				<1
Gobiidae				<1
Paguridae				<1
Sphyraenidae				<1

Note: N = total number, F = frequency of occurrence, V = aggregate total volume, IRI = index of relative importance

TABLE 2. PREY ITEMS OF SMALL NON-CTC AMBERJACK FROM THE LOWER MAIN HAWAIIAN ISLANDS (N = 82) LISTED IN DECREASING IMPORTANCE BY TAXA. TAXA OF LESSER PREY (THOSE WITH IRI VALUES BELOW 100) ARE LISTED WITH THEIR RESPECTIVE IRI VALUES ONLY.

	%N	%F	%V	IRI
Taxa of prey				
Fishes	51.2	90.2	95.9	13,268
Crustaceans	43.1	22.0	2.5	1,003
Cephalopods	5.7	20.7	1.6	151
Major lower taxa prey				
Decapterus spp.	6.1	32.9	67.5	2,421
Natantia	40.6	11.0	1.8	466
Symphysanodon maunaloae	10.6	14.6	2.3	188

Taxa of lesser prey			
Teuthoidea	68	*Etelis coruscans*	3
Symphysanodon sp.	56	Bothidae	2
Fish	39	*Heterocarpus ensifer*	2
Pristipomoides sp.	19	Myctophidae	2
Crustaceans	17	Caproidae	1
Synodontidae	16	Caridea	1
Priacanthidae	14	*Decapterus macrosoma*	1
Selar crumenophthalmus	13	Lutjanidae	1
Serranidae	12	Mullidae	1
Engraulidae	10	*Scorpaenopsis* sp.	1
Emmelichthyidae	9	*Symphysanodon typus*	1
Percophididae	9	*Anthias* sp.	<1
Carangidae	8	Labridae	<1
Octopoda	6	Reptantia	<1
Tetraodontidae	6	Scorpaenidae	<1
Cephalopods	4		

Note: N = total number, F = frequency of occurrence, V = aggregate total volume, IRI = index of relative importance

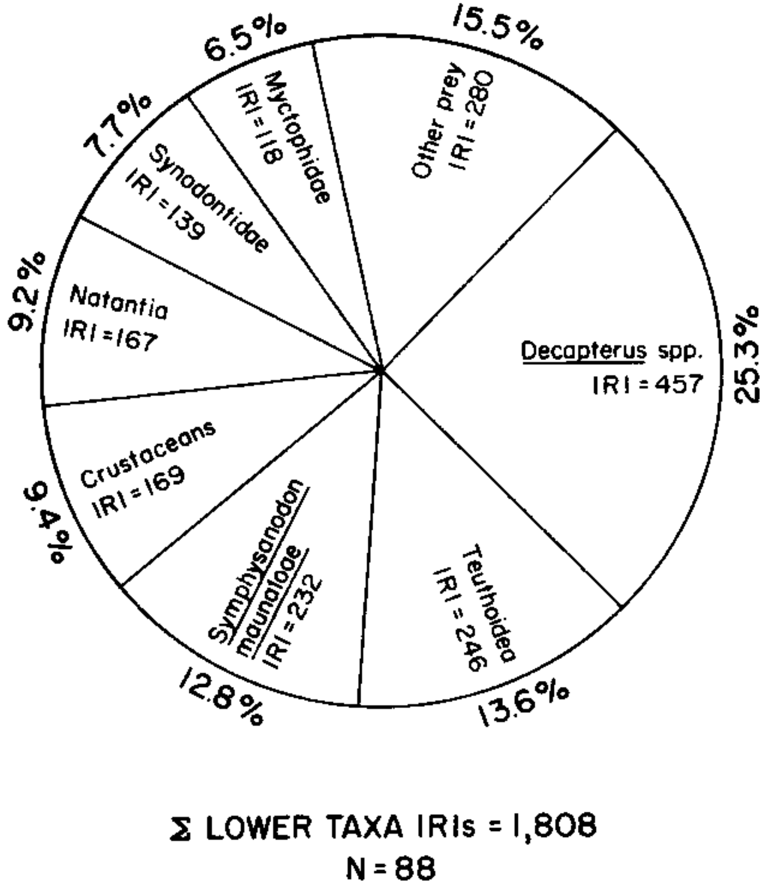

Figure 2. Relative contribution (percent of total IRI) of lower taxa prey in the diet of small CTC amberjack from the LMHI. Taxa of lesser prey are grouped together in the "other prey" category.

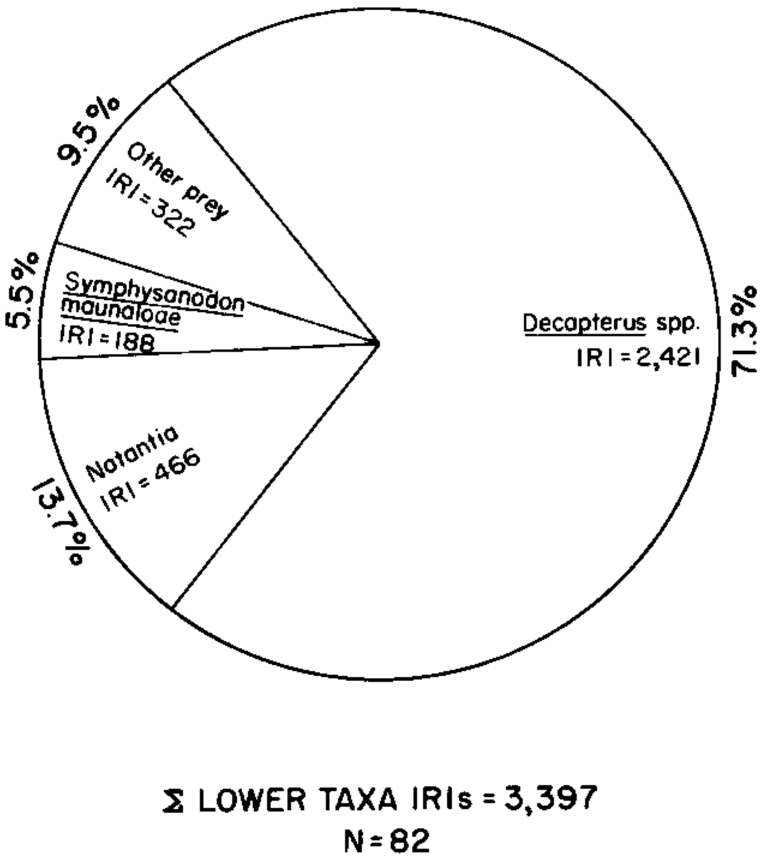

Figure 3. Relative contribution (percent of total IRI) of prey in the diet of small non-CTC amberjack from the LMHI. Taxa of lesser prey are grouped together in the "other prey" category.

TABLE 3. PREY ITEMS OF LARGE CTC AMBERJACK FROM THE LOWER MAIN HAWAIIN ISLANDS (N = 45) LISTED IN DECREASING IMPORTANCE BY TAXA. TAXA OF LESSER PREY (THOSE WITH IRI VALUES BELOW 100) ARE LISTED WITH THEIR RESPECTIVE IRI VALUES ONLY.

	%N	%F	%V	IRI
Taxa of prey				
Fishes	67.3	95.6	98.2	15,822
Cephalopods	29.0	26.7	1.4	812
Crustaceans	3.7	6.7	0.4	27
Major lower taxa prey				
Decapterus spp.	10.5	33.3	32.4	1,429
Teuthoidea	28.4	24.4	1.4	727
Myctophidae	13.0	13.3	0.3	177
Engraulidae	22.2	4.4	0.7	101
Taxa of lesser prey				
Carangidae	73	Natantia		8
Fish	46	Pleuronectiformes		6
Balistidae	37	*Ariomma* sp.		4
Auxis rochei	26	Caridea		3
Mullidae	23	Dactylopteridae		3
Pontinus macrocephala	22	*Auxis* sp.		2
Pristipomoides sieboldii	22	*Decapterus macrosoma*		2
Tetraodontidae	19	*Heterocarpus ensifer*		2
Bothidae	13	Scombridae		2
Auxis thazard	11	Gonostomatidae		1
Priacanthidae	10	Octopoda		1
Fistulariidae	9	Synodontidae		1

Note: N = total number, F = frequency of occurrence, V = aggregate total volume, IRI = index of relative importance

TABLE 4. PREY ITEMS OF LARGE NON-CTC AMBERJACK FROM THE LOWER MAIN HAWAIIAN ISLANDS (N = 53) LISTED IN DECREASING IMPORTANCE BY TAXA. TAXA OF LESSER PREY (THOSE WITH IRI VALUES BELOW 100) ARE LISTED WITH THEIR RESPECTIVE IRI VALUES ONLY.

	%N	%F	%V	IRI
Taxa of prey				
Fishes	59.4	86.8	98.8	13,732
Crustaceans	33.5	20.8	0.5	707
Cephalopods	7.1	11.3	0.7	83
Major lower taxa prey				
Decapterus spp.	14.7	35.8	38.2	1,894
Auxis thazard	2.4	5.7	18.4	119
Taxa of lesser prey				
Lutjanidae	54	Balistidae		5
Myctophidae	54	Caridea		5
Carangidae	52	*Decapterus macrosoma*		5
Natantia	48	*Ariomma* sp.		4
Selar crumenophthalmus	41	Fistulariidae		4
Teuthoidea	41	Tetraodontidae		4
Fish	35	Cephalopods		3
Auxis sp.	32	Polymixiidae		2
Crustaceans	32	*Symphysanodon typus*		2
Reptantia	32	Synodontidae		2
Symphysanodon maunaloae	28	Labridae		1
Heterocarpus ensifer	24	Penaeidea		1
Moridae	10	Amphipoda		< 1
Pristipomoides sieboldii	10	Octopoda		< 1
Scorpaenidae	9	Paralepididae		< 1
Lutjanus sp.	8	*Squilla* sp.		< 1
Pristipomoides sp.	8	Triglidae		< 1
Scombridae	6			

Note: N = total number, F = frequency of occurrence, V = aggregate total volume, IRI = index of relative importance

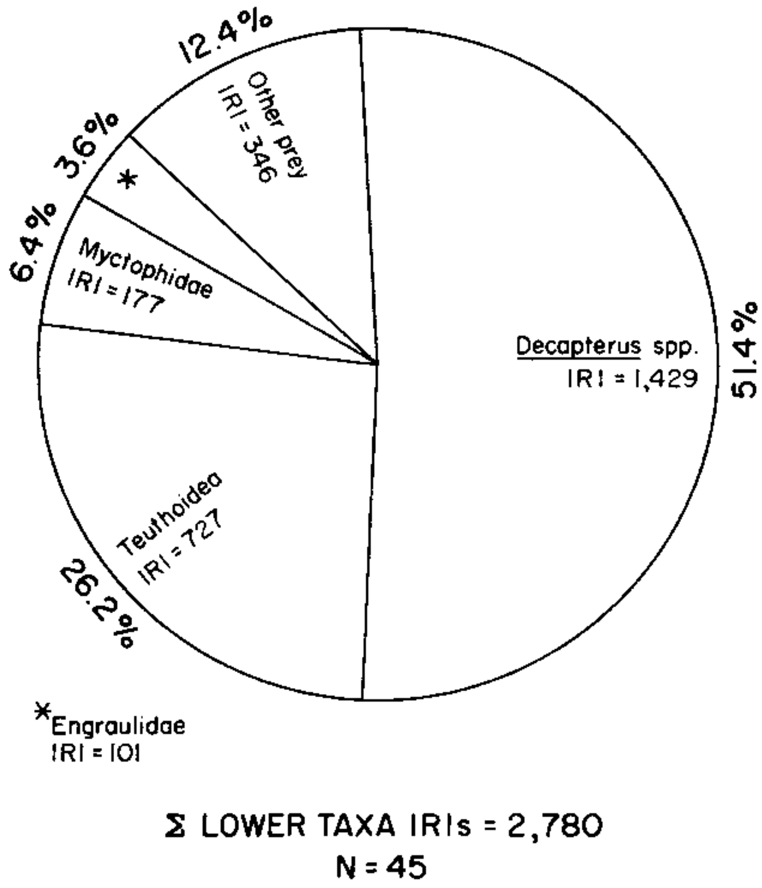

Figure 4. Relative contribution (percent of total IRI) of prey in the diet of large CTC amberjack from the LMHI. Taxa of lesser prey are grouped together in the "other prey" category.

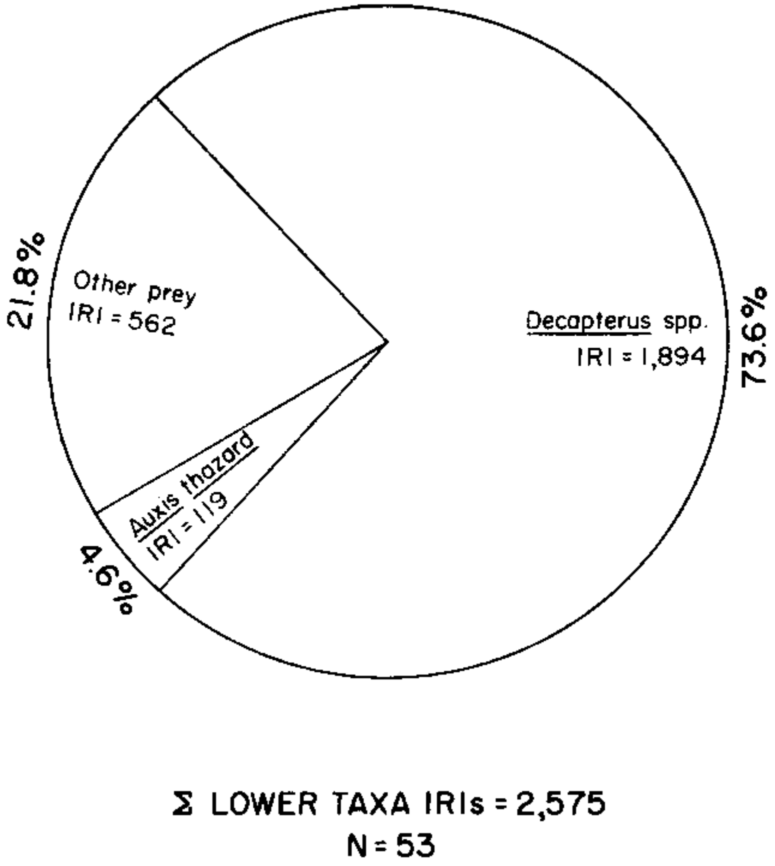

Figure 5. Relative contribution (percent of total IRI) of prey in the diet of large non-CTC amberjack from the LMHI. Taxa of lesser prey are grouped together in the "other prey" category.

The predominance of Decapterus spp. were similar, in terms of percentage of total IRI (Figures 3 and 5), in small and large fish of the non-CTC group. Although Decapterus spp. ranked highest in both weight classes of the CTC group, its percentage of total IRI among large amberjack was twice that found among the small amberjack (Figures 2 and 4). Additionally, Teuthoidea and Myctophidae appeared to be major food items in both weight classes of the CTC group, but were not present as such in either of the weight classes of the non- CTC group.

Classification of prey into ecological habitats revealed that small CTC amberjack fed more on bottom prey and midwater prey was secondary in importance (Table 5, Figure 6). The reverse situation was true among the small non-CTC amberjack (Figure 7, Table 6).

Large amberjack of both groups showed an increase in water column-associated prey and a decrease in bottom prey (Figures 8 and 9, Tables 7 and 8) compared with small amberjack (Figures 6 and 7, Tables 5 and 6), particularly within the CTC group. The small CTC amberjack were unique in having higher contributions of bottom prey than midwater prey in their diet.

The parasites found most frequently among the stomach contents of CTC and non-CTC amberjack were nematodes and trematodes. The nematode-trematode ratio ranged from 2 to 3:1 in both weight classes of the CTC and non-CTC groups.

The diet of non-CTC amberjack was compared between fish from the NWHI and the LMHI. For small amberjack in both areas, fish were the predominant class taxon and minor contributions were made by crustaceans and cephalopods (Tables 2 and 9). In the NWHI, Octopoda dominated among lower taxa (IRI = 572) followed by Decapterus spp. (IRI = 180), Natantia (IRI = 159), and Ammodytidae (IRI = 109) (Figure 10, Table 9). In contrast, the LMHI samples exhibited a great predominance of Decapterus spp. followed by Natantia and S. maunaloae (Figure 3, Table 2).

The most important class taxon among large amberjack in both areas was fish and less important were crustaceans and cephalopods (Tables 4 and 10). In the NWHI, D. tabl (IRI = 660) was the highest ranked lower taxon followed by Teuthoidea (IRI = 375), Decapterus spp. (IRI = 235), Balistidae (IRI = 167), fish (IRI = 164), and Tetraodontidae (IRI = 141) (Figure 11, Table 10). This contrasts with the high predominance of Decapterus spp. followed by A. thazard in the LMHI (Figure 5, Table 4).

In the NWHI Octopoda predominated among the small size class whereas D. tabl dominated in the large class, while in the LMHI, Decapterus spp. dominated among both weight classes.

TABLE 5. PREY ITEMS OF SMALL CTC AMBERJACK FROM THE LOWER MAIN HAWAIIAN ISLANDS (N = 84) GROUPED BY ECOLOGICAL HABITAT (BOTTOM, MIDWATER, AND BOTH) SHOWING THE DIETARY CONTRIBUTION (IRI) OF EACH HABITAT

Primarily bottom prey

Ammodytidae
Anguilliformes
Anthias sp.
Antigonia steindachneri
Balistidae
Bleekeria gilli
Chaetodontidae
Congridae
Dactylopteridae
Embolichthys sp.
Emmelichthyidae
Gobiidae
Grammatonotus laysanus
Labridae
Lutjanidae
Munida sp.
Octopoda
Paguridae
Penaeidea
Percophididae
Pleuronectiformes
Pomacentridae
Pontinus macrocephala
Portunidae
Priacanthidae
Pristipomoides sp.
Reptantia
Scorpaenidae
Serranidae
Symphysanodon maunaloae
Symphysanodon typus
Synodontidae
Xanthichthys mento

%N	%F	%V	IRI
36.6	61.9	49.4	5,323

Primarily midwater prey

Auxis thazard
Decapterus spp.
Engraulidae
Myctophidae
Teuthoidea

%N	%F	%V	IRI
28.4	44.0	40.5	3,032

Prey primarily associated with both habitats

Caridea
Heterocarpus ensifer
Plesionika longirostris
Plesionika sp.
Mullidae
Natantia
Selar crumenophthalmus
Sphyraenidae
Tetraodontidae

%N	%F	%V	IRI
35.1	19.0	10.1	859

Omitted prey

Carangidae
Cephalopods
Crustaceans
Fish

Note: N = total number, F = frequency of occurrence, V = aggregate total volume, IRI = index of relative importance

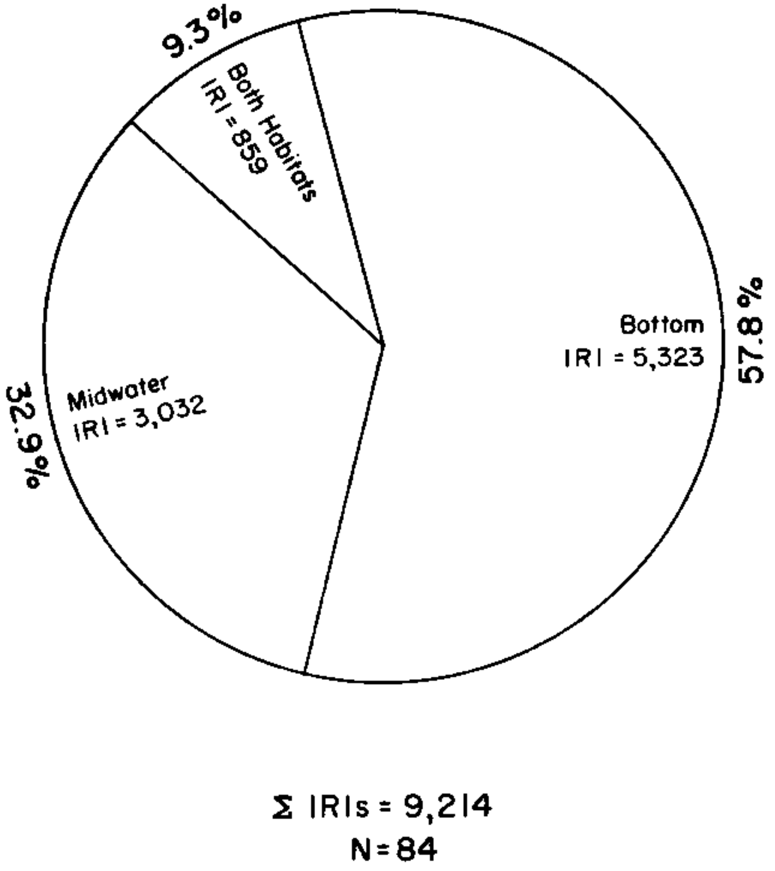

Figure 6. Relative contribution (percent of total IRI) of the three prey habitat types in the diet of small CTC amberjack from the LMHI

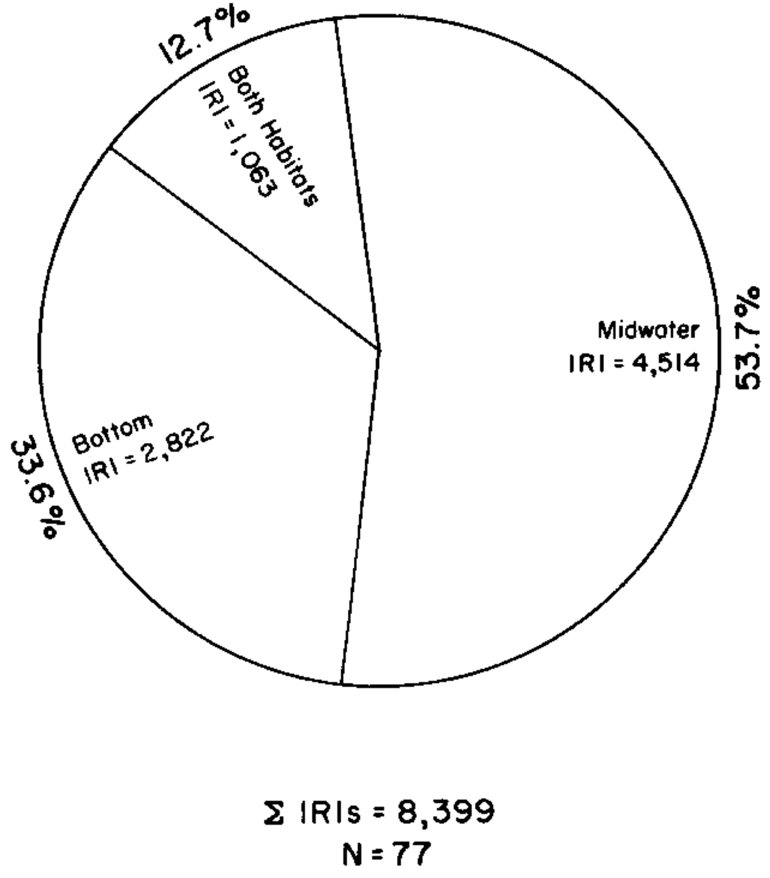

Figure 7. Relative contribution (percent of total IRI) of the three prey habitat types in the diet of small non-CTC amberjack from the LMHI

TABLE 6. PREY ITEMS OF SMALL NON-CTC AMBERJACK FROM THE LOWER MAIN HAWAIIAN ISLANDS (N = 77) GROUPED BY ECOLOGICAL HABITAT (BOTTOM, MIDWATER, AND BOTH) SHOWING THE DIETARY CONTRIBUTION (IRI) OF EACH HABITAT

Primarily bottom prey

- *Anthias* sp.
- Bothidae
- Caproidae
- Emmelichthyidae
- *Etelis coruscans*
- Labridae
- Lutjanidae
- Octopoda
- Percophididae
- Priacanthidae
- *Pristipomoides* sp.
- Reptantia
- Scorpaenidae
- *Scorpaenopsis* sp.
- Serranidae
- *Symphysanodon maunaloae*
- *Symphysanodon* sp.
- *Symphysanodon typus*
- Synodontidae

%N	%F	%V	IRI
39.3	48.0	19.5	2,822

Primarily midwater prey

- *Decapterus macrosoma*
- *Decapterus* spp.
- Engraulidae
- Myctophidae
- Teuthoidea

%N	%F	%V	IRI
15.9	52.0	70.9	4,514

Prey primarily associated with both habitats

- Caridea
- *Heterocarpus ensifer*
- Mullidae
- Natantia
- *Selar crumenophthalmus*
- Tetraodontidae

%N	%F	%V	IRI
44.9	19.5	9.6	1,063

Omitted prey

- Carangidae
- Cephalopods
- Crustaceans
- Fish

Note: N = total number, F = frequency of occurrence, V = aggregate total volume, IRI = index of relative importance

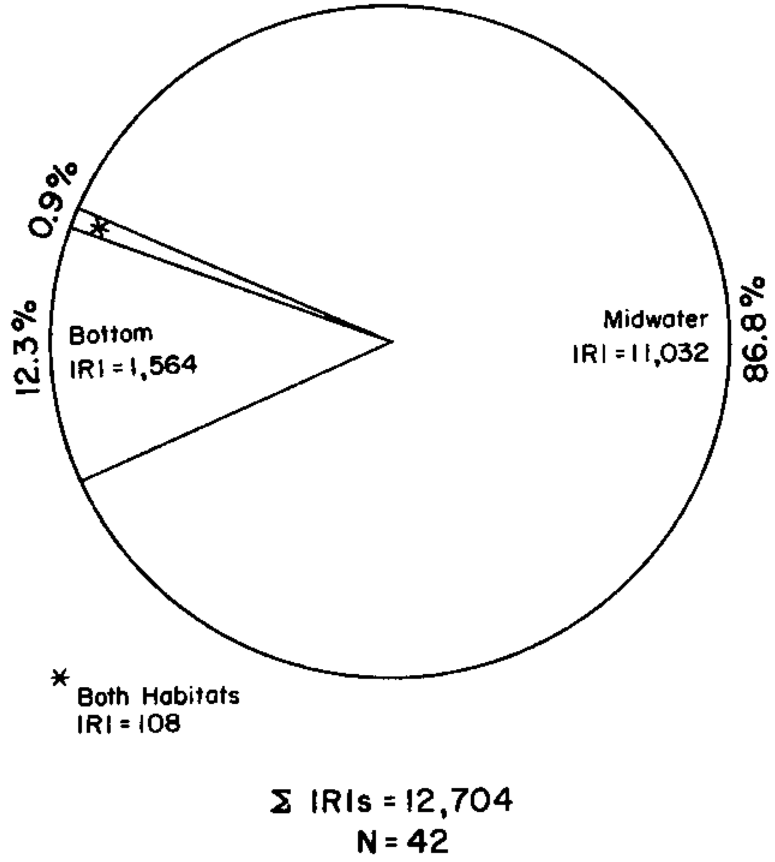

Figure 8. Relative contribution (percent of total IRI) of the three prey habitat types in the diet of large CTC amberjack from the LMHI

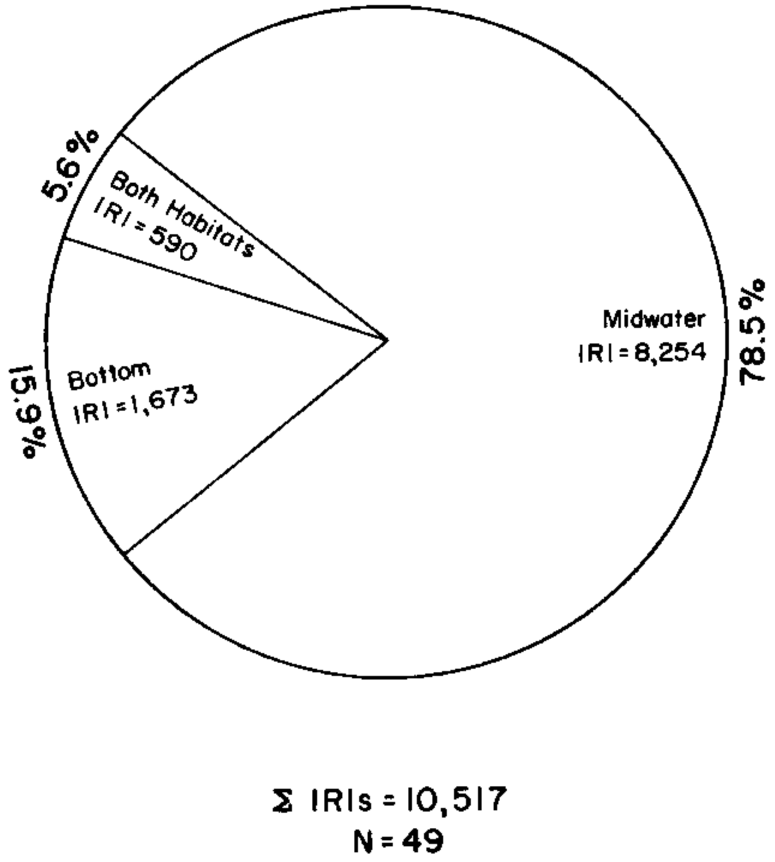

Figure 9. Relative contribution (percent of total IRI) of the three prey habitat types in the diet of large non-CTC amberjack from the LMHI

TABLE 7. PREY ITEMS OF LARGE CTC AMBERJACK FROM THE LOWER MAIN HAWAIIAN ISLANDS (N = 42) GROUPED BY ECOLOGICAL HABITAT (BOTTOM, MIDWATER, AND BOTH) SHOWING THE DIETARY CONTRIBUTION (IRI) OF EACH HABITAT

	Prey items	%N	%F	%V	IRI
Primarily bottom prey	Balistidae Bothidae Dactylopteridae Fistulariidae Mullidae Octopoda Pleuronectiformes *Pontinus macrocephala* Priacanthidae *Pristipomoides sieboldii* Synodontidae	9.9	28.6	44.8	1,564
Primarily midwater prey	*Ariomma* sp. *Auxis rochei* *Auxis* sp. *Auxis thazard* *Decapterus macrosoma* *Decapterus* spp. Engraulidae Gonostomatidae Myctophidae Scombridae Teuthoidea	84.2	81.0	52.0	11,032
Prey primarily associated with both habitats	Caridea *Heterocarpus ensifer* Natantia Tetraodontidae	5.9	11.9	3.2	108
Omitted prey	Carangidae Fish				

Note: N = total number, F = frequency of occurrence, V = aggregate total volume, IRI = index of relative importance

TABLE 8. PREY ITEMS OF LARGE NON-CTC AMBERJACK FROM THE LOWER MAIN HAWAIIAN ISLANDS (N = 49) GROUPED BY ECOLOGICAL HABITAT (BOTTOM, MIDWATER, AND BOTH) SHOWING THE DIETARY CONTRIBUTON (IRI) OF EACH HABITAT

Primarily bottom prey

Balistidae
Fistulariidae
Labridae
Lutjanidae
Lutjanus sp.
Moridae
Octopoda
Penaeidea
Polymixiidae
Pristipomoides sieboldii
Pristipomoides sp.
Reptantia
Scorpaenidae
Symphysanodon maunaloae
Symphysanodon typus
Synodontidae
Triglidae

%N	%F	%V	IRI
26.3	34.7	21.9	1,673

Primarily midwater prey

Amphipoda
Auxis sp.
Auxis thazard
Ariomma sp.
Decapterus macrosoma
Decapterus spp.
Myctophidae
Paralepididae
Scombridae
Squilla sp.
Teuthoidea

%N	%F	%V	IRI
43.4	71.4	72.2	8,254

Prey primarily associated with both habitats

Caridea
Heterocarpus ensifer
Natantia
Selar crumenophthalmus
Tetraodontidae

%N	%F	%V	IRI
30.3	16.3	5.9	590

Omitted prey

Carangidae
Cephalopods
Crustaceans
Fish

Note: N = total number, F = frequency of occurrence, V = aggregate total volume, IRI = index of relative importance

TABLE 9. PREY ITEMS OF SMALL NON-CTC AMBERJACK FROM THE NORTHWESTERN HAWAIIAN ISLANDS (N = 92) LISTED IN DECREASING IMPORTANCE BY TAXA. TAXA OF LESSER PREY (THOSE WITH IRI VALUES BELOW 100) ARE LISTED WITH THEIR RESPECTIVE IRI VALUES ONLY.

	%N	%F	%V	IRI
Taxa of prey				
Fishes	60.6	82.6	66.3	10,482
Cephalopods	8.7	25.0	31.1	995
Crustaceans	30.7	13.0	2.6	433
Major lower taxa prey				
Octopoda	4.9	16.3	30.2	572
Decapterus spp.	2.6	10.9	13.9	180
Natantia	27.6	5.4	1.9	159
Ammodytidae	11.2	7.6	3.2	109
Taxa of lesser prey				
Serranidae	81	Carangidae (jack)		2
Fish	73	*Scomber japonicus*		2
Teuthoidea	45	Fistulariidae		1
Anthias sp.	44	Mullidae		1
Emmelichthyidae	40	Ostraciontidae		1
Tetraodontidae	40	Penaeidea		1
Priacanthidae	36	Percophididae		1
Embolichthys sp.	25	Acanthuridae		<1
Pseudomonocanthus		Argentinidae		<1
garretti	18	*Bleekeria gilli*		<1
Symphysanodon		Bothidae		<1
maunaloae	17	Bramidae		<1
Congridae	16	Cephalopods		<1
Decapterus tabl	15	Dactylopteridae		<1
Crustaceans	11	Euphausiacea		<1
Ariomma sp.	6	Exocoetidae		<1
Synodontidae	6	Moridae		<1
Balistidae	4	Nomeidae		<1
Myctophidae	4	Pegasidae		<1
Pleuronectiformes	4	*Psenes* sp.		<1
Symphysanodon typus	4	Reptantia		<1
Anguilliformes	2	Scorpaenidae		<1
Aracana aculeata	2	Triglidae		<1
Caproidae	2	Zeidae		<1

Note: N = total number, F = frequency of occurrence, V = aggregate total volume, IRI = index of relative importance

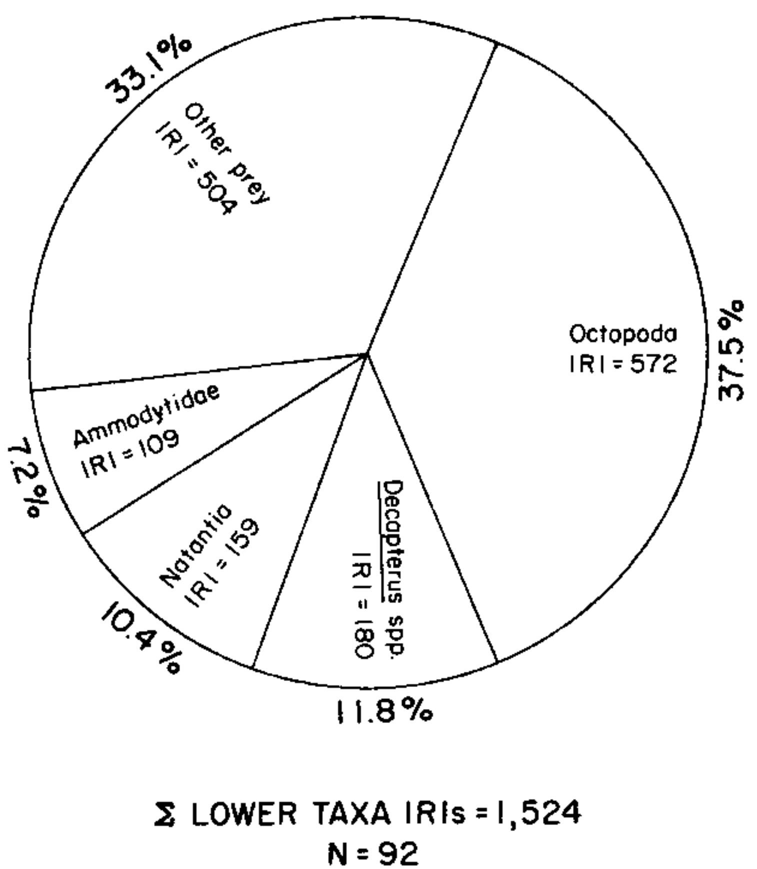

Figure 10. Relative contribution (percent of total IRI) of prey in the diet of small non-CTC amberjack from the NWHI. Taxa of lesser prey are grouped together in the "other prey" category.

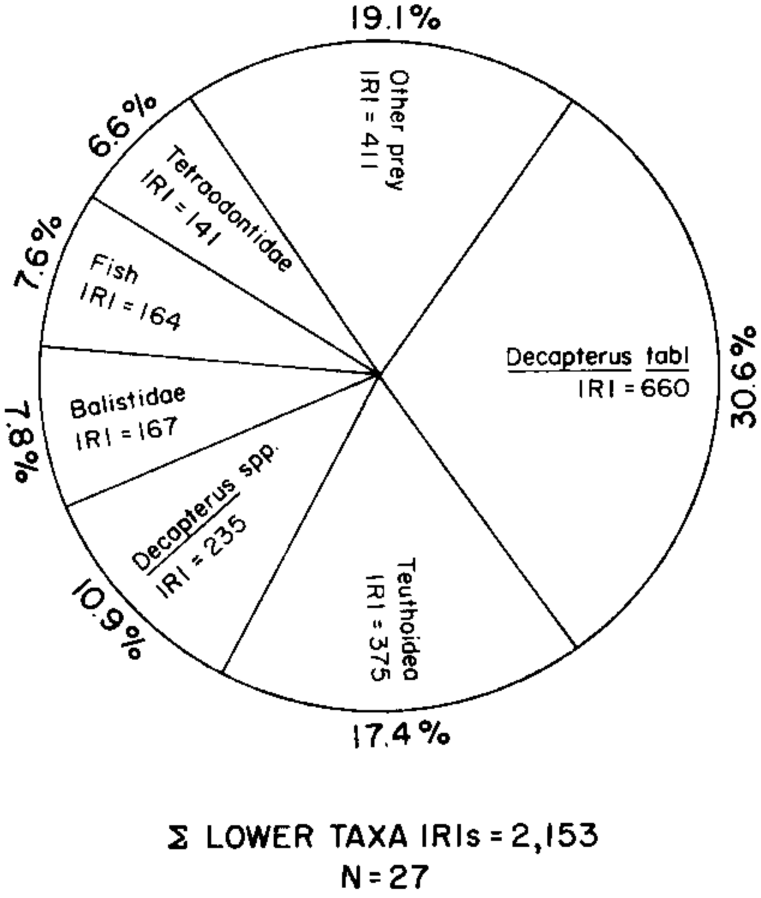

Figure 11. Relative contribution (percent of total IRI) of prey in the diet of large non-CTC amberjack from the NWHI. Taxa of lesser prey are grouped together in the "other prey" category.

TABLE 10. PREY ITEMS OF LARGE NON-CTC AMBERJACK FROM THE NORTHWESTERN HAWAIIAN ISLANDS (N = 27) LISTED IN DECREASING IMPORTANCE BY TAXA. TAXA OF LESSER PREY (THOSE WITH IRI VALUES BELOW 100) ARE LISTED WITH THEIR RESPECTIVE IRI VALUES ONLY.

	%N	%F	%V	IRI
Taxa of prey				
Fishes	58.2	77.8	96.2	12,012
Cephalopods	20.9	33.3	3.1	799
Crustaceans	20.9	18.5	0.7	400
Major lower taxa prey				
Decapterus tabl	9.9	14.8	34.7	660
Teuthoidea	16.5	22.2	0.4	375
Decapterus spp.	5.5	14.8	10.4	235
Balistidae	12.1	7.4	10.5	167
Fish	6.6	22.2	0.8	164
Tetraodontidae	3.3	11.1	9.4	164
Taxa of lesser prey				
Pseudomonocanthus garretti				82
Octopoda				79
Fistulariidae				75
Crustaceans				64
Reptantia				37
Muraenidae				14
Congridae				9
Mullidae				9
Symphysanodon maunaloae				8
Carangidae				5
Polymixiidae				5
Priacanthidae				5
Anguilliformes				4
Argentinidae				4
Natantia				4
Synodontidae				4

Note: N = total number, F = frequency of occurrence, V = aggregate total volume, IRI = index of relative importance

The results of habitat classification of prey revealed that among small NWHI amberjack, bottom-associated prey was most important (Table 11, Figure 12), whereas for small LMHI amberjack, the water column-associated prey dominated (Figure 7, Table 6). For large NWHI amberjack, bottom prey ranked higher than midwater prey (Figure 13, Table 12). However, the large LMHI amberjack showed a predominance of midwater prey (Figure 9, Table 8).

The dietary change from small to large amberjack in both areas involved an increase of midwater prey and a decrease in bottom prey.

Nematodes and trematodes were the most frequent gut parasites, regardless of weight class and area. The ratio of nematodes to trematodes for the NWHI sample ranged from 3 to 4:1 compared with 2 to 3:1 for the LMHI sample.

TABLE 11. PREY ITEMS OF SMALL NON-CTC AMBERJACK FROM THE NORTHWESTERN HAWAIIAN ISLANDS (N = 85) GROUPED BY ECOLOGICAL HABITAT (BOTTOM, MIDWATER, AND BOTH) SHOWING THE DIETARY CONTRIBUTION (IRI) OF EACH HABITAT

Primarily bottom prey

- Acanthuridae
- Ammodytidae
- Anguilliformes
- *Anthias* sp.
- *Aracana aculeata*
- Balistidae
- *Bleekeria gilli*
- Bothidae
- Caproidae
- Carangidae
- Congridae
- Dactylopteridae
- *Embolichthys* sp.
- Emmelichthyidae
- Fistulariidae
- Moridae
- Octopoda
- Ostraciontidae
- Pegasidae
- Penaeidea
- Percophididae
- Pleuronectiformes
- Priacanthidae
- *Pseudomonocanthus garretti*
- Reptantia
- *Scomber japonicus*
- Scorpaenidae
- Serranidae
- *Symphysanodon maunaloae*
- *Symphysanodon typus*
- Synodontidae
- Triglidae

%N	%F	%V	IRI
53.6	74.1	71.1	9,240

Primarily midwater prey

- Argentinidae
- *Ariomma* sp.
- Bramidae
- *Decapterus* spp.
- *Decapterus tabl*
- Exocoetidae
- Myctophidae
- Nomeidae
- *Psenes* sp.
- Teuthoidea

%N	%F	%V	IRI
9.3	36.5	23.2	1,186

Prey primarily associated with both habitats

- Euphausiacea
- Mullidae
- Natantia
- Tetraodontidae
- Zeidae

%N	%F	%V	IRI
37.1	14.1	5.7	603

Omitted prey

- Cephalopods
- Crustaceans
- Fish

Note: N = total number, F = frequency of occurrence, V = aggregate total volume, IRI = index of relative importance

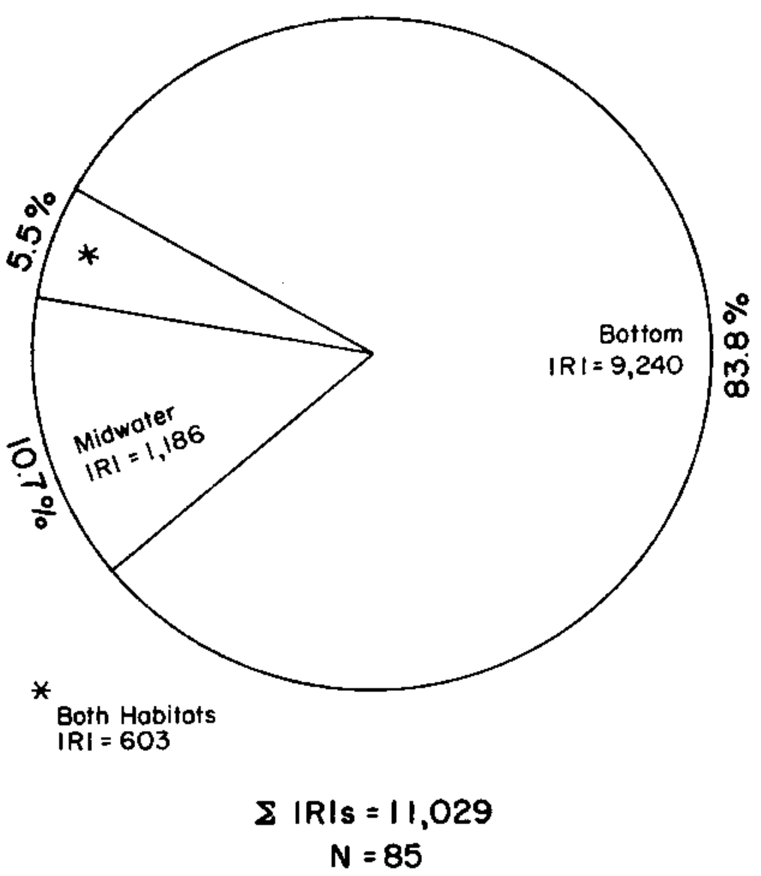

Figure 12. Relative contribution (percent of total IRI) of the three prey habitat types in the diet of small non-CTC amberjack from the NWHI

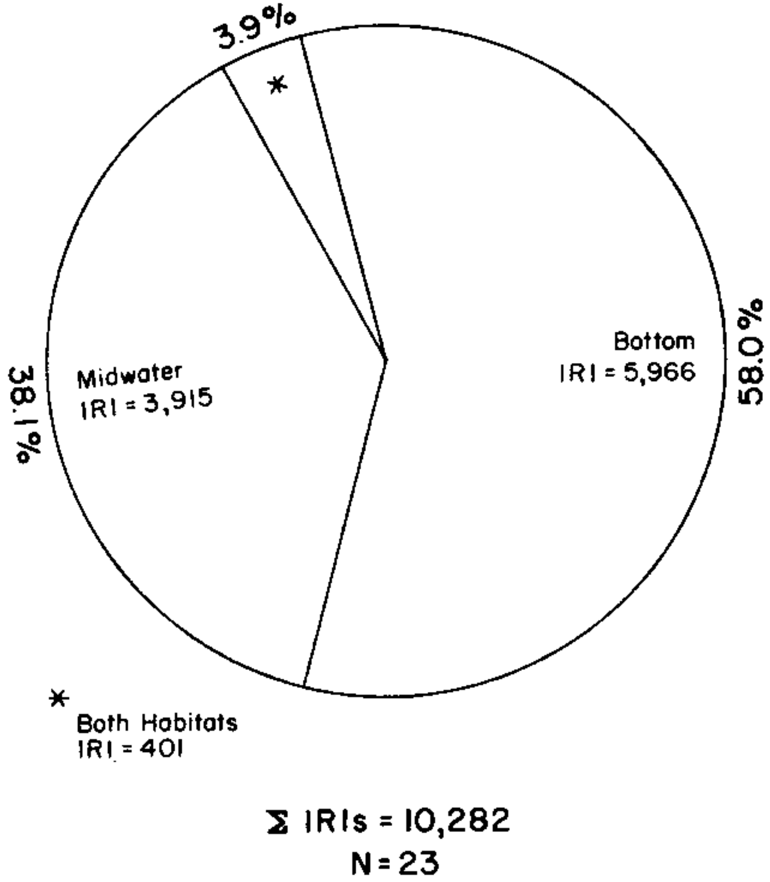

Figure 13. Relative contribution (percent of total IRI) of the three prey habitat types in the diet of large non-CTC amberjack from the NWHI

TABLE 12. PREY ITEMS OF LARGE NON-CTC AMBERJACK FROM THE NORTHWESTERN HAWAIIAN ISLANDS (N = 23) GROUPED BY ECOLOGICAL HABITAT (BOTTOM, MIDWATER, AND BOTH) SHOWING THE DIETARY CONTRIBUTION (IRI) OF EACH HABITAT

Primarily bottom prey

Anguilliformes
Balistidae
Congridae
Fistulariidae
Muraenidae
Octopoda
Polymixiidae
Priacanthidae
Pseudomonocanthus garretti
Reptantia
Symphysanodon maunaloae
Synodontidae

%N	%F	%V	IRI
47.8	65.2	43.7	5,966

Primarily midwater prey

Argentinidae
Decapterus spp.
Decapterus tabl
Teuthoidea

%N	%F	%V	IRI
43.5	43.5	46.5	3,915

Prey primarily associated with both habitats

Mullidae
Natantia
Tetraodontidae

%N	%F	%V	IRI
8.7	21.7	9.8	401

Omitted prey

Carangidae
Crustaceans
Fish

Note: N = total number, F = frequency of occurrence, V = aggregate total volume, IRI = index of relative importance

DISCUSSION

Decapterus spp. were the most important lower prey taxon in the diet of LMHI amberjack, regardless of their toxicity or size. *Decapterus* spp. were also the most important component among the midwater prey which dominated in the non-CTC and large CTC amberjack. Among small CTC amberjack, however, *Decapterus* spp. were less predominant and this was reflected in the higher contribution of bottom prey as opposed to midwater prey. Therefore, dietary differences between the small CTC amberjack and the other three groups are primarily reflected in the smaller contribution of *Decapterus* spp. in the former group. To help understand the dietary differences observed thus far in relation to whether

Decapterus spp. might be involved in the transmission of ciguatoxin, the following pertinent information is summarized.

The genus *Decapterus* is represented by four species within the Hawaiian Archipelago. *Decapterus macarellus* is the most abundant species in the LMHI but in the NWHI their abundance is unknown. In this paper this species is called *Decapterus* spp. because *D. macarellus* and *D. muroadsi* (an infrequent conspecific), are not readily distinguishable. The other two species, *D. macrosoma* and *D. tabl*, are easily distinguishable from each other as well as from *Decapterus* spp.

A life history study by Yamaguchi (1953) characterized *D. macarellus* as usually inhabiting the middle and upper layers of the neritic zone, although at times being found in shallow water and far out at sea. Yamaguchi concluded that *D. macarellus* fed on zooplankton, primarily crustaceans. Dietary studies on other members of the genus, including *D. tabl*, showed them to be primarily planktivorous (Tiews et al., 1970). This feeding mode among members of *Decapterus* indicates little interaction with benthic fauna. Assuming that ciguatoxin has a benthic origin in the LMHI, similar to what Yasumoto et al. (1977a, 1977b) found in French Polynesia, *Decapterus* appears to be an unlikely intermediary for ciguatoxin transmission through the food chain. Additionally, *Decapterus* is a popular food fish in Hawaii, yet Kubota (1981) found no instances of it being implicated among reported ciguatera poisoning cases from 1900 to December 1980. From this background information, several hypotheses have been developed to explain the dietary patterns found among the four groups investigated in the LMHI.

For amberjack, a temporal and spatial change of available prey would prevail when *Decapterus* is absent or scarce. In this situation the most abundant prey would then be bottom forms because *Decapterus* appears to be the only abundant midwater prey in the diet. If this switch to feeding on bottom prey coincided with ciguatoxicity among the local reef fauna, the link in the transmission of ciguatoxin would be completed. This chain of events would explain the lower *Decapterus*, higher bottom prey tendencies that occur in the small CTC amberjack. It is also assumed that large CTC and non-CTC amberjack possess increased mobility and speed, thus enhancing their ability to capture and consume larger and faster midwater prey. This is evident by the large amounts of *Decapterus* and the occurrence of *Auxis* in their diet. Hence, large amberjack are probably less apt to feed on bottom prey if midwater prey are readily available. Kimura et al. (1981) found that large amberjack had the same incidence of ciguatoxicity as small ones for the LMHI and NWHI areas combined. Thus ciguatoxin appears more likely to be transmitted to small rather than large amberjack. Ciguatoxicity in large amberjack is likely attributable to the retention of ciguatoxin from an earlier exposure. Although ciguatoxin retention in kahala has not been investigated, Banner et al. (1966) did conduct such a study on the reef carnivore, *Lutjanus bohar*, from Christmas

Island. Results indicated that no statistically detectable losses in toxicity occurred among a group of L. bohar held in captivity at Coconut Island, Oahu, Hawaii for up to 30 months. Banner et al. did qualify their results, however, by suggesting that the toxicity level in some ciguatoxic fish may gradually diminish over time.

These hypotheses, however, appear to be contradicted by the NWHI amberjack. The diet of small non-CTC amberjack in the NWHI contains more bottom prey than that of the small CTC amberjack in the LMHI. With greater feeding of amberjack on bottom prey, the incidence of ciguatoxicity among amberjack in the NWHI would be expected to be higher than the toxicity rate determined for the LMHI fish. However, Polovina and Ito (1981) found no apparent relationship between incidence of toxicity and area. It therefore appears plausible, as shown by Yasumoto et al. (1979) in the overall higher population counts of G. toxicus at Gambier Islands compared with Tahiti, that the NWHI offer less suitable conditions for ciguatoxin outbreaks than the LMHI. If this situation is true, then the increased utilization of bottom prey by NWHI amberjack would not necessarily cause a greater incidence of ciguatoxicity when compared with the LMHI. Still unaccounted for is the reason for the increase in bottom prey in both weight groups in the NWHI, when Decapterus is known to occur there, perhaps in great abundance. The high occurrence of Octopoda in the diet of the small NWHI amberjack is the only instance of a lower prey taxon exceeding Decapterus spp. and D. tabl in percentage of total IRI. By comparison, Octopoda in all four groups in the LMHI is consistently negligible. It thus appears plausible that sufficient readily available bottom prey exists within the NWHI such that midwater prey, namely Decapterus, are fed upon less often by the small amberjack. Even so, the trend toward increased midwater prey in the diet as the amberjack grows larger in the LMHI is also evident in the NWHI, although to a lesser degree. This trend apparently indicates that the large NWHI amberjack are increasingly capable of consuming the swifter and frequently larger midwater prey, a situation more strongly indicated by their weight class counterparts in the LMHI.

CONCLUSIONS

Data presented in this report support the hypothesis that small amberjack in the LMHI are more susceptible to becoming ciguatoxic when feeding preference shifts away from Decapterus to bottom prey. Since large amberjack feed more on Decapterus, the occurrence of large CTC amberjack is mainly attributed to ciguatoxin's long retention time. The data also suggest that a more readily available bottom prey fauna exists in the NWHI and that conditions for CTC outbreaks are less than optimal there compared with the LMHI. Tests of these hypotheses should address the following: determination of ciguatoxicity in Decapterus and bottom prey species over time and area; diet of CTC amberjack from the NWHI; retention time of ciguatoxin in amberjack; confirmation of a solely benthic mode of ciguatera origin and, if so, the determination of population abundance of the ciguatoxin-producing agent in the NWHI and LMHI.

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FOOD AND ENERGETIC REQUIREMENTS OF SEABIRDS AT FRENCH FRIGATE SHOALS, HAWAII

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ABSTRACT

A time-and-energy model for the energetic requirements of 18 species of seabirds at French Frigate Shoals in the Northwestern Hawaiian Islands (NWHI) is presented. Estimates of the energy needs for producing eggs and chicks, and the time-and-energy budgets of breeding and non-breeding adults are used to evaluate consumptive rates of various prey species. The caloric density of prey species and the caloric contribution to the diet of each seabird is analyzed. A conservative estimate for the total annual energetic requirements of more than 500,000 seabirds breeding and/or residing at French Frigate Shoals exceeds 7,700 kcal x 10^6. This energetic demand is met by a consumption of more than 6,000 metric tons of various food items.

seabirds
energetic requirements
food consumption

INTRODUCTION

This report is a summary of a quantitative model of energetic requirements for Hawaiian seabirds at French Frigate Shoals in the NWHI. The ultimate objective is to determine the amount of food consumed by 18 species of seabirds breeding and/or residing at French Frigate Shoals. Since this cannot be measured directly, the energy requirements of the total seabird population are estimated and the amount of food needed to supply that energy is then calculated. The caloric content of major prey species has been determined to evaluate total consumptive needs.

Energy requirements are of special interest because they provide information on the energy flow through the avian component of the ecosystem. The energy expenditures incurred for adult daily existence metabolism and activities related to breeding, the production of eggs, and raising young to fledging are considered. A modeling approach to explore seabird bioenergetics and patterns of prey consumption in the NWHI is useful to assess the impact of seabirds upon the marine ecosystem. A numerical estimate of the amount of food that Hawaiian seabirds are taking out of the ocean, in relation to the local oceanic food resources, should be useful in management of bird colonies and consideration of human fisheries in the NWHI (see paper in this proceedings by Fefer et al.).

METHODS

Egg Production Requirements

The energetic costs of egg production are assessed as the mean total caloric content (Pettit, Whittow, and Grant, in press) multiplied by the reciprocal of egg production efficiency (77 percent, Brody, 1945). The masked booby and brown booby generally produce a clutch of two eggs while other Hawaiian seabirds produce a single egg. This model assumes a breeding pair produces one clutch per year.

Chick Energy Requirements

Chick daily energy requirements are obtained from $M = 1.353 W^{.8140}$ (Kendeigh et al., 1977) where M = metabolic requirement in $\text{kcal}\cdot\text{day}^{-1}$ and W = mass in g. Chick masses are input as growth equations fitted according to the method of Ricklefs (1967) or generated by a non-linear regression computer technique (Pettit, Simond, and Whittow, unpublished manuscript). Numbers of fledgling chicks were obtained by applying the highest observed reproductive success (percent egg hatched x percent chicks fledged) for that species in the NWHI (FWS, unpublished report).

Adult Energy Requirements

Annual energy requirements of 18 species are estimated using a bioenergetics model. Existence energy requirements of adult birds are estimated by applying the bioenergetics equation for non-passerines in 15-hour photoperiods (Kendeigh et al., 1977) and interpolating linearly between the value at 0°C ($M = 4.142 W^{.5444}$) and 30°C ($M = 1.068 W^{.6637}$) where M = metabolic requirements in $\text{kcal}\cdot\text{day}^{-1}$; W = mass in g. Although existence metabolism refers, by definition, to the existence energy requirements of caged birds (Kendeigh et al., 1977), it is felt that the island-based activities of seabirds at French Frigate Shoals are reasonably close to their existence metabolism. The energy cost of flight activities are computed separately and they refer mainly to gliding flight over the ocean. Total energy requirements for island-based activites are based upon the number of days present at French Frigate Shoals and the average monthly ambient temperature. Mean ambient temperatures were determined from daily minimum and maximum air temperature data for Tern Island, French Frigate Shoals collected by U.S. Fish and Wildlife Service (FWS) personnel (Honolulu). Average monthly temperatures ranged from 21°C to 27°C. Estimation of at-sea existence energy requirements are based upon the metabolic requirements for foraging flight (Furness and Cooper, 1982; Flint and Nagy, 1982). Time spent at sea is considered to be primarily gliding flight and increases the metabolic requirement by $M = 0.5232\ W^{.7347}$ $\mathrm{kcal \cdot day^{-1}}$ over daily existence requirements. Numbers of breeding and non-breeding adults were obtained from colony counts provided by the FWS. Other breeding statistics were taken from published literature or unpublished data (FWS; Pettit and Whittow; Pettit, Grant, and Whittow).

The deposition of fat is not considered here because it does not occur to any great extent. Molting production costs are also ignored since molting is spread out over the entire year in many species and thus, estimation of daily existence energy requirements reflects some minimal daily cost of molting.

Caloric Content of Prey Species and Consumptive Rates

The caloric content of food items was determined on fresh fish and squid collected by National Marine Fisheries Service personnel (Honolulu), in areas adjacent to NWHI. Samples were identified and immediately frozen until caloric analysis. After thawing, the sample was homogenized and dried to a constant weight at 45°C to determine water content. The sample was then pulverized and the caloric content of approximately 10 mg samples was determined with a Phillipson microbomb calorimeter. Ash content was measured by burning 0.5 g samples at 600°C for at least 6 hours. Values from the literature were used to determine caloric content of prey species unavailable for laboratory measurements.

Consumptive rates of various prey species were determined from the total annual energy requirement for each species of seabird, multiplied by 1.25 to account for digestive losses and assimilation efficiency. The average percent composition of each prey item in the total dietary intake (Harrison et al., 1983) was used to determine the caloric contribution of each order or family prey species to the overall consumptive rate of each seabird per year. This report is a summary of the dietary contribution of the major food items comprising at least 75 percent of the diet of each species of seabird. The percent volume composition of each prey species in the diet (Harrison et al., 1983) has been converted to percent wet weight based on the assumption that most prey items have a neutral buoyancy in fresh water; thus, volume (cc) equals mass (g). The caloric density of each prey item ($kcal \cdot g^{-1}$ wet) was then applied to determine the caloric contribution (percent) of the food to the diet.

Model Input

Table 1 presents the mean fresh caloric density of most food items consumed by seabirds at French Frigate Shoals. All of the major prey taxa have been analyzed. Estimates of caloric content are also provided for food items of lesser importance.

Tables 2 to 4 present species, populations of breeders and non-breeders, time spent at French Frigate Shoals, time spent at sea, number of eggs produced, number of chicks fledged, and associated energy requirements for the three represented orders of seabirds.

Table 5 presents the mean adult mass, mean egg mass, mean incubation period, and mean egg laying date for each species. Chick growth input data (growth equation and nestling period) are presented in Table 6.

RESULTS AND DISCUSSION

Energy Requirements

The total energy requirements for each species may be derived from data presented in Tables 2 to 6. The total projection of energy flow through the seabird population may be expressed algebraically as:

$$E_T = 1.25\ (E_E + E_C + E_L + E_S)$$

where

E_T = total energy consumed (kcal)
E_E = energy content of an average egg (kcal) x cost of synthesis x number of eggs.
E_C = gross energy for development of chick (kcal) x number of chicks
E_L = adult island-based energy expenditure (kcal)
E_S = adult at-sea energy expenditure (kcal)
1.25 = constant which corrects for assimilation efficiency (80 percent of caloric intake)

A summary of calculated energy requirements for breeders and non-breeders is presented in Table 7. The total annual energy needs of seabirds at French Frigate Shoals is approximately 7,700 kcal x 10^6. While the sooty storm petrel and blue-grey noddy contribute to the overall energy demands, their populations are very small and they have not been assessed accurately, and thus no attempt is made to quantify the energetic need of these two species.

TABLE 1. WATER, ASH AND CALORIC CONTENT OF PREY SPECIES CONSUMED BY HAWAIIAN SEABIRDS

Food Item	Water Content (%)	Ash Content (%)	Caloric Content (kcal per g.)	Reference*
FISH				
Ammodytidae sp.	75.0	13.7	.86	1
Antherinidae sp.	75.0	--	.75	1
Balistidae sp.	78.6	--	.81	1
Belonidae sp.	78.0	--	.84	1
Blenniidae sp.	76.5-79.0	--	1.13-0.81	1
Bramidae				
Pteraclis velifer	59.7	10.4	1.88	2
Carangidae				
Decapturus sp.	76.0	17.1	.82	1
D. macarellus	76.0	17.0	1.16	1
Seriola sp.	75.0	28.0	.65	1
Caranx sp.	76.0	17.0	.94	1
C. crumenopthalmus	77.2	--	.76	3
Chaetodontidae sp.	78.0	--	.86	1
Congridae	71.3	--	1.70	1
Coryphaenidae				
Coryphaena sp.	68.8	18.3	1.25	2
Engraulidae sp.	75.2	14.2	1.06	1
Exocoetidae				
Exocoetus sp.	75.3	11.0	1.00	1
E. monocirrhus	75.2	10.8	1.22	2
E. sp. ova	46.0	2.87	3.257	2
Cypselurus speculiger	70.7	12.1	1.46	2
C. spilonotopterus	70.4	12.8	1.45	2
C. oligolepsis	77.5	--	.91	3
Gemplidae				
Gempylus serpens	59.1	15.9	1.91	2
Gobbidae sp.	79.2	--	.85	1
Hemiramphidae sp.	76.0-78.0	11.0-19.0	.83-.90	1
Holocentridae				
Myripristis kuntee	65.8	26.4	1.53	2
Istiophoridae				
Istiophorus platypterus	75.1	--	1.01	1
Makaira nigricans	73.0	--	1.21	1
Kyphosidae sp.	79.1	--	.86	1
Labridae sp.	77.1	--	.92	1
Monocanthidae				
Pervagor spilosoma	53.8	20.4	2.24	2
Mugilidae				
Mugil valgiensis	77.8	--	.94	3
Mullidae sp.	78.8	--	.92	3
Myctophidae				
Benthosoma fibulatum	70.1	16.6-19.4	1.54	2
Myctophum sp.	66.1	14.5	2.16	4
Myctophum selecnoides	65.2	17.9	1.78	2
Ostraciontidae				
Lactoria fornasini	44.4	19.4	2.54	2
Pomacentridae				
Chromis sp.	75.0	--	1.00	1
Scomberesocidae				
Cololabis saira	66.8	--	1.82	1
Scombridae				
Katsuwonus pelamis	68.7	15.8	1.51	2

*(1) Sidwell, 1981; (2) Pettit and Whittow, unpublished data; (3) Composition of Food, 1974; (4) Clarke and Prince, 1980.

TABLE 1. WATER, ASH AND CALORIC CONTENT OF PREY SPECIES CONSUMED BY HAWAIIAN SEABIRDS (continued)

Food Item	Water Content (%)	Ash Content (%)	Caloric Content (kcal per g.)	Reference
Serranidae sp.	78.8	--	.88	1
Soleidae sp.	80.0	11	.80-.90	1
Sphyraenidae sp.	78.0	--	1.06	1
Synodentidae				
Saurida tumbil	62.2	16.7	1.86	2
Trichiuridae sp.	65.8	18.8	1.55	2
Xiphiidae sp.	74.5	--	1.18	1
Xiphias gladius	75.5	--	1.18	3
Pleuronectoidei	78.8	--	.84	1
MOLLUSCA				
DECAPODA (SQUID)				
Ommastrephidae				
Ommastrephes sp.	78.0	9.0	.88	1
Symplectoteuthis sp.	76.2	8.8	1.15	2
roe	64.2	4.2	1.11	1
OCTOPODA sp.	82.3	--	.70	1
DECOPODA				
shrimp				
Pehaeidea sp.	78.0	14.1	.60	1
CRAB				
Brachyura sp.	75.0	10.0	.95	1
INSECTA				
Gerridae (water strider)				
Halobates sp.	60.0-65.0	4.2	2.19	2
Orthoptera (grasshopper)				
Locusta sp.	66.3	12.3	.81	3
STOMACH OIL				
Laysan albatross	--	--	8.3-12.6	2
Wedge-tailed shearwater	--	--	9.4	2

TABLE 2. ENERGETIC REQUIREMENTS OF PROCELLARIIFORMES AT FRENCH FRIGATE SHOALS

SPECIES	STATUS	POPU-LATION	E_L Island-Time Energy		E_S At-Sea-Time Energy		E_E Egg Energy		E_C Chick Energy	
			Time on Land (days) T_L	Energy Requirement (kcal·day^{-1}) EM_L	Time at Sea (days) T_S	Energy Requirement (kcal·day^{-1}) EM_S	Total Energy for Synthesis (kcal) E_{ES}	No. of Eggs	Gross Energy for Devel. (kcal) E_{CD}	No. of Chicks
Black-footed Albatross (Diomedea nigripes)	B	9,000	75	224.6	175	403.0	673.4	4,500	130,000	3,240
	NB	9,000	125	224.6	125	403.0	—	—	—	—
Laysan Albatross (D. immutabilis)	B	2,000	75	203.7	175	363.0	640.9	1,000	130,000	780
	NB	4,660	125	203.7	125	363.0	—	—	—	—
Wedge-tailed Shearwater (Puffinus pacificus)	B	3,500	75	64.4	125	106.3	148.2	1,750	15,700	1,400
	NB	6,790	100	64.4	100	106.3	—	—	—	—
Christmas Shearwater (Puffinus nativitatus)	B	40	75	60.8	135	100.0	131.3	20	13,870	12
	NB	50	105	60.8	105	100.0	—	—	—	—
Bonin Petrel (Pterodroma hypoleuca)	B	100	75	39.0	130	62.4	106.6	50	7,600	30
	NB	100	105	39.0	100	62.4	—	—	—	—
Bulwer's Petrel (Bulweria bulwerii)	B	1,000	65	23.3	150	38.6	52.0	500	3,700	300
	NB	1,000	110	23.3	105	38.6	—	—	—	—
Sooty Storm Petrel (Oceanodroma tristami)	B	+	65	21.7	95	35.3	39.0	+	3,200	+
	NB	+	80	21.7	80	35.3	—	—	—	—

Note: B = breeder
NB = non-breeder

TABLE 3. ENERGETIC REQUIREMENTS OF PELECANIIFORMES AT FRENCH FRIGATE SHOALS

			E_L ISLAND-TIME ENERGY		E_S AT SEA TIME ENERGY		E_E EGG ENERGY		E_C CHICK ENERGY	
SPECIES	STATES	POPULATION	Time on Land T_L (days)	Energy Req. EM_L ($kcal \cdot day^{-1}$)	Time at Sea T_S (days)	Energy Req. at Sea EM_S ($kcal \cdot day^{-1}$)	E_{ES} (kcal)	Number of Eggs	E_{CU} (kcal)	Number of Chicks
Red-tailed Tropic Bird (*Phaethon rubricauda*)	B	1,200	100	86.7	100	145.9	148.2	600	20,250	348
	NB	1,200	100	86.7	100	145.9	—	—	—	—
Masked Booby (*Sula dactylatra*)	B	1,200	200	190.5	165	337.9	184.6	600	66,200	384
	NB	400	185	190.5	180	337.9	—	—	—	—
Brown Booby (*Sula leucogaster*)	B	120	200	140.7	165	244.5	145.6	60	31,100	49
	NB	50	185	140.7	180	244.5	—	—	—	—
Red-footed Booby (*Sula sula*)	B	1,200	200	124.2	165	214.0	76.7	600	35,800	438
	NB	980	185	124.2	180	214.0	—	—	—	—
Great Frigatebird (*Fregata minor*)	B	750	200	147.3	165	256.7	171.6	375	80,800	135
	NB	1,670	185	147.3	180	256.7	—	—	—	—

TABLE 4. ENERGETIC REQUIREMENTS OF CHARADRIIFORMES AT FRENCH FRIGATE SHOALS

SPECIES	STATUS	POPULATION	E_L		E_S		E_E		E_C	
			T_L (days)	EM_L ($kcal \cdot day^{-1}$)	T_S (days)	EM_S ($kcal \cdot day^{-1}$)	E_{ES} (kcal)	Number of Eggs	E_{CD} (kcal)	Number of Chicks
Sooty Tern	B	156,000	65	42.0	85	67.5	92.3	78,000	5,000	31,200
(*Sterna fuscata*)	NB	265,600	75	42.0	75	68.5	—	—	—	—
Grey-backed Tern	B	2,000	65	34.7	85	55.2	62.4	1,000	5,500	530
(*Sterna lunata*)	NB	2,000	75	34.7	75	55.2	—	—	—	—
Blue-grey Noddy	B	+	200	18.4	165	27.0	26.0	+	900	+
(*Procelsterna Caerulea*)	NB	+	185	18.4	180	27.0	—	—	—	—
Brown Noddy	B	15,000	200	42.9	165	69.3	85.8	7,500	3,200	4,425
(*Anous stolidus*)	NB	12,270	185	42.9	180	69.3	—	—	—	—
Black Noddy	B	1,700	200	28.8	165	45.0	55.9	850	1,900	660
(*Anous tenuirostris*)	NB	2,890	185	28.8	180	45.0	—	—	—	—
White Tern	B	1,500	200	29.2	165	46.0	61.1	750	2,300	240
(*Gygis alba*)	NB	2,550	185	29.2	180	46.0	—	—	—	—

TABLE 5. SPECIES STATISTICS FOR MODEL INPUT

Species	Mean Adult Mass(g)	Mean Egg Mass(g)	Mean Egg Energy Content (kcal)	Maximum Egg Laying Period
Black-footed Albatross	2,800	305	518	Nov-Dec
Laysan Albatross	2,400	285	493	Nov-Dec
Wedge-tailed Shearwater	390	60	114	Jun-Jul
Christmas Shearwater	356	53	101	May-Jun
Bonin Petrel	176	40	82	Feb-Mar
Bulwer's Petrel	99	22	40	Jun-Jul
Sooty Storm Petrel	84	15*	30†	Jan-Feb
Red-tailed Tropicbird	624	70	114	Apr-May
Masked Booby	2,160	70	71 (142)§	Feb-Apr
Brown Booby	1,340	55	56 (112)§	Apr-May
Red-footed Booby	1,100	58	59	Jan-Jun
Great Frigatebird	1,440	89	132	Mar-May
Sooty Tern	198	37	71	Mar-Jun
Grey-backed Tern	146	28	48	Apr-May
Blue-grey Noddy	53	13*	20†	Mar-Apr
Brown Noddy	205	40	66	Apr-May
Black Noddy	108	25	43	Feb-Mar
White Tern	111	23	47	Mar-Apr

*Estimated from length x breadth measurements
†Estimated
§Caloric content of two-egg clutch

TABLE 6. GROWTH PARAMETERS OF HAWAIIAN SEABIRDS

Species	Growth Equation	Nestling Period (days)	Reference
Black-footed Albatross	$M_t = 3,100/1+e^{-.049(t-41.2)}$	140	Fisher, 1971
Laysan Albatross	$M_t = 3,100/1+e^{-.049(t-41.2)}$	170	Fisher, 1971
Wedge-tailed Shearwater	$M_t = [7.955(1-.595e^{-.043t})]$	102	Pettit et al., 1984
Christmas Shearwater	$M_t = [7.284(1-.593e^{-.055t})]$	105	M. Naughton, unpublished data
Bonin Petrel	$M_t = 250/1+e^{-.091(t-19.3)}$	85	Pettit et al., 1982
Bulwer's Petrel	$M_t = 125/1+e^{-.158(t-12.0)}$	63	M. Naughton, unpublished data
Sooty Storm Petrel	$M_t = 100/1+e^{-.108(t-22.5)}$	75	Boersma et al., 1980 (data for Fork-tailed Storm Petrel)
Red-tailed Tropicbird	$M_t = 800/1+e^{-.074(t-23.1)}$	85	Fleet, 1974
Masked Booby	$M_t = 2,300/1+e^{-.094(t-36.4)}$	119	Nelson, 1978
Brown Booby	$M_t = 1,300/1+e^{-.079(t-36.9)}$	98	Nelson, 1978
Red-footed Booby	$M_t = 1,250/1+e^{-.056(t-40.4)}$	105	Pettit and Whittow, unpublished
Great Frigatebird	$M_t = 1,725/1+e^{-.059(t-44.7)}$	180	A. Newman, unpublished
Sooty Tern	$M_t = 190/1+e^{-.099(t-15.2)}$	60	Brown, 1976
Grey-backed Tern	$M_t = 190/1+e^{-.099(t-15.2)}$	60	Brown, 1976 (data for Sooty Tern)
Blue-grey Noddy	$M_t = 58/1+e^{-.270(t-11.0)}$	35	Rauzon, Harrison, and Clapp, unpublished
Black Noddy	$M_t = 115/1+e^{-.158(t-11.3)}$	40	Pettit, Grant, and Whittow, 1984
White Tern	$M_t = 100/1+e^{-.096(t-19.0)}$	55	Pettit, Grant, and Whittow, 1984

The greatest energy consumers are, in order of highest consumption, sooty terns, black-footed albatross, Laysan albatross, and brown noddies. Only the brown noddies in this group of high total energy consumers are permanent residents of French Frigate Shoals. Several species are nearly equal in their energy requirements of approximately 200 kcal x 10^6 per year: wedge-tailed shearwater, masked booby, and great frigatebird.

Consumptive Rates of Prey Species

Energy requirements of each seabird species can be converted to fish consumption based upon the composition of the bird's diet and the energetic equivalents for various food items. Percentage composition is given in terms of the caloric contribution of each prey species to the overall energetic need for each species of

TABLE 7. TOTAL ENERGY REQUIREMENTS OF SEABIRDS AT FRENCH FRIGATE SHOALS

Species	Breeders (kcal x 10^6)	Non-Breeders (kcal x 10^6)	Eggs (kcal x 10^6)	Chicks (kcal x 10^6)	Total (kcal x 10^6)
Black-footed Albatross	786.3	706.1	3.03	421.2	1,916.6
Laysan Albatross	157.6	330.1	0.64	101.4	589.7
Wedge-tailed Shearwater	63.4	115.9	0.26	22.0	201.6
Christmas Shearwater	0.7	0.8	0.003	.2	1.7
Bonin Petrel	1.1	1.0	0.005	.2	2.3
Bulwer's Petrel	7.3	6.6	0.03	1.1	15.0
Red-tailed Tropicbird	27.9	27.9	0.09	7.0	62.9
Masked Booby	112.6	42.3	0.11	25.4	180.4
Brown Booby	8.2	3.5	0.009	1.5	13.2
Red-footed Booby	72.2	60.3	0.05	15.7	148.2
Great Frigatebird	53.9	122.7	0.06	10.9	187.6
Sooty Tern	1,320.9	2,201.2	7.20	171.6	3,700.9
Grey-backed Tern	13.9	13.5	0.06	2.9	30.4
Brown Noddy	300.2	250.4	0.64	14.2	565.4
Black Noddy	22.4	38.8	0.05	1.3	62.5
White Tern	20.1	34.9	0.05	0.6	55.6

seabird. Energy intake is converted to metric tons by applying the caloric equivalent for each gram of fresh prey. Diets and consumptive figures are given in Tables 8 to 10 for each order of seabird.

Among procellariiformes, squid and flying fish (Exocoetidae) predominate in the diets of albatross. Shearwaters rely primarily upon Carangidae (opelu), Mullidae (goatfish), and squid for their energetic needs. Petrels prey upon smaller marine organisms including mesopelagic fish, crustaceans, and squid. Among pelecaniformes, Exocoetidae predominate in the diets. Squid are important in the diets of red-footed boobies and red-tailed tropicbirds, species which forage in deep-water areas adjacent to French Frigate Shoals. Among charadriiformes, a great variety of fish and squid are consumed, indicating the opportunistic foraging stategies among members of this order.

French Frigate Shoals presents a unique opportunity for modeling of seabird energetics in the NWHI. It is the only island group in the NWHI in which all 18 species seabirds are present. As the site of a FWS refuge station, data for population numbers of breeding and non-breeding birds, reproductive success, growth characteristics of chicks, and time-and-energy budgets of adults have been collected with a degree of precision which is not possible for other island groups in the NWHI. Thus, the energetic estimates presented here provide a useful intitial assessment of food consumption which may be applied to the estimated total population of seabirds in the NWHI (see paper in this proceedings by Fefer et al.).

French Frigate Shoals is also the largest breeding site for the masked booby. As Table 9 suggests, the energetic needs of this species are largely met by a diet of opelu and flying fish. The most specialized diets are those of the black-footed albatross (44 percent flying fish eggs) and the grey-backed tern (42 percent cowfish). These seabirds select prey which are low in water content and high in calories. The prevalence of squid in the diet of all seabirds underscores the importance of this marine resource.

Similar modeling efforts for seabirds at higher latitudes suggest approximately 11 to 30 percent of the annual production of small fish and squid may be consumed to meet energetic requirements (Evans, 1973; Wiens and Scott, 1975; Furness, 1978). Clearly, seabirds consume a significant fraction of their local marine production. Ecologically, however, this is not a completely one-way transfer of energy. As much a 30 to 40 percent of the energy content of the food is voided as feces or wasted. This return of calories and nutrients to the ocean contributes to the fertilization of phytoplankton production which may be especially important in the vicinity of seabird colonies in relatively barren tropical waters (Hutchinson, 1950; Zelickman and Golovkin, 1972).

TABLE 8. FOOD AND ENERGETIC REQUIREMENTS OF PROCELLARIIFORMES AT FRENCH FRIGATE SHOALS

Species	Black-footed Albatross		Laysan Albatross		Wedge-tailed Shearwater		Christmas Shearwater		Bonin Petrel		Bulwer's Petrel		Sooty Storm Petrel	
	kcal x10⁶	Metric Tons	kcal x10⁶	Metric Tons	kcal x10⁶	Metric Tons	kcal x10⁶	Metric Tons	kcal x10⁶	Metric Tons	kcal x10⁶	Metric Tons	kcal x10⁶	Metric Tons
FISH														
Carangidae					45.5	52.4	0.2	0.2						
Exocoetidae					9.7	8.0	0.2	0.2						
Exocoetidae (ova)	1,357.0	417.5	61.9								1.2	0.4		
Gonostomatidae							0.03	0.03*	0.06	0.05*	1.2	1.0*		
Mullidae					33.7	36.6	0.2	0.3	0.07	0.08				
Myctophidae					14.5	7.9			0.8	0.4	6.5	3.5		
Sternoptychidae									0.3	0.2*	4.1	3.4*	+	—
Synodontidae									0.08	0.04				
Other fishes					31.2	20.2	0.2	0.2*	0.08	0.06*	0.5	0.4*	+	—
SQUID	306.6	300.6	348.6	341.7	54.6	53.5	0.9	0.9	0.4	0.4	0.8	0.8		
CRUSTACEANS			34.2	45.6	1.6	2.1			0.09	0.12	0.3	0.5		
INSECTA														
Gerridae									0.01	0.01	0.3	0.1	+	—
Argasidae														
COELENTERATA														
Vellidae			25.4	21.1*										
ALL OTHERS	253.0	210.8*	119.6	99.8	10.8	8.9	0.04	0.3*	0.5	0.4*	0.1	0.3*	+	—
TOTALS	1,916.6	928.9	589.7	527.2	201.5	189.6	1.7	2.1	2.3	1.7	15.0	10.4		

*Estimated using mean value of 1.2 $kcal \cdot g^{-1}$

+Indicates significant prey species in the diet (see Methods)

TABLE 9. FOOD AND ENERGETIC REQUIREMENTS OF PELECANIFORMES AT FRENCH FRIGATE SHOALS

Prey Species	Red-tailed Tropicbird		Masked Booby		Brown Booby		Red-footed Booby		Great Frigatebird	
	kcal x10^6	Metric Tons	kcal x10^6	Metric Tons	kcal x10^6	Metric Tons	kcal x10^6	Metric Tons	kcal x10^6	Metric Tons
FISH										
Carangidae	6.8	7.8	41.3	47.5	3.1	3.6	12.0	13.8	13.5	15.5
Coryphaenidae	6.6	5.3	5.8	4.6					3.9	3.2
Exocoetidae	22.1	18.3	114.9	95.0	4.3	3.5	72.6	60.0	126.1	104.2
Molidae	3.8	2.7*					2.8	2.3*		
Mullidae					1.9	2.1	1.9	2.1		
Hemiramphidae	1.2	1.4	4.0	4.6	1.1	1.3	2.4	2.8	6.8	7.9
Other fish	2.2	1.8*	9.4	7.8*	2.1	1.7*	20.0	16.7*	16.3	13.6*
SQUID	11.8	13.4	4.5	4.4	0.6	0.6	36.0	35.3	19.9	19.5
ALL OTHERS	8.4	7.0*	0.5	0.5*	0.08	0.06*	0.5	0.4*	1.1	0.9*
TOTALS	62.9	57.7	180.4	164.4	13.2	12.9	148.2	133.4	187.6	164.8

*Estimated using mean value of 1.2 kcal·g^{-1}

TABLE 10. FOOD AND ENERGETIC REQUIREMENTS OF CHARADRIIFORMES AT FRENCH FRIGATE SHOALS

Prey Species	Sooty Tern		Grey-backed Tern		Blue-Grey Tern		Brown Noddy		Black Noddy		White Tern	
	kcal x10^6	Metric Tons	kcal x10^6	Metric Tons	kcal x10^6	Metric Tons	kcal x10^6	Metric Tons	kcal x10^6	Metric Tons	kcal x10^6	Metric Tons
FISH												
Atherinidae									0.7	0.9	1.3	1.7
Belonidae											1.7	2.1
Carangidae	203.5	234.0	0.3	0.3			45.8	52.6	0.6	0.7	1.3	1.5
Chilodactylidae			0.3*	0.3							1.8	1.5*
Clupeidae			1.2	1.0*					6.4	5.4*	0.9	0.8*
Coryphaenidae			0.9	0.7							2.8	2.2
Exocoetidae	359.0	296.7	2.1	1.7	+	--	56.5	46.7	5.3	4.3	13.9	11.5
Gempylidae	192.4	100.8			+	--	27.1	14.2	2.3	1.2	1.4	0.7
Gobiidae									1.3	1.5		
Istiophoridae			0.2	0.2							1.6	1.5
Mullidae	451.5	490.8	1.2	1.4	+	—	136.8	148.7	15.2	16.5	9.1	9.9
Myctophidae											2.8	1.5
Nomeidae			0.7	0.6*							0.7	0.6*
Ostraciontidae			19.3	7.6								
Synodontidae					+	—	57.7	31.0	20.4	11.0	1.3	0.7
Unidentified fish	114.9	95.6*	1.6	1.3*	+	—	36.8	30.6*	5.9	4.9*	8.2	6.9*
SQUID	1,846.7	1,810.5	0.7	0.7	+	—	171.9	168.5	3.4	3.4	5.9	5.8
ANTHROPODA												
Copepoda					+	—						
Crab			0.4	0.3								
INSECTA												
Gerridae					+							
ALL OTHERS	532.9	444.1*	1.5	1.3*	+	—	43.5	36.3*	1.0	0.9*	0.9	0.8
TOTALS	3,700.9	3,472.5	30.4	17.4			565.4	528.6	62.5	50.7	55.6	49.7

*Estimated using mean value of 1.2 kcal·g^{-1}
+Indicates significant prey species in the diet

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INVESTIGATIONS INTO ESCAPE VENT EFFECTIVENESS AND GHOST FISHING IN CAPTIVE POPULATIONS OF THE SPINY LOBSTER, *PANULIRUS MARGINATUS*

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ABSTRACT

The spiny lobster, *Panulirus marginatus*, comprises one of the major fishery resources of the Hawaiian Archipelago. It is usually captured with a double-chambered wire trap whose mesh size is unregulated. Sublegal lobsters fully recruited into the fishery and caught in traps are sorted on deck. Deck sorting is time-consuming for the fisherman and frequently damaging to the lobsters, and its value as a stock conservation method is now being questioned. This study was designed to determine if spiny lobsters can be effectively "sorted" on the bottom by fishing with traps equipped with escape vents. This study also investigated whether lobsters would enter traps "baited" only with live lobster and thus be subject to ghost fishing. Three types of escape vents, single, bar, and mesh, were tested. The unbaited, vented traps were loaded with individually identified lobsters and left on the bottom of a large tank overnight. Results indicated that the overall escape rate of sublegal lobsters was approximately 60 percent with the escape rate decreasing linearly with increasing carapace length. There was no significant difference in escape rate between males and females. Differences in escape rates between vent types indicated that escape vent effectiveness may depend on total vent area. Since vented traps are able to sort out sublegal lobsters on the bottom, it is recommended either that traps be equipped with escape vents or that a minimum mesh size be required. In all the escape vent trials, ghost fishing did occur. Seven percent of the unloaded females and 9 percent of the unloaded males in the tank population were attracted to the vented traps baited only with live lobsters. It is recommended that lobster trap lids be fastened with biodegradable material. If not, lost traps should be included as part of total fishing effort until their estimated time of deterioration.

escape vent
ghost fishing
Panulirus marginatus

INTRODUCTION

Conservation and management measures for spiny lobster stocks are in general designed to preserve the reproductive capacity of the stock and/or to protect smaller, more rapidly growing individuals until they can be harvested at some optimal level. Two of the most common methods used to accomplish these objectives are closed seasons, which presumably coincide with the peak reproductive period, and restrictions on the capture of females with eggs and individuals measuring less than a specified size. In the Hawaiian Archipelago, the spiny lobster, *Panulirus marginatus*, is usually captured in a double-chambered wire trap whose mesh size is unregulated. Lobsters which are undersized or gravid are sorted out on deck and returned to the sea. In the process they can be injured by handling, desiccated, sun-blinded, displaced from their home reef, and exposed to predators. Mortalities have been estimated at 20 to 50 percent among sublegal lobsters held on deck for more than a few minutes for a related species, *P. argus*, in the Florida spiny lobster fishery (Gulf of Mexico and South Atlantic Fishery Management Councils, 1981).

The intent of this study was to determine if spiny lobsters can be effectively "sorted" on the bottom by fishing with traps equipped with escape vents. Escape vents are currently required in several spiny lobster fisheries, most notably that of *P. cygnus* in Western Australia. In New Zealand, Ritchie (1966) conducted an escape vent survey in the field on a species of *Jasus*. He concluded from his results that escape vent effectiveness depended on total escape vent area, the amount of bait used, the time taken for it to be consumed, the length of time the trap was left on the bottom, and the size composition of the population being fished. He also determined that traps equipped with escape vents caught a larger number of legal-sized lobsters.

This study was conducted in the laboratory on a completely known population. It was designed to determine the number, size composition, and sex ratio of lobsters escaping from a vented trap and to test if these variables might change with different types of vents.

Since the study involved loading a trap with live, identified lobsters, an additional question was investigated. Would a trap "baited" only with live lobsters attract additional lobsters into and, therefore, subject a population to ghost fishing? In the Caribbean and the Gulf states, undersized lobsters are commonly used as long-lasting "attractants" in traps and this use is regulated in the fishery management plans for these regions. Undersized lobsters can also serve as attractants in lost traps, which total 37 percent of all traps used each year in Florida (Caribbean Fishery Management Council, 1981). To protect stocks from extensive depletion due to ghost fishing by lost traps, the fishery management plans of both Puerto Rico and the Virgin Islands of the United States and the South Atlantic and Gulf states require that all traps be equipped with degradable panels.

METHODS

Three separate known populations of spiny lobsters were exposed to each of the three types of escape vents tested. The lobsters were kept in three large, flow-through tanks at the Kewalo Research Facility of the Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service. The density of the populations used in this study was approximately 1.2 lobsters per square meter. The lobsters measured between 5.10 and 10.60-cm carapace length (CL). The lobsters were individually identified by clipping the lateral spines of the tail according to a binary code.

The trap design used in this study was a standard California two-chambered trap covered with 2.5-cm x 1.0-cm mesh. Traps were covered with the small mesh to sample smaller size classes that are not fully retained by the 5-cm x 10-cm mesh of the standard trap. Traps equipped with mesh of smaller dimensions than the standard California version are often used on the fishing grounds of the Hawaiian Archipelago. The end panel on the inner chamber of these traps was replaced with an end panel fitted with one of three different types of escape vents: (1) single vent: a single 6-cm x 29-cm opening located in the center of the end panel (Figure 1, part a); (2) bar vent: a single, bar-shaped opening, 6 cm x 74 cm, located along the bottom of the end panel (Figure 1, part b); and (3) 15-vent mesh: an open mesh of 15 escape vents each measuring 6 cm x 7.2 cm (Figure 1, part c).

In these experiments, an unbaited, venced trap was set on the bottom of the tank and loaded with 26 lobsters captured by a scuba diver. The identity, size, sex, and condition of the lobsters were recorded. Since the percentage of escapement of sublegal lobsters was of primary interest, the majority of the lobsters loaded into the trap was <8.15-cm CL and could conceivably escape through the 6-cm wide escape vent. During preliminary trials, the largest lobster able to escape through a 6-cm escape vent was an 8.04-cm CL female. After 24 hours, a fine mesh panel was tied across the escape vent end and the trap was retrieved. The lobsters in the trap were identified, measured, and returned to the tank. This was repeated 11 times at 8-day intervals for each type of vent being tested.

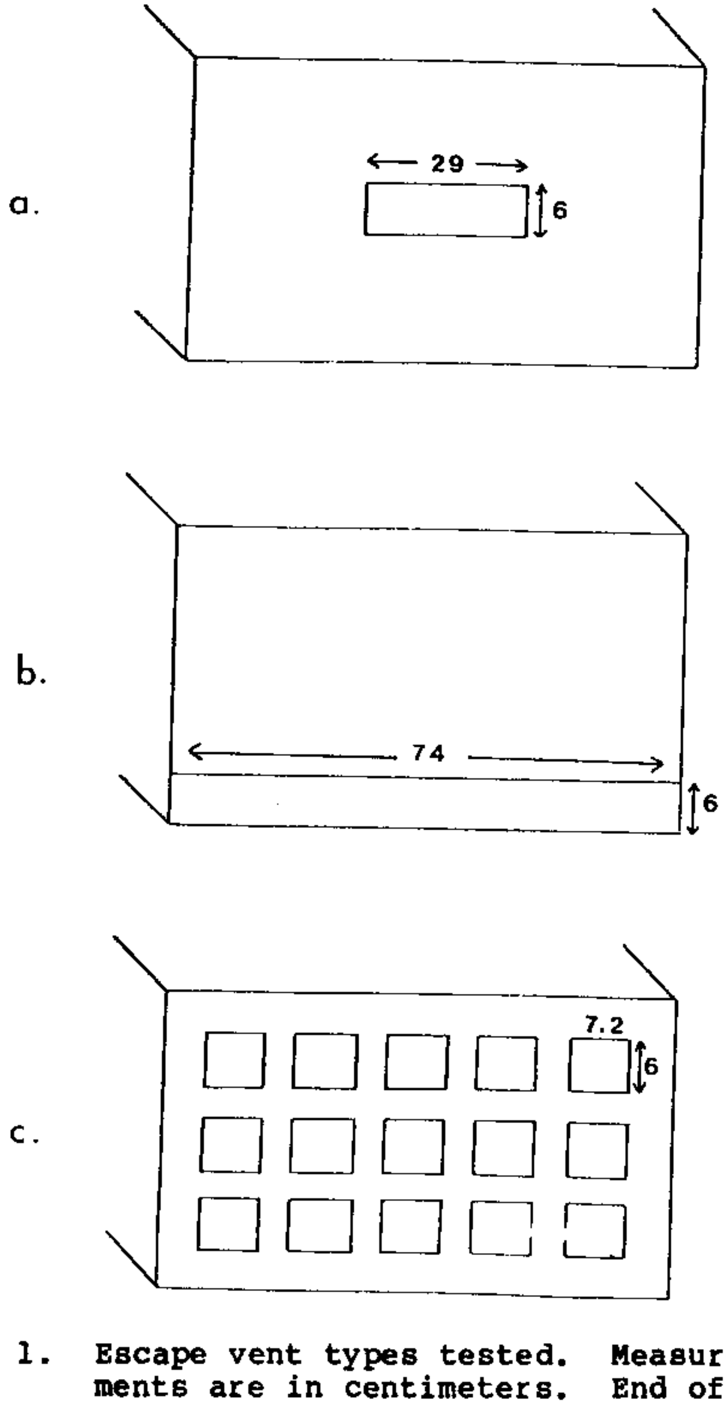

Figure 1. Escape vent types tested. Measurements are in centimeters. End of inner chamber of standard California-type lobster trap is illustrated: (a) single vent, (b) bar vent, and (c) 15-vent mesh. A 6-cm width will permit most lobsters <8.15-cm carapace length to escape.

The ratio of escaped to loaded was regressed against carapace length using Model I regression analysis for all 11 trials combined. All possible combinations of vent types and sex were analyzed. If the regression analysis indicated a significant regression slope, analysis of covariance was applied to test for significant differences in the regression slopes between the sexes (vent types, separate and combined) and between vent types (sexes, separate and combined). Hochberg's GT2 method was used to test for significant differences among the adjusted means if the analysis of covariance indicated that the sexes and/or the vent types had similar slopes. The analyses were done utilizing statistical programs developed by the Statistical Analysis System Institute (1979). The G-test of independence in R x C contingency tables (Sokal and Rohlf, 1981) was used to compare the number of escapes with the number of retentions for each vent type. Three sublegal (as of 1981) size classes for each sex were analyzed: 6.60 to 7.09-cm CL, 7.10 to 7.59-cm CL, and 7.60 to 8.09-cm CL.

The ratios for each sex, by size class, of ghosts to the total population minus pre- and post-molt lobsters were calculated for all traps equipped with escape vents. Those loaded that were too large to escape were not included in the analysis. The number entering the trap as ghosts was compared with the number that could have entered but did not. Analysis was done by size class and sex on the combined data from the 33 escape vent trials using the G-test of independence. All work was done on the IBM 370/158 computer at the University of Hawaii Computing Center.

RESULTS

The ratio of escaped to loaded for the males in the single vent trap diminished as carapace size increased. Using Model I regression analysis, this ratio was found to decrease linearly for those sizes tested ($P < 0.001$). The escaped to loaded ratio for single vent females also diminished as carapace length increased ($P < 0.05$). Analysis of covariance indicated no significant difference between the slopes of males and females ($P > 0.05$). The single vent permitted an overall escapement of 40 percent of the males and 52 percent of the females.

The ratio of escaped to loaded males and females from the trap equipped with a bar vent also diminished with increasing carapace length. The slope of the regression equation for both males and females was significant ($P < 0.001$). Analysis of covariance indicated no significant difference in the slopes between males and females ($P > 0.05$). The bar vent permitted 60 percent of the males and 50 percent of the females to escape.

The results for males and females in the 15-vent mesh trap were similar to the results from the other vent types tested.

Model I regression analysis indicated significant linear regression for both males and females ($P < 0.01$). There was no significant difference between the slopes for males and females ($P > 0.05$). The 15-vent mesh permitted an escapement of 57 percent of the males and 53.5 percent of the females.

In the interest of protecting future yield, the most important size classes relative to escape vents are those that are fully recruited to the gear but not yet of legal size. In this study that size range was divided into three size classes: 6.60 to 7.09-cm CL, 7.10 to 7.59-cm CL, and 7.60 to 8.09-cm CL. A visual comparison of the percent escapement of those size classes for each sex using each of the three types of escape vents tested is shown in Figure 2. The differences between the three do not point in any one clear direction. The number of escapes was compared with the number not escaping using the G-test of independence (Sokal and Rohlf, 1981) for each of the three size classes by vent type and sex. The results indicated homogeneity for the females ($P > 0.05$). Females in those size classes had equal probability of escape from any of the vent types. For males 6.60 to 7.09-cm CL, and 7.10 to 7.59-cm CL, there was heterogeneity when the single and bar vents were compared ($P < 0.05$). Apparently males in those size classes escaped significantly more often from the bar vent than from the single vent.

Figures 3 and 4 show the combined results for all three vent types for each sex. It is clear that escape vents of these types do permit considerable sublegal escapement on the bottom, with the percentage diminishing in an approximately linear way as carapace length increases. Among the fully recruited but not yet legal-sized lobsters (6.60 to 8.09-cm CL), escapement was essentially the same for males and females: approximately 47 percent of all those loaded escaped. For all those lobsters loaded that were less than 7.10-cm CL that may be fully recruited to smaller meshed traps, escapement among males and females was also similar, around 72 to 73 percent. Analysis of covariance indicated no significant difference between males and females ($P > 0.05$). Hochberg's GT2 test for significant differences among the adjusted means indicated that there was a single regression line for escapement for both sexes.

When escapements for the sexes are combined and compared by vent types, the results indicate that the bar vent permits the most escapement and the single vent the least. Analysis of covariance indicated that the slopes for the bar and 15-vent mesh were not significantly different from one another ($P > 0.05$). The GT2 test indicated that there was a single regression line for escapement for these two vent types. However, the slope for the single vent was marginally different from the bar and 15-vent mesh ($P = 0.0466$). Total vent area may be a factor in escapement.

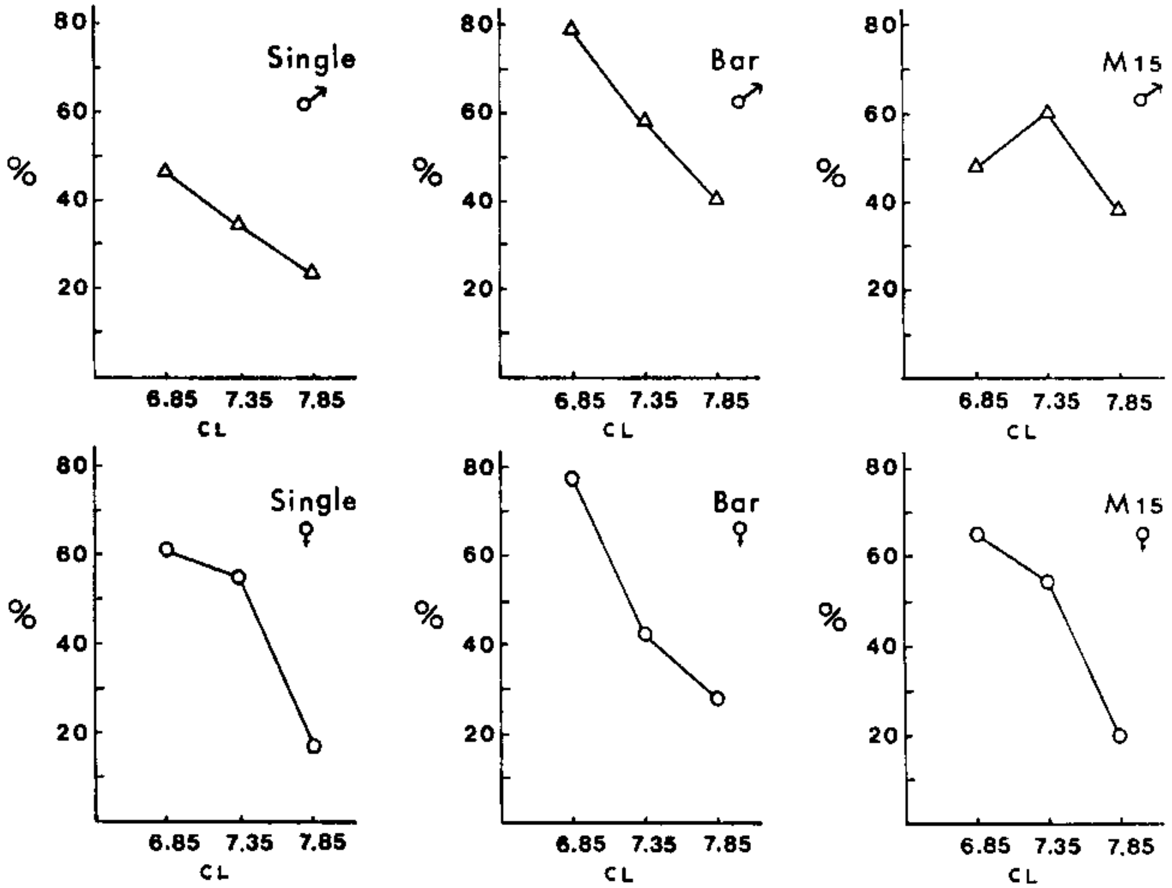

Figure 2. Percent escapement by escape vent type, sex, and carapace length for the three size classes fully recruited to the trap but less than legal size

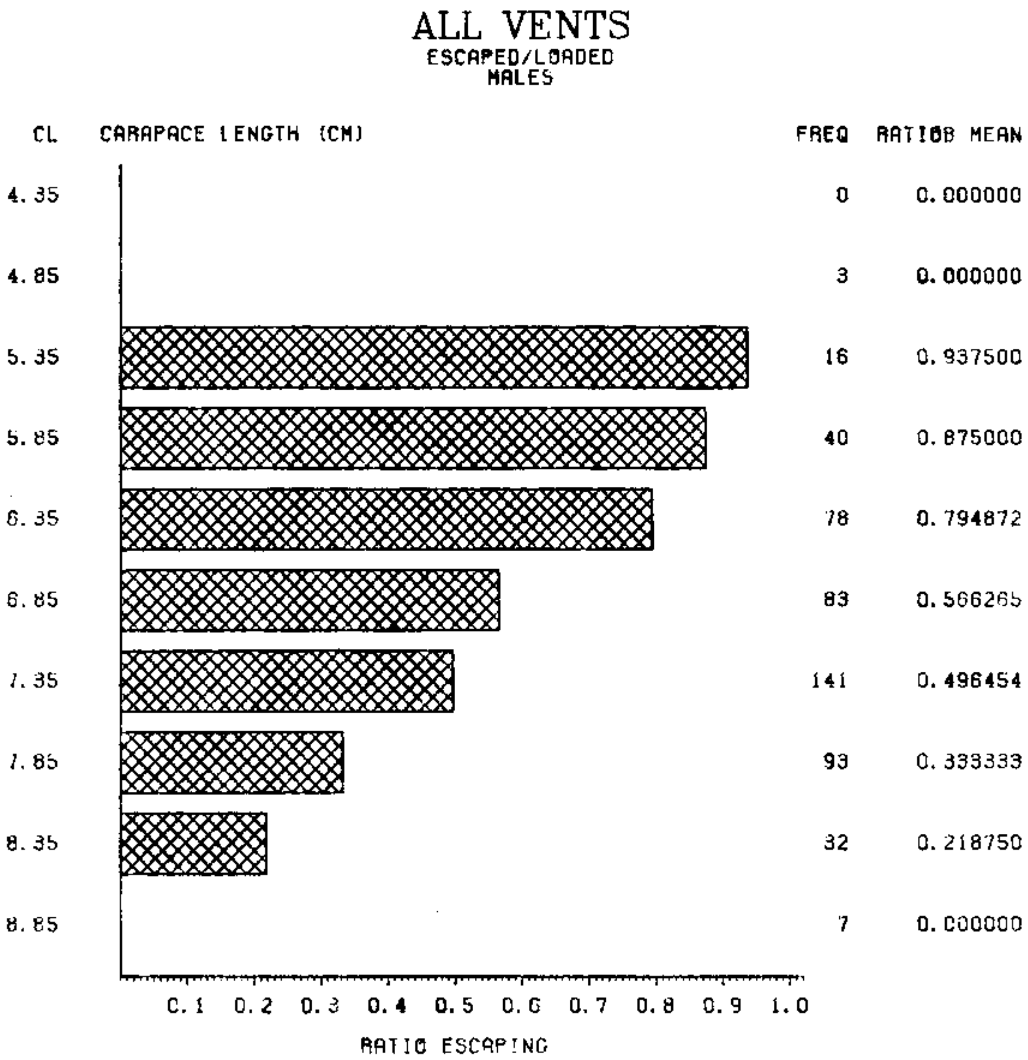

Figure 3. Ratio of total males escaped to total males loaded, by size class, combined results for traps with the three types of escape vents tested. Frequency is total number loaded. Data are from 33 trials.

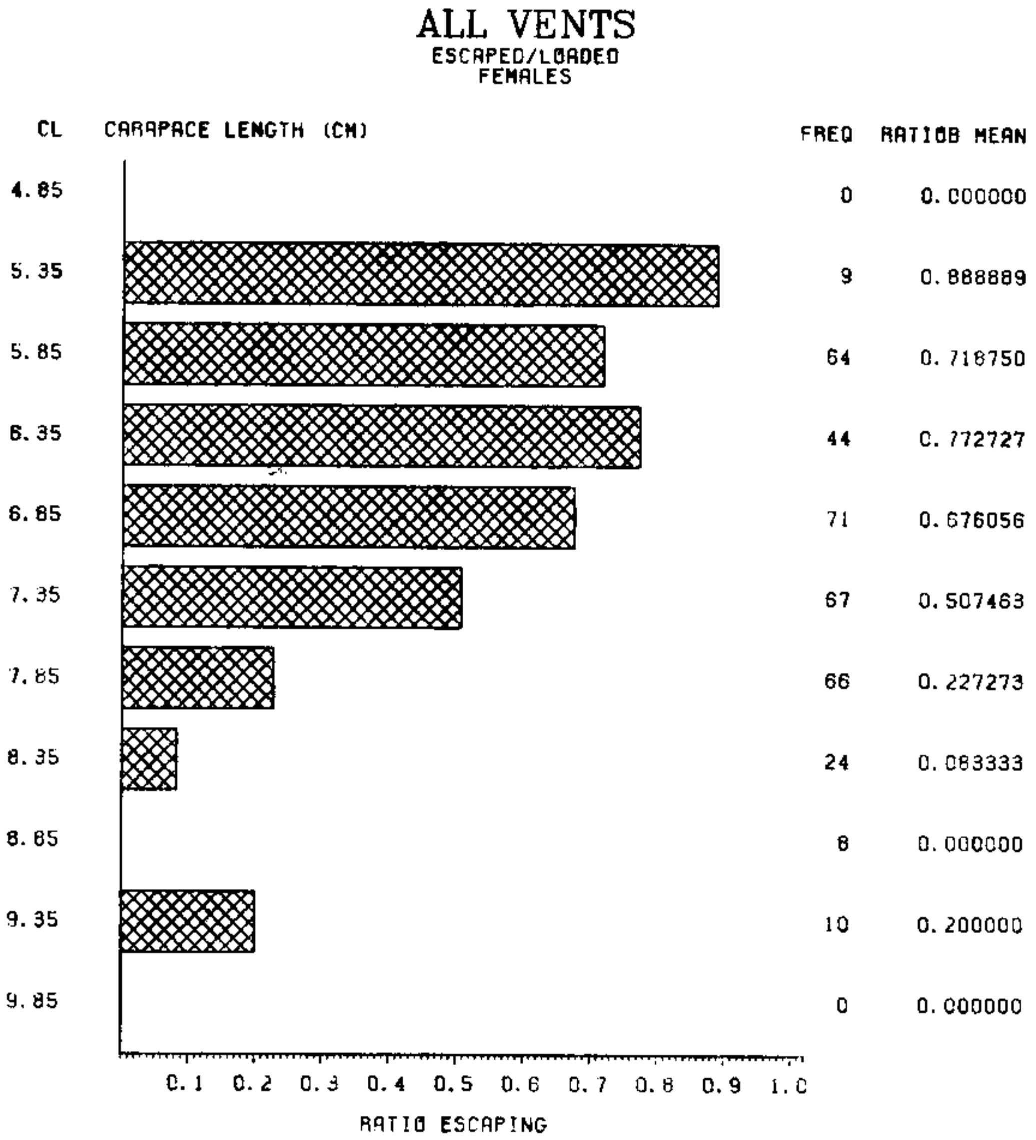

Figure 4. Ratio of total females escaped to total females loaded, by size class, combined results for traps with the three types of escape vents tested. Frequency is total number loaded. Data are from 33 trials.

To determine if there was a predictable escape rate for all the vent types tested, the escapement was analyzed using Model I regression analysis. The percentage that escaped of those lobsters loaded into a vented trap was plotted against carapace length by sex and vent type (Figure 5). The dashed lines indicate the 95 percent confidence limits for the mean predicted value. For escape vents of smaller or larger minimum dimensions

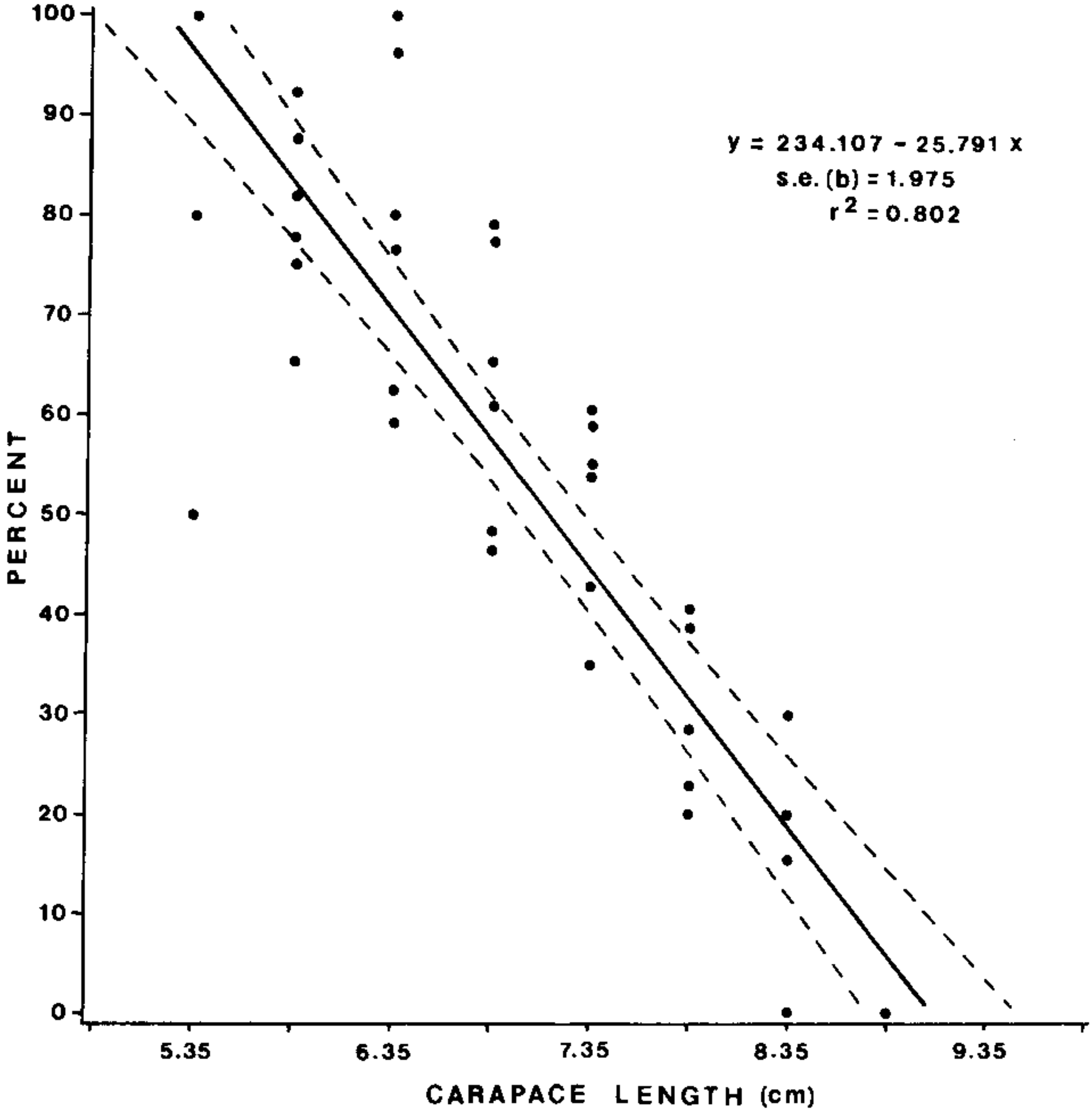

Figure 5. Percent of lobsters escaping traps fitted with an escape vent, by size class. Data for both sexes and all vent types are included. Regression line is fitted through the points. Dashed lines are the 95 percent confidence limits for the mean predicted values. Equation for the slope, its standard error, and the r^2 value are given.

than the one tested, this plot can be shifted to the left or right to predict escapement. The amount of left or right adjustment would be determined by the size of the largest lobster able to fit through the vent opening.

Visual observations of a standard trap in the tank revealed that the lobsters do not generally escape throught the trap entrance. Escape behavior consisted of much random movement around the bottom and sides of the trap and included much probing with the telson through the trap mesh. Escape behavior through the entrances was observed when a shortened version of the standard trap was used. In this trap, the vertical distance from the trap floor to the inner edge of the entrance cone was reduced from 14 to 8 cm. Lobsters were also observed escaping through the entrance cone if the standard trap was set repeatedly in the midst of the same population at intervals of less than 8 days apart.

DISCUSSION

The results of the escape vent experiments indicated that lobsters will use the vents if traps are equipped with them. Overall, the most effective escape vent configuration of the three tested was the bar vent across the lower edge of the end panel of the inner chamber. This type of vent is already in use by some spiny lobster fisheries, including those of New Zealand. Although not all sublegal lobsters escaped within the 24-hour test period, the average escapement of approximately 60 percent of all lobsters <8.10-cm CL is very encouraging.

Evidence from other studies indicates that the present practice of sorting and discarding sublegals on deck may not be an effective stock conservation method. There is evidence that lobsters may become blinded by the sun due to bleaching of the pigment of their superpositioned eyes, which are adapted to intensify images under low light conditions (Phillips et al., 1980). In addition, they can become desiccated and injured on deck and may eventually be deposited in unsuitable habitat as the fishing vessel moves on to another location. Escape vents permitting "sorting" on the sea bottom would also save the fisherman time and effort. The total area available for escapement may be an important factor in escape vent effectiveness. It is recommended that either traps be equipped with escape vents of a size and configuration that would permit most sublegal lobsters to escape, or trap mesh size be regulated so as to prevent the trapping of sublegal lobsters.

Ghost fishing occurred in all the escape vent trials. When the unbaited vented trap was retrieved, it almost always contained lobsters that had not been put there the afternoon before. The overall ghost to population ratio for males was 0.0923:1, for females 0.0745:1, and 0.0851:1 for males and females combined (distribution by carapace length is given in Figure 6). Although the size class frequencies of the ghost lobsters were analyzed

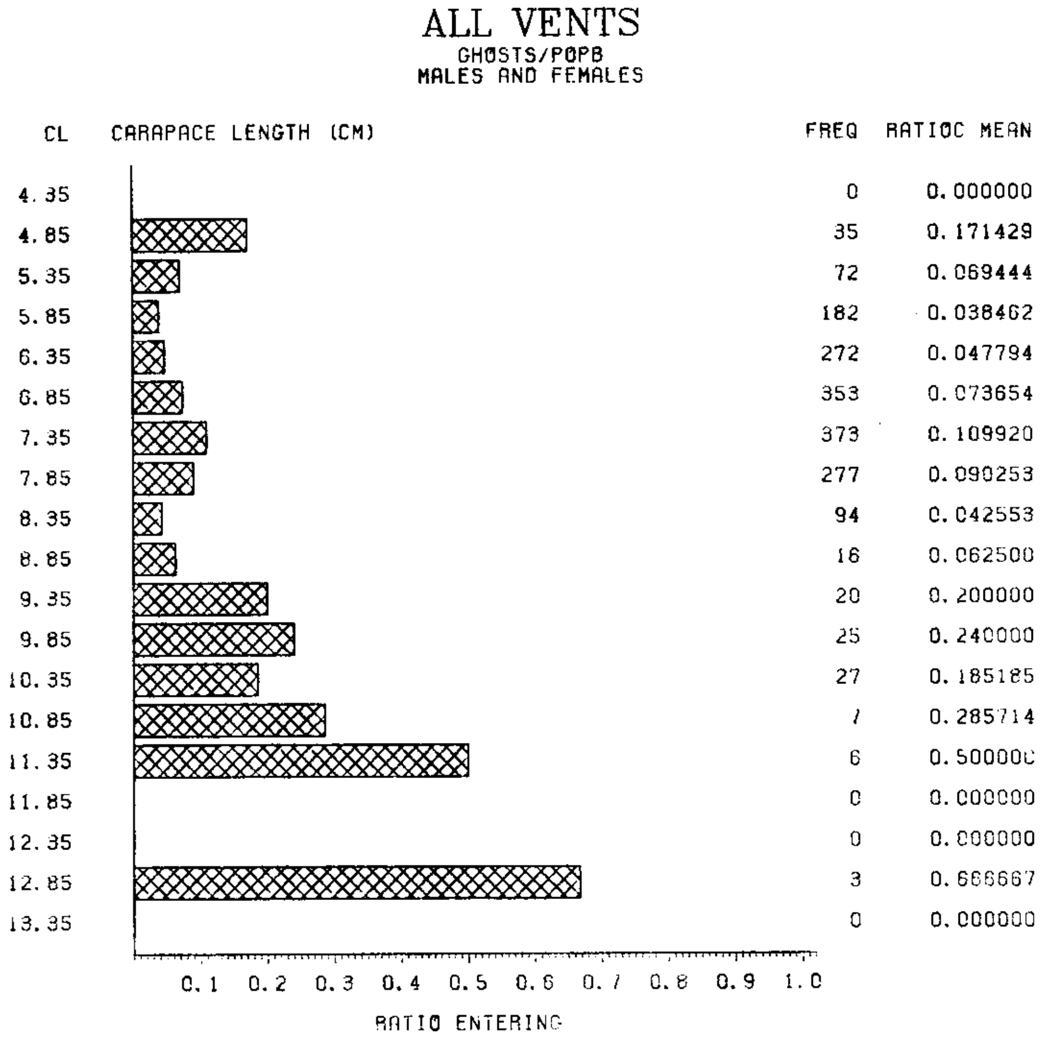

Figure 6. Ratio of total ghosts, male and female, to total population minus pre- and post-molts by size class for all traps equipped with escape vents. Frequency is total population minus pre- and post-molts by size class. Data are from 33 trials.

with a G-test of independence to determine if each size had an equal probability of being captured, it could not be determined if any particular size groups were more likely to be attracted to ghost traps. The G-test is unreliable when sample sizes are small and the number of ghosts in each size class was small, averaging approximately eight.

To help understand what happens to a lost trap, a standard wire trap was left on the bottom of the tank for 15 months while this study was being conducted. During that time, the trap did not deteriorate sufficiently to allow lobsters to escape. The lobsters inhabiting the tank used it as an aggregating location and the lid had to be removed to prevent them from becoming permanently trapped inside.

The results of this study indicate that the presence of live lobsters in a trap is sufficient to attract additional lobsters, even after the bait is gone. Lost traps therefore may cause a great deal of damage to a fishery, and it is recommended that trap lids be fastened with rapidly deteriorating degradable material to prevent lost traps from continuing to fish on the sea bottom. If not, lost traps must be considered part of the total effort expended in the fishery until their estimated time of deterioration.

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FEEDING RELATIONSHIPS OF GOATFISHES IN THE NORTHWESTERN HAWAIIAN ISLANDS

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ABSTRACT

Trophic relationships of goatfishes (family Mullidae) were studied at Midway Islands because of the ecological significance and potential fishery value of these fishes in the Northwestern Hawaiian Islands (NWHI). Gut contents of the five most common goatfish species were visually analyzed for numbers and volume of all identifiable prey items. Two-liter sand cores were collected in the local feeding areas. The sand was dissolved in nitric acid and the benthic invertebrates identified and counted. The diet of *Parupeneus porphyreus* consisted entirely of crustaceans, dominated by xanthid crabs and stomatopods. The diet of *Mulloides vanicolensis* was dominated by xanthid crabs, followed by gastropod molluscs and polychaetes. *Mulloides flavolineatus* ate mostly polychaetes, then xanthid crabs and bivalve molluscs. The diet of *Parupeneus multifasciatus* was almost entirely crabs (xanthid and portunids) and shrimp. Xanthid crabs dominated the diet of *Parupeneus pleurostigma*; other significant prey groups were polychaetes, portunid crabs, and alpheid shrimp. For the three species with best data, calculated dietary overlap using the Proportional Similarity Index was considerable -- a maximum of 66.6 percent for the *P. multifasciatus* vs *P. pleurostigma* comparison. The invertebrate communities of the sand samples were dominated by polychaetes (44 species from 22 families) and molluscs (126 species from 50 families, including micromolluscs). Quantitative comparisons of the make-up of polychaete assemblages in the sand samples and in the guts of *M. flavolineatus* (an important polychaete predator) showed some similarity, but also showed considerable evidence of dietary specialization. In general, goatfish at Midway Islands appeared to be generalized feeders, eating mostly small crustaceans, polychaetes, and bivalve and opisthobranch molluscs (diets similar to those reported for mullids on Oahu and Hawaii). The Midway research provides a general understanding of the food base required to support the common goatfishes of a potential fishery in the NWHI and thus provides an important basis for managing these pristine stocks.

goatfishes
gut contents
Northwestern Hawaiian Islands
trophic relationships

INTRODUCTION

The family Mullidae is distributed worldwide in tropical waters (Figure 1). Eleven species belonging to three genera occur in Hawaii (Gosline and Brock, 1960; Randall, 1980). All species occur in marine environments and are carnivorous (Fowler, 1933). In the high Hawaiian islands there is a commercial and subsistence fishery for goatfish, which are highly esteemed as food. The ancient Hawaiians used species of *Mulloides* and *Parupeneus* as food and offerings to the gods (Titcomb, 1972). There is currently no inshore reef fishery in the Northwestern Hawaiian Islands (NWHI), where the entire reef ecosystem is in an essentially natural state. If an inshore fishery is developed, goatfish would be prime target species.

Figure 1. The moano (*Parupeneus multifasciatus*), one of five abundant and trophically important goatfish species studied at Midway Islands, shown in a typical reef/sand habitat

Some knowledge of the food consumed by mullids and its availability is necessary to more fully understand the importance of these fishes in shallow coral reef ecosystems. The diet of mullids has been investigated in the West Indies (Randall, 1967); Puerto Rico (Bauer, 1981); India (Thomas, 1969); Madagascar (Harmelin-Vivien, 1979); and Japan (Suyehiro, 1942). Within the Pacific basin the only published information comes from generalized community diet studies at Enewetak, Marshall Islands (Hiatt and Strasburg, 1960) and off Kona, Hawaii (Hobson, 1974) and from a comprehensive study of the feeding habits of juvenile and adult _Parupeneus porphyreus_ in Hawaii (Mahi, 1969).

The invertebrate infauna of soft sediments provide a food resource for a number of coral reef fishes including the goatfishes which all possess a pair of sensory barbels on the lower jaw to aid in locating prey. Goatfish barbels contain abundant taste buds which are enervated by a large branch of the facial nerve (Holland, 1976; Suyehiro, 1942). The barbels are used to detect potential prey in the sand, then by "blowing" through the mouth or digging with the pectoral fins the goatfish removes the sand to expose the prey (K.N. Holland, 1981: personal communication; personal observation).

The mullids include both diurnal (e.g., _Parupeneus multifasciatus_) and nocturnal or crepuscular (e.g., _Mulloides vanicolensis_, _Parupeneus porphyreus_) feeders (Hobson, 1974; Mahi, 1969; Harmelin-Vivien, 1979). Based on earlier studies, the major food items consumed by most species are crabs, shrimps, amphipods and other small crustaceans, polychaetes, and bivalve and gastropod molluscs.

Research was undertaken to determine the extent of goatfish predation on sand/rubble infauna as well as the species composition of the sand infaunal community from representative habitats at Midway Islands. By comparing potential prey (from sand samples) with the actual prey (from gut contents), feeding selectivity, if any, can be determined. These data and published information on predation by goatfish make it possible to establish the major trophic relationships between piscivores, goatfish, and sand-dwelling invertebrates.

MATERIALS AND METHODS

Samples of sand and goatfish were obtained from five stations (1, 10, 14, 16, and 21) in the lagoon at Midway Islands (Figure 2), which were chosen as representative of the diverse habitat types in the NWHI. Goatfish were collected at the same times and locations as the sand samples. In most cases the goatfish were feeding in the areas from which the sand samples were taken. All collections were made during the day between 1000 and 1600 hours.

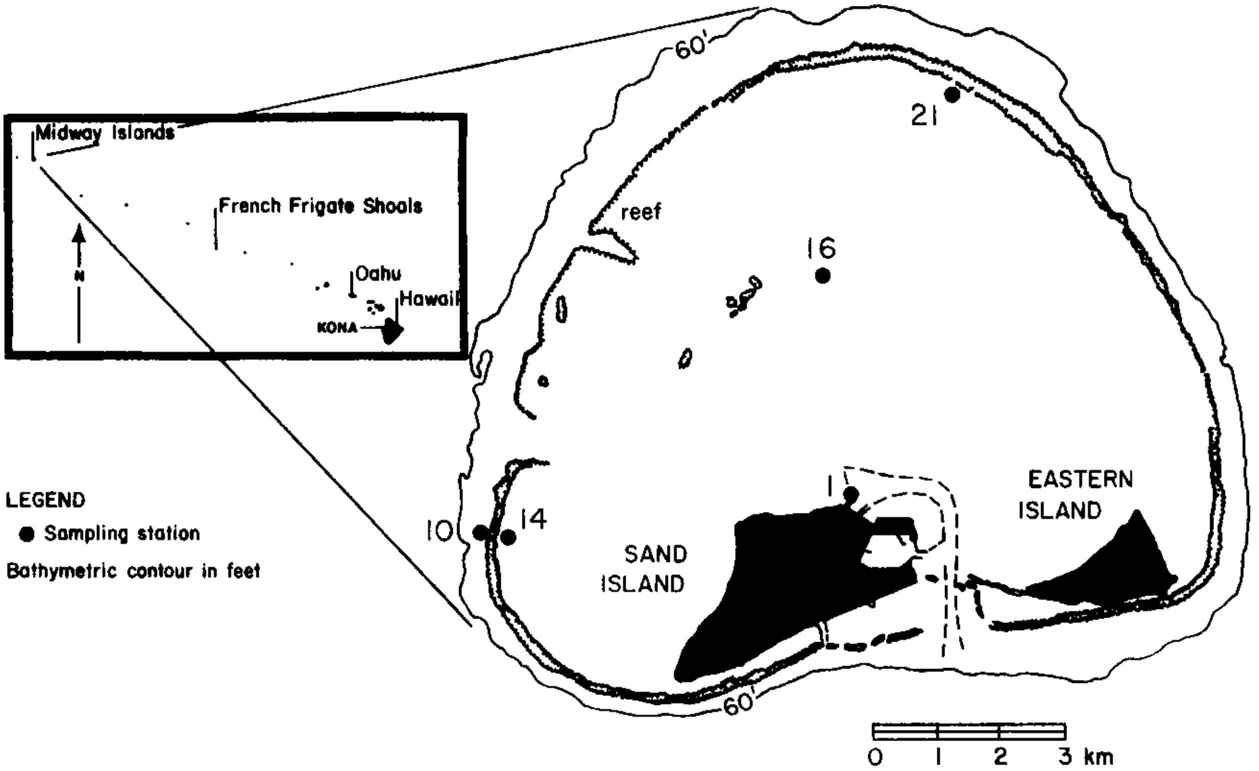

Figure 2. Location of sample sites at Midway Islands

A total of 101 fish belonging to five species were collected. The numbers of each species caught were: 31 *Mulloides flavolineatus*, 22 *M. vanicolensis*, 20 *Parupeneus multifasciatus*, 14 *P. pleurostigma*, and 14 *P. porphyreus*. The Hawaiian names for these species are weke ula, weke aa, moano, malu, and kumu, respectively.

Fish were caught using the Hawaiian pole spear. Upon capture the gut cavity was injected with 100 percent formalin, and then the fish were preserved in 10 percent formalin. Fish were weighed, measured (standard, fork, and total lengths), and gutted. Sex and reproductive condition (i.e., immature, mature, or gravid stage) were determined.

Gut contents were removed and stomach and intestinal fractions kept separate. Identifiable organisms were counted, and the volume of each prey category and of unidentified food material was measured by water displacement.

The Index of Relative Importance, IRI (Pinkas et al., 1971), was calculated for each prey category. This index is defined as:

$$IRI = F(N + V)$$

where

F = frequency of occurrence in percent
N = percent of total individuals
V = percent of total volume

Diet overlap between species was calculated using the Proportional Similarity Index, PSI:

$$PSI = 1 - 0.5\Sigma\ (p_i - q_i)$$

where

p_i = proportion of the ith prey category in the diet of one species
q_i = proportion of the ith category in the second species

Three replicate sand samples were taken at each location using 2-liter cylindrical corers. The sand was fixed with 10 percent formalin in seawater, and rose bengal was added as a vital stain. In the laboratory a 25-ml subsample was removed and processed separately for micromolluscs. All macrofauna was removed from the remaining sand which was then dissolved in nitric acid and formalin (Brock and Brock, 1977) to remove the carbonate fraction; the residue was sorted under magnification. Species diversity was calculated using the Shannon-Weaver information index H' (Pielou, 1966).

RESULTS

Fish diets

The diet of Parupeneus porphyreus was solely comprised of crustaceans. The laboratory results showed that six fish ate four species of xanthid crabs, two ate two species of stomatopods, and one ate a Portunus sp.

Xanthid crabs were the dominant prey of Mulloides vanicolensis, followed by gastropod molluscs and polychaetes. Species of crabs eaten included a portunid, Thalamita sp., and a xanthid, Leptodius exaratus. Thirty-five of the 38 gastropods found in the guts were Cysticus huna (family Marginellidae) which feeds on sponges and ascidians (E.A. Kay, 1981: personal communication), but no sponge spicules or ascidian remains were found in M. vanicolensis guts. Three species of polychaetes were found: Nothria holobranchiata, Lysidice sp., and a dorvilleid.

Polychaetes were the dominant prey of Mulloides flavolineatus as revealed by their presence in all the guts sampled. Bivalve molluscs and xanthid crabs ranked second and third, respectively. Amphipods, isopods, tanaids, crab megalops, and opisthobranch molluscs were eaten by 50 percent or more of the fish. Cyclopoid copepods and colonial tunicates were each found in only one gut, and brittle stars in two guts. The xanthid crabs consumed were mostly small individuals (carapace width of 1 to 3 mm), whereas the ocypodid and portunid crabs were larger (mean carapace width of 3.87 mm), although infrequently found in the guts. *M. flavolineatus* was the only mullid species with measurable amounts of sands in the guts.

Crabs and shrimp comprised the first five ranked prey items of *Parupeneus multifasciatus*. Ninety-five percent of the guts contained xanthid crabs and 65 percent portunid crabs. Major shrimp components in the diet were unidentified carideans, alpheids, and *Rhynchocinetes rugulosus*, which ranked second, third, and fifth, respectively of all food items. *P. multifasciatus* was the only goatfish species in this study whose guts contained *R. rugulosus*. The portunid crabs consumed included *Thalamita integra* and *T. admete*. Twelve species of xanthid crabs were eaten, with 44 of the 90 crabs found being *Leptodius exaratus*. The polychaetes eaten were the glycerid, *Glycera tesselata*; opheliids, *Armandia intermedia* and *Polyophthalmus pictus*; and two nereid species.

Xanthid crabs were the dominant prey of *Parupeneus pleurostigma*, with nine species found in the gut contents. Seventy-nine of the 162 xanthid crabs (48.8 percent) were *Leptodius exaratus*. Prey in the guts of 50 percent or more fish were polychaetes, portunid crabs, and alpheid shrimp. With the addition of polychaetes, the first six ranked prey of *Parupeneus pleurostigma* were similar to the first five of *P. multifasciatus*. Portunid crabs identified to species were *Portunus longispinosus* and *Thalamita integra*. *Portunus* spp. comprised 57.1 percent of the portunids eaten. Two fish ate the ocypodid crab, *Macropthalmus telescopicus*, and one ate a majiid crab. The amphipods, *Lysianassa ewa* and *Eriopisa* sp., were eaten by one fish as was the isopod, *Paranthura ostergaardi*.

Polychaete prey included a polynoid, *Nothria holobranchiata*; two eunicids, *Nematonereis unicornis* and *Eunice* sp.; ?*Notocirrus* sp.; *Glycera tesselata*; *Capitella capitata*; and the opheliids, *Armandia intermedia* and *Polyophthalmus pictus*. More polychaete species were consumed by *P. pleurostigma* than by *P. multifasciatus*, but fewer than by *Mulloides flavolineatus*.

Dietary overlap, as measured by the Proportional Similarity Index among the three goatfish species with best data, was calculated using the Index of Relative Importance (Table 1). Most of the dietary overlap between *P. multifasciatus* and *P. pleurostigma* was based on xanthid crabs and shrimps. Xanthid crabs were the top ranked prey for both species and were also important prey for *M. flavolineatus*. Caridean shrimp were a more important prey for *P. multifasciatus*, and polychaetes were more important for *P. pleurostigma*.

TABLE 1. DIETARY OVERLAP AMONG GOATFISH SPECIES AT MIDWAY ISLANDS

Species	*Mulloides flavolineatus*	*Parupeneus pleurostigma*	*Parupeneus multifasciatus*
M. flavolineatus	100.00	--	--
P. pleurostigma	41.00	100.00	--
P. multifasciatus	28.75	66.59	100.00

Note: Overlap calculated using Proportional Similarity Index

Benthic communities

The most abundant animals in the benthic samples were polychaetes and molluscs. Table 2 summarizes the abundance and diversity of the infauna other than molluscs. Forty-four species belonging to 22 families of polychaetes were found. The most conspicuous components were *Nothria holobranchiata*, *Glycera tesselata*, and the eunicids. One hundred twenty-six mollusc species representing 50 families were found in the 25-ml subsamples. Other invertebrate taxa in the sand samples included isopods, tanaids, gammarid amphipods, sipunculans, and the phoronid, *Phoronis psammophila*. Most of the animals were small, the largest being the mole crab, *Hippa pacifica*, and the trichonotid fish, *Crystallodytes cookei* (sand diver).

TABLE 2. CHARACTERISTICS OF INVERTEBRATE COMMUNITIES IN SAND SAMPLES AT MIDWAY ISLAND

	Station				
	1	10	14	16	21
Species (all taxa)	23	17	18	14	16
Individuals (N)	565	100	615	91	275
Polychaete species	15	9	10	8	11
Polychaetes (N)	484	57	226	31	108
Species Diversity (H')	2.09	2.14	1.77	1.79	1.48
Species Evenness (J)	0.67	0.78	0.49	0.68	0.55

Note: Numbers are the means of three 2-liter samples per station

Because polychaetes were so important in the diet of the goatfish, Mulloides flavolineatus, dietary preference using PSI was calculated comparing polychaetes in the benthos and in the diet of M. flavolineatus at stations 14 and 21, two stations with the largest fish sample sizes. The values of PSI were 0.1167 and 0.2695, respectively. Occurrence in the sand and in fish guts at station 21 is compared graphically in Figure 3. Clearly there is some overlap, but polychaetes do not appear to be eaten in direct proportion to their abundance.

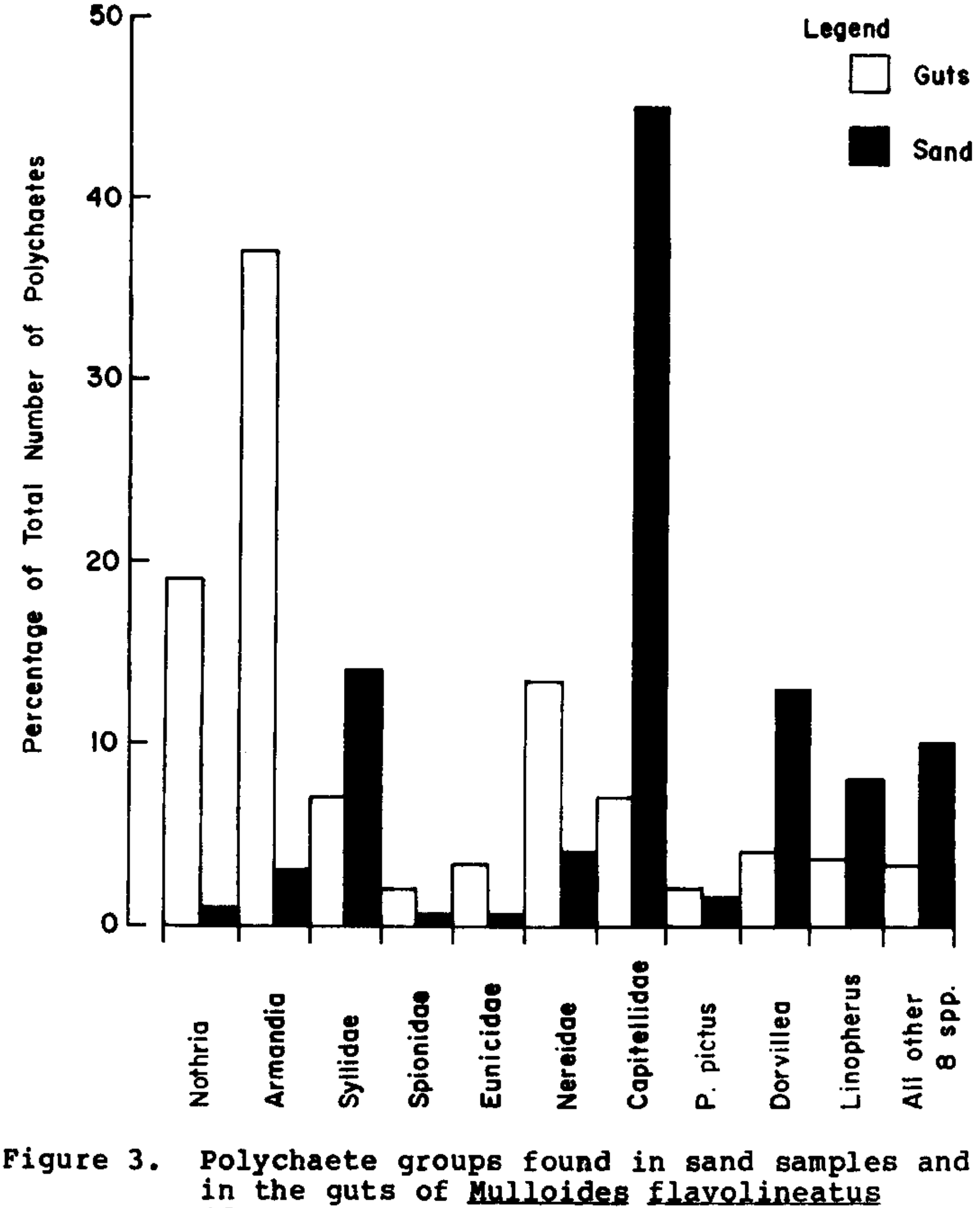

Figure 3. Polychaete groups found in sand samples and in the guts of Mulloides flavolineatus (data from station 21)

DISCUSSION

The prey eaten by goatfish at Midway are very similar to those eaten by the same species at Kona (island of Hawaii) and Oahu (Mahi, 1969; Hobson, 1974). Xanthid crabs were the dominant prey of *Parupeneus porphyreus* taken from Midway and Kona and fish taken from Oahu ranging from 110 to 180-mm standard length. In *P. porphyreus* larger than 180 mm, fish become the co-dominant prey with xanthid crabs on Oahu (Mahi, 1969). No fish remains were found in the Midway fish gut contents, however, even though most of the *P. porphyreus* with recognizable gut contents were larger than 180 mm. The importance of fish in the diet of large *P. porphyreus* collected on Oahu from June through November may reflect utilization of a prey that became seasonally abundant, e.g., by recruitment of larval fish to the reef. However, when the collections were made at Midway in August, the effects of such a recruitment may also have been present.

Echinoderms were important prey for *Mulloides vanicolensis* at Kona (Hobson, 1974) but were not found in the guts of Midway fish. Otherwise, the diet of *M. vanicolensis* was similar at Kona and Midway.

There is considerable dietary overlap between *Parupeneus multifasciatus* and *P. pleurostigma* but less between these two species and *Mulloides flavolineatus* (Table 1). Polychaetes are the dominant prey of *M. flavolineatus*, and crabs and shrimp are dominant prey of the two *Parupeneus* species. This dietary difference reflects differences in feeding behavior. *Mulloides flavolineatus* forages more over open sand and digs a deeper hole, whereas *P. multifasciatus* and *P. pleurostigma* tend to feed closer to the coral and rocky substrata and in sand patches on the reef (personal observation). Xanthid crabs would be more abundant closer to the coral reef than in open sand area.

The diet of *Mulloides flavolineatus* contains most of the animals found in the sand samples, suggesting that this species tends to take advantage of prey as encountered. However, the PSI calculated on polychaete species shows dietary specialization by *M. flavolineatus*, especially on two polychaete species: *Armandia intermedia* and *Northria holobranchiata* (Figure 3). The relative abundance of these two species in the goatfish diet is greater than their relative abundance in the sand samples. Species of capitellids which are extremely abundant in the benthos constitute a relatively small percentage of the diet. The consumption of some species increases as their abundance in the sand increases; e.g., nereid and dorvilleid species were more abundant and were eaten more at station 21 than at station 14. Interpretation of these results on feeding "selectivity" is not straightforward. Among other complicating factors is the behavior of the prey. Many species live in tubes or within the sediment, and some can quickly retract exposed body parts. These tend to be less affected by fish predation than species which are active close to or on the surface (Virnstein, 1979; Hulberg and Oliver, 1979).

Most of the polychaete families known from other Pacific locations, e.g., Oahu, Hawaii (Bailey-Brock, 1979), the Cook Islands (Gibbs et al., 1975), and the Great Barrier Reef (Hutchings, 1974; Gibbs, 1978), were collected at Midway. Several lower taxa were common to two or more locations, indicating a wide distribution for many polychaete taxa in the tropical Pacific (cf. Kohn and Lloyd, 1973). The numbers of families, species, and individuals of polychaetes collected at Midway were comparable with those of other Pacific areas such as Australia (Reichelt, 1979; Gibbs, 1978; Hutchings, 1974) and the Cook Islands (Gibbs, 1975).

CONCLUSIONS

Goatfish at Midway Islands are generalized feeders, eating mostly small crustaceans, polychaetes, and bivalve and opisthobranch molluscs. Polychaetes were the dominant prey of *Mulloides flavolineatus*, with xanthid crabs ranking second. Xanthid crabs and shrimps were the dominant prey for *Parupeneus multifasciatus* and *P. pleurostigma*. Polychaetes were relatively important for *P. pleurostigma* but less so for *P. multifasciatus*. The sample size for *Parupeneus porphyreus* and *Mulloides vanicolensis* was small because of the nocturnal activity of these species. Xanthid crabs were the dominant prey for the latter two species, with *M. vanicolensis* also eating small gastropods.

Mulloides flavolineatus appeared to show positive selection for certain polychaete species and negative selection for others. The capitellid polychaetes which were seldom eaten were extremely small, making them energetically unattractive as food. *Nothria holobranchiata* and *Armandia intermedia*, the two species which comprise two-thirds of the total numbers of polychaetes eaten by *M. flavolineatus*, are surface sediment dwellers. *Armandia intermedia* lacks a protective tube, whereas *Nothria holobranchiata* lives in a vertically oriented, sand-grain covered tube. It is probable that the feeding activity of *M. flavolineatus* may force *N. holobranchiata* to leave its tube, which may account for entire worms or large sections of worms found in the fish gut contents. *Mulloides flavolineatus* is probably best described as an "active generalist" (Birkeland and Neudecker, 1981).

Goatfishes are particularly well adapted to seeking out cryptic prey or animals buried in the sand, which would be unavailable to visual predators (Hobson, 1974). The presence in the gut contents of nocturnally active animals such as the shrimp, *Rhynchocinetes rugulosus*, confirms this. Larger crustaceans and large, hard-shelled gastropods were mostly absent from the gut contents. The feeding morphology and dentition of goatfish limits them to small and/or soft-bodied prey (Hiatt and Strasburg, 1960; Al-Hussaini, 1947).

The results of this research have provided a general understanding of the food base required to support the common goatfish species that are currently important in the developed fisheries of the high islands. A number of benthic invertebrate groups have been identified as important diet items. Some of these appear to occur commonly in the sand flats sampled and others are apparently taken from coral rock and other hard substrates. Related research in the NWHI is establishing similar diet information on most of the major common demersal fish species and providing a description of the benthic fauna of hard substrates. When combined with the present results, this will provide an estimate of the total utilization of the benthic resource base. It will also improve the ability to make reasonable predictions of how fishing for one or more species may affect other species that share common food resources. This provides an important basis for managing these pristine NWHI stocks.

ACKNOWLEDGMENTS

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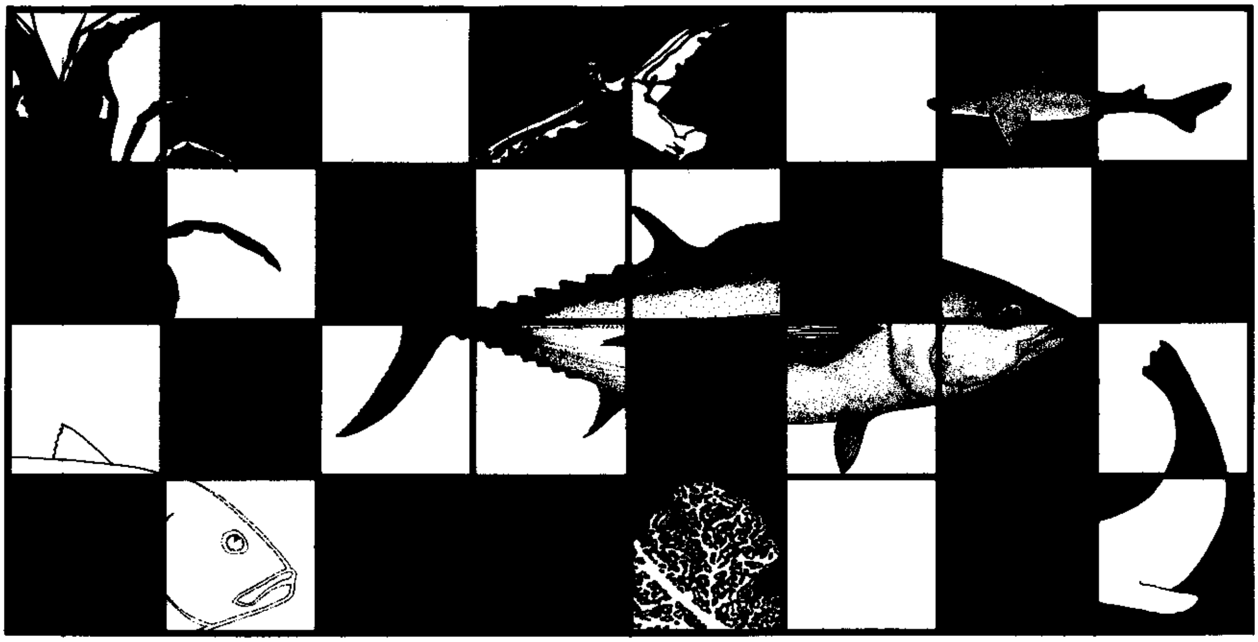

HAWAIIAN SEABIRD FEEDING ECOLOGY. In Wildlife Monographs, vol. 85, 71 pp., (©1983 Wildlife Society). Craig S. Harrison, Thomas S. Hida, and Michael P. Seki (U.S. Fish and Wildlife Service, P.O. Box 50167, Honolulu, Hawaii 96850; Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, Honolulu, Hawaii 96812).

ABSTRACT

The Northwestern Hawaiian Islands are the nesting grounds of about 10 million seabirds of 18 species. Fishery development proposals for this area led to a need for food habit studies of these birds to aid in their management. Food habits are diverse, with 56 families of fish, 8 families of squid, and 11 groups of crustaceans identified. Similar to other tropical seabird communities, this community feeds largely on flyingfishes and squids. In addition, however, this community consumes many *Decapterus* spp., juvenile goatfishes, juvenile lizardfishes, and mesopelagic fishes that rarely occur in the diets of tropical seabirds elsewhere. Albatrosses fed largely on squids and flyingfish eggs; pelecaniforms on large flyingfishes, squids, and *Decapterus* spp.; terns and shearwaters on flyingfishes, juvenile goatfishes, juvenile lizardfishes, and *Decapterus* spp.; small nocturnal procellariiform[e]s on lanternfishes and hatchetfishes; and small terns on small larval fishes and sea-striders. The breeding season for most species tends to be spring-summer and coincides with the period of maximum food availability. Most winter breeding species are adapted for nocturnal feeding, and some may be outcompeted for nesting sites during spring and summer. All species seem to be opportunistic in their feeding habits, but some resource partitioning is evident both in species composition and in size of prey. Differences in diet may be a reflection of morphology, feeding techniques, time of day that feeding occurs, seasonality of breeding, and feeding location. These results will enable wildlife and fishery managers to more accurately predict the effects of various fisheries on marine birds.

HEAVY METAL RESIDUES IN LAYSAN DUCK FEATHERS. In Marine Pollution Bulletin, vol. 12, no. 10, pp. 354-355, (1981). D.L. Stoneburner and C.S. Harrison (Institute of Ecology, University of Georgia, Athens, Georgia 30602; U.S. Fish and Wildlife Service, P.O. Box 50167, Honolulu, Hawaii 96850).

ABSTRACT

The heavy metal data presented herein indicate that the wild Laysan Duck population may not be contaminated with metal-laden industrial wastes. It is therefore possible that the food chain which supports the duck population is uncontaminated, with the possible exception of prey taken from pelagic sea bird carcasses. Such a short, geographically isolated food chain, involving a non-migratory avian carnivore, could be an ideal system for the investigation of bio-concentration, bio-accumulation and bio-magnification of naturally occurring heavy metals.

HEAVY METAL RESIDUES IN SOOTY TERN TISSUES FROM THE GULF OF MEXICO AND NORTH CENTRAL PACIFIC OCEAN. In The Science of the Total Environment, vol. 17, pp. 51-58, (©1981 Elsevier Scientific Publishing Company). D.L. Stoneburner and C.S. Harrison (Institute of Ecology, University of Georgia, Athens, Georgia 30602; U.S. Fish and Wildlife Service, P.O. Box 50167, Honolulu, Hawaii 96820).

ABSTRACT

The comparison of mean cadmium, mercury and selenium concentrations in the eggs, feathers and body tissues of breeding Sooty Tern from the Dry Tortugas, Florida, and Lisianski Island, Hawaii, supports the hypothesis that a physiological mechanism exists which functions in the detoxification of heavy metals. The data, collected from two geographically isolated populations of this pelagic bird, indicate that the mechanism responds in a uniform manner to widely different environmental levels of heavy metals. Our data and observations suggest that the mechanism evolved in response to natural fluxes of heavy metal concentrations in the marine ecosystem, not in response to recent injections of heavy metal laden industrial wastes.

SEABIRD PREDATION ON THE SEA-SKATER *HALOBATES SERICEUS* (HETEROPTERA: GERRIDAE). In *Marine Biology*, vol. 74, pp. 303-309, (©1983 Springer-Verlag). L. Cheng and C.S. Harrison (Scripps Institution of Oceanography, University of California, La Jolla, California 92093; U.S. Fish and Wildlife Service, P.O. Box 50167, Honolulu, Hawaii 96850).

ABSTRACT

Regurgitated food samples were collected from 18 species of seabirds on 8 of the Northwestern Hawaiian Islands between February 1978 and February 1981. Sea-skaters (*Halobates sericeus*) was found in the diets of 9 species, but can be considered to be an important food item for only 4 species: the blue-gray noddy (*Procelsterna cerulea*); the bonin petrel (*Pterodroma hypoleuca*); the gray-backed tern (*Sterna lunata*); and Bulwer's petrel (*Bulweria bulwerii*). The blue-gray noddy, by far the most important avian predator of *Halobates* spp., may at times feed exclusively on this food item and may appreciably reduce the populations of sea-skaters within their foraging territories.

THE HAWAIIAN MONK SEAL ON LAYSAN ISLAND: 1982. Doris J. Alcorn (Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, P.O. Box 3830, Honolulu, Hawaii 96812). Published by U.S. Department of Commerce, NOAA Technical Memorandum NMFS, NOAA-TM-NMFS-SWFC-42, 37 pp., 1984.

ABSTRACT

A 3-1/2 month observational study of the endangered Hawaiian monk seal, Monachus schauinslandi, was conducted on Laysan Island from 15 March to 30 June, and an additional census was conducted on 10 July 1982. Monk seals were identified by natural markings and scars, and an identification file including sketches and photographs was established. A census was conducted approximately every 2 days. Reproduction, injuries, and mortalities were monitored, and scats, spews, and net flotsam were collected.

Total beach counts, excluding pups, ranged from 66 to 119 and averaged 90 seals. Thirty pups were born, and the average lactation period (for 16 mothers) was 39.4 days.

Five seals died, two of which were nursing pups. At least nine injuries occurred, two of which were serious. Three nonfatal entanglements in debris were seen, and 26 net and rope fragments capable of entangling seals were found and sampled.

Collections were made of 40 parasitic scat samples, 210 scats, 7 spews, and specimens from 3 necropsies.

Three observations not previously reported for Hawaiian monk seals were: 1) sharks killed and consumed a monk seal, 2) a pup suckled on its natural mother and a foster mother long enough to comprise a total nursing period twice the normal period, and 3) interatoll movement of an adult female was recorded wherein she pupped on Laysan Island and moved to Lisianski Island to molt.

REVISED BIBLIOGRAPHY OF THE HAWAIIAN MONK SEAL MONACHUS SCHAUINSLANDI MATSCHIE 1905. George H. Balazs* and G. Causey Whittow (Hawaii Institute of Marine Biology, P.O. Box 1346, Kaneohe, Hawaii 96744; John A. Burns School of Medicine, Department of Physiology, and Pacific Biomedical Research Center, Kewalo Marine Laboratory, Honolulu, Hawaii 96822). Published by University of Hawaii Sea Grant College Program Miscellaneous Report UNIHI-SEAGRANT-MR-79-03, 79 pp., 1979.

AUTHOR'S ABSTRACT

A comprehensive bibliography of 416 references is presented on the subject of the Hawaiian monk seal, *Monachus schauinslandi*. In addition to books and papers in scientific journals, the bibliography includes newspaper articles and unpublished reports known to the authors current to January 1979.

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DIVING PATTERNS OF THE HAWAIIAN MONK SEAL, LISIANSKI ISLAND, 1982. Fredrick V. Schlexer (Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, P.O. Box 3830, Honolulu, Hawaii 96812). Published by U.S. Department of Commerce, NOAA Technical Memorandum NMFS, NOAA-TM-NMFS-SWFC-41, 4 pp., 1984.

ABSTRACT

Depth of dive data were obtained from seven Hawaiian monk seals instrumented with multiple depth of dive recorders (MDR's) at Lisianski Island, Northwestern Hawaiian Islands, 1 July-14 September 1982. Data were obtained from the following seals: 4 adult males, 1 subadult female, 1 juvenile male, and 1 juvenile female. The mean depth of dives was greater than 36 m (20 fathoms). Some dives were recorded in the maximum recording range of the MDR's used, 150-180 m.

GROWTH RATES OF IMMATURE GREEN TURTLES IN THE HAWAIIAN ARCHIPELAGO. In Biology and Conservation of Sea Turtles, ed. K.A. Bjorndal, pp. 117-125, (1982). Proceedings of the World Conference on Sea Turtle Conservation, Smithsonian Institution Press. George H. Balazs* (Hawaii Institute of Marine Biology, P.O. Box 1346, Kaneohe, Hawaii 96744).

AUTHOR'S ABSTRACT

Tag and recapture studies of immature green turtles (*Chelonia mydas*) living at six locations throughout the Hawaiian islands revealed mean growth rates ranging from only 8 mm to 44 mm per month in carapace length. Green turtles in the northwestern segment of the archipelago were found to exhibit the slowest rates of growth. This appears to be due to limitations on the sources and abundance of acceptable marine benthic algae used for food. The slow growth rates, and protracted time estimated as being needed to reach sexual maturity, may have significant implication with respect to mortality rates and recruitment to the breeding colony.

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RECOVERY RECORDS OF ADULT GREEN TURTLES OBSERVED OR ORIGINALLY TAGGED AT FRENCH FRIGATE SHOALS, NORTHWESTERN HAWAIIAN ISLANDS.

George H. Balazs* (Hawaii Institute of Marine Biology, P.O. Box 1346, Kaneohe, Hawaii 96744). Published by University of Hawaii Sea Grant College Program Cooperative Report UNIHI-SEAGRANT-CR-83-03, 42 pp., 1982. Also, U.S. Department of Commerce, NOAA Technical Memorandum NMFS, NOAA-TM-NMFS-SWFC-36.

AUTHOR'S ABSTRACT

An analysis is presented of tag recoveries resulting from 10 years (1973-83) of research monitoring the migratory breeding colony of the Hawaiian green turtle, *Chelonia mydas*. Tag recovery records during this period were made for 207 adult females and 87 adult males. Data summaries are given on the aspects of long-distance migrations, reproductive cycles, site fixity, longevity, and tag shedding.

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STATUS OF SEA TURTLES IN THE CENTRAL PACIFIC OCEAN. In Biology and Conservation of Sea Turtles, ed. K.A. Bjorndal, pp. 243-252, (1982). Proceedings of the World Conference on Sea Turtle Conservation, Smithsonian Institution Press. George H. Balazs* (Hawaii Institute of Marine Biology, P.O. Box 1356, Kaneohe, Hawaii 96744).

AUTHOR'S ABSTRACT

The conservation status of sea turtle populations is summarized and discussed for the Central Pacific locations of the Hawaiian Archipelago, Line Islands, Phoenix Islands, Cook Islands, American Samoa, Western Samoa, Tokelau, Tuvalu, Wake, Johnston, Howland and Baker. While incomplete information exists for many of these areas, there is nevertheless evidence to indicate that the numbers of turtles have declined within historical times. Only those islands under United States jurisdiction currently have governmental regulations pertaining to sea turtles.

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SYNOPSIS OF BIOLOGICAL DATA ON THE GREEN TURTLE IN THE HAWAIIAN ISLANDS. George H. Balazs* (Hawaii Institute of Marine Biology, P.O. Box 1346, Kaneohe, Hawaii 96744). Published by University of Hawaii Sea Grant College Program Cooperative Report UNIHI-SEAGRANT-CR-81-02, 141 pp., 1980. Also, U.S. Department of Commerce, NOAA Technical Memorandum NMFS, NOAA-TM-NMFS-SWFC-7.

AUTHOR'S ABSTRACT

A comprehensive synopsis is presented of all known biological, ecological, and other information relevant to the natural history of the green turtle (*Chelonia mydas*) population in the Hawaiian Archipelago. Data are derived from both a review of the existing published literature, as well as original research conducted by the author. The bibliography contains 670 citations current to September 1979.

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RADIO TELEMETRY OF HAWAIIAN GREEN TURTLES AT THEIR BREEDING COLONY. In _Marine Fisheries Review_, vol. 44, no. 5, pp. 13-20, (1982). Andrew E. Dizon and George H. Balazs* (Southwest Fisheries Center, National Marine Fisheries Service, NOAA, P.O. Box 271, La Jolla, California 92038; Hawaii Institute of Marine Biology, P.O. Box 1346, Kaneohe, Hawaii 96744).

ABSTRACT

Little is known about the range and movements of green turtles, _Chelonia mydas_, during the critical period of their life history when they gather on their breeding grounds to copulate and nest. In order to investigate these behaviors, we developed radio telemetry techniques to determine position and environmental temperature. Access to the turtles is facilitated because Hawaiian _Chelonia_ have a unique behavior of land basking. For about 3 weeks in the middle of the breeding season, we plotted the movements of four males and four females.

This report concentrates primarily on tracking methods, but we also discuss the distribution of the turtles and their fidelity to the nesting beach. Although there are two nesting complexes of the breeding atoll and they are separated by 9 km, no movements between the two areas were observed. Both males and females remained in proximity to what we believe is their natal beach.

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BASKING BEHAVIOR OF THE HAWAIIAN GREEN TURTLE (CHELONIA MYDAS). In Pacific Science, vol. 36, no. 2, pp. 129-139, (©1982 University Press of Hawaii). G.C. Whittow and G.H. Balazs* (John A. Burns School of Medicine, Department of Physiology, and Pacific Biomedical Research Center, Kewalo Marine Laboratory, Honolulu, Hawaii 96822; Hawaii Institute of Marine Biology, P.O. Box 1346, Kaneohe, Hawaii 96744).

ABSTRACT

Observations were made on green turtles basking on the white sand beaches at French Frigate Shoals in the Northwestern Hawaiian Islands. The highest rectal temperature recorded from the basking turtles was 31.3°C, but the surface temperature of the carapace attained values as great as 42.8°C. During basking, the turtles flipped sand onto their carapaces, but they did not appear to orientate their position in relation to the sun. The duration of basking was inversely related to the mean temperature of a black globe, and the basking beaches were relatively cool. The pattern of breathing during basking consisted of periods of breath-holding alternating with single breaths. The amount of time that the turtles basked varied from 0.3 to 7.5 percent of the total time they were under observation. The biological significance of basking and the advantages that might accrue to Hawaiian green turtles from their unique basking behavior are discussed.

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THE THERMAL BIOLOGY OF HAWAIIAN BASKING GREEN TURTLES (*CHELONIA MYDAS*). In *American Zoologist*, vol. 19, no. 3, (1979). G.C. Whittow and G.H. Balazs* (Pacific Biomedical Research Center, Kewalo Marine Laboratory, Honolulu, Hawaii 96822; Hawaii Institute of Marine Biology, P.O. Box 1346, Kaneohe, Hawaii 96744).

ABSTRACT

Observations were made on green turtles basking on the white sand beaches at French Frigate Shoals in the Northwestern Hawaiian Islands. The highest rectal temperature recorded from the basking turtles was 31.39°C, but the surface temperature of the carapace attained values as great as 42°C. During basking, the turtles flipped sand onto their carapaces but they did not seem to orientate their position in relation to that of the sun. The duration of basking appeared to be inversely related to the mean black-globe temperature, and the basking beaches were relatively cool. The pattern of breathing during basking consisted of periods of breath-holding (x = 219 sec) alternating with single breaths. Among the advantages which might accrue to Hawaiian sea turtles from their unique basking behavior, evasion of tiger sharks, their main predator, may be important.

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ACROPORA IN HAWAII. PART 1. HISTORY OF THE SCIENTIFIC RECORD, SYSTEMATICS, AND ECOLOGY. In *Pacific Science*, vol. 35, no. 1, (©1981 University Press of Hawaii). Richard W. Grigg, John W. Wells, and Carden Wallace (Hawaii Institute of Marine Biology, P.O. Box 1346, Kaneohe, Hawaii 96744; Cornell University, Department of Geological Sciences, Ithaca, New York 14850; James Cook University of North Queensland, Queensland, Australia 4811).

ABSTRACT

Present occurrence of the coral genus *Acropora* in Hawaii has long been questioned. This paper reviews the scientific literature concerning this controversy and presents the results of a recent resource survey of the entire Hawaiian Archipelago that clearly establishes the presence of three species of *Acropora* in Hawaii. These species are *Acropora cytherea*, *A. valida*, and *A. humilis*. Taxonomic descriptions for each species are presented, along with notes on their worldwide geographic distributions. In Hawaii, the three species are found only on six islands in the middle of the chain. Extension of their ranges throughout the archipelago may be limited by discontinuous and sporadic larval recruitment.

ACROPORA IN HAWAII. PART 2. ZOOGEOGRAPHY. In Pacific Science, vol. 35, no. 1, pp. 15-24, (©1981 University Press of Hawaii). Richard W. Grigg (Hawaii Institute of Marine Biology, P.O. Box 1346, Kaneohe, Hawaii 96744).

ABSTRACT

Acropora was present in Hawaii during the Miocene but disappeared from the geological record during the Pleistocene. In the present (Holocene), Acropora appears to be in the process of recolonizing the archipelago. Three species have been found, all with centers of distribution in the middle of the chain at French Frigate Shoals. The most likely source of the Acropora recolonizing Hawaii is Johnston Island by way of the subtropical countercurrent. Few other species of coral in Hawaii were extirpated during the Pleistocene. Thus the history of Acropora in the archipelago may not be representative of shallow-water marine forms in general. Nevertheless, the record of Acropora in Hawaii supports the theory that distributional discontinuities between many Pacific Island coral reef faunas are due to the net product of local extinction and recolonization.

COMMUNITY STRUCTURE, SUCCESSION AND DEVELOPMENT OF CORAL REEFS IN HAWAII. In Marine Ecology - Progress Series, vol. 11, pp. 1-14, (©1983 Inter-Research). Richard W. Grigg (Hawaii Institute of Marine Biology, P.O. Box 1346, Kaneohe, Hawaii 96744).

ABSTRACT

Reef building corals in the Hawaiian Archipelago consist of only 42 species belonging to 16 genera. The Hawaiian coral fauna is highly depauperate relative to the Indo-West Pacific Ocean, a result most likely due to geographic isolation. Although impoverished, the species composition of reef building corals is remarkably uniform throughout the archipelago. Differences in species composition which do exist appear to be caused by varying patterns of disturbance and recruitment. Although patchy distributional patterns exist within islands, the differences in species composition between islands are small. Where adequate substrata prevail within the euphotic zone most species are present. Hence species composition tends to be an all or none phenomenon. Contrary to most terrestrial ecosystems, a positive correlation does not exist between species richness and habitat area (0 to 20 m). This may be due to low habitat complexity within the zone for reef building corals and high rates of recruitment between islands. It also suggests that most reef building corals in Hawaii are generalized species. The fact that most do not drop out moving northwestward in the chain is evidence of their generalized life history (eurytopy). The most significant differences between coral reefs found on different islands, are differences in community structure. On seaward reefs differences in community structure appear to be primarily caused by differences in physical disturbance from long period swell; they can be interpreted as differences in successional age. Moving northwestward within the chain, coral growth rates steadily decline. This has the effect of lengthening the successional process and increasing the likelihood of intervening disturbance. A hypothetical model operational over generations is presented demonstrating the effect of disturbance on the successional process for coral reefs in general. The development of large-scale morphological features

such as spurs and grooves, fringing and barrier reefs and atolls involve processes operational over geological periods of time. The chronology of the Hawaiian Archipelago is now sufficiently well known to serve as a time scale against which the development of these structures can be measured.

DARWIN POINT: A THRESHOLD FOR ATOLL FORMATION. In Coral Reefs, vol. 1, pp. 29-34, (©1982 Springer-Verlag). R.W. Grigg (Hawaii Institute of Marine Biology, P.O. Box 1346, Kaneohe, Hawaii 96744).

ABSTRACT

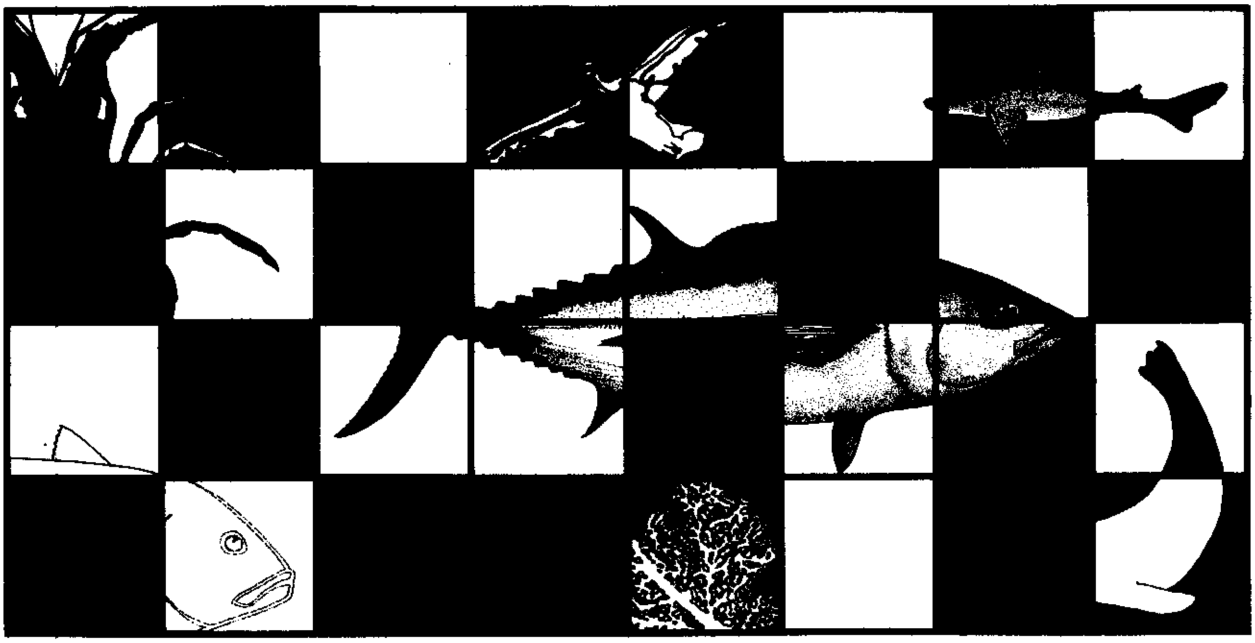
A threshold for atoll formation, herein termed the Darwin Point, exists at the northern end of the Hawaiian Archipelago at 29° N latitude. Hawaiian atolls and coral islands transported northwest by tectonic movement of the Pacific Plate appear to have "drowned" near the Darwin Point during the last 20 million years. Measures of gross carbonate production by corals across the archipelago show that growth rates decrease with increasing latitude. At the Darwin Point, corals may contribute only 20% of the calcium carbonate necessary to keep pace with recent changes in sea level and thus appear to be more important as builders of framework than producers of limestone. Reduction in this function rather than total carbonate production may be the determining factor in the formation of atolls and coral islands. Elsewhere in the world other Darwin Points may exist but probably not at the same latitude due to differences in ecological conditions, coral species composition, island area, rates of erosion and tectonic histories.

IMPACT OF A KAOLIN CLAY SPILL ON A CORAL REEF IN HAWAII. In Marine Biology, vol. 65, pp. 269-276, (©1981 Springer-Verlag). S.J. Dollar and R.W. Grigg (Hawaii Institute of Marine Biology, P.O. Box 1346, Kaneohe, Hawaii 96744).

ABSTRACT

On April 27, 1980, the Greek freighter "Anangel Liberty" went aground on the reef at French Frigate Shoals, a National Wildlife Refuge in the Hawaiian Islands. The vessel was refloated with no major damage or fuel spillage after 2,200 tons (2,200,000 kg) of koalin cargo had been jettisoned on the reef. Huge plumes of suspended clay raised major concern over the possibility of widespread ecological damage. However, field investigations conducted 14 d after the kaolin was dumped revealed that environmental impact was very minor and highly localized; it was evident that most of the kaolin had been suspended and removed from the area. The only significant damage was a 2 to 3 m deep channel plowed through the reef by the freighter. Within 50 m of both sides of the channel, some coral was smothered and colonies of *Pocillopora* spp. were alive but slightly bleached. Beyond 50 m there was no apparent impact, nor did any clay settle on the bottom. This incident illustrates that some events which initially appear to have potential pollutant impact do not produce significant and irreversible environmental changes and emphasizes the need to analyze such events on a case-by-case basis.

Abstracts of Unpublished Papers



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THE STATUS AND CONSERVATION OF SEABIRDS IN THE HAWAIIAN ARCHIPELAGO AND JOHNSTON ATOLL*

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ABSTRACT

The Hawaiian Archipelago and Johnston Atoll are important breeding areas for more than five million seabirds of 22 species. This area encompasses a large portion of the worldwide breeding range of nine species and sub-species. Today, most of the important colonies are in state or federal wildlife refuges, but strict enforcement of refuge regulations is rare or ineffective. Populations in the Northwestern Hawaiian Islands have generally recovered from the severe depredations of the early twentieth century, which included guano mining, feather hunting, and the introduction of rabbits which destroyed native vegetation and nesting habitat on important colonies. Threats today include the introduction of predators (especially rats), incidental take from military activities, competition with commercial fisheries, introduced plants, and a general exposure to the man-made threats of the twentieth century. On the main Hawaiian islands, several sub-species are in danger of extinction from introduced predators and increasing urbanization. Many conservation projects are underway and most areas are well-surveyed. Research is needed to better understand many aspects of the biology of seabirds, develop methods to recognize stress on a population, and learn to control or eliminate introduced flora and fauna. In certain areas, feral animals must be eliminated. Fisheries proposed in waters adjacent to colonies in the Northwestern Hawaiian Islands must be regulated to reduce

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*The complete paper has been accepted for publication in <u>ICBP Technical Bulletin</u> and is currently in press.

competition with birds for prey resources and to prevent the incidental introduction of exotic flora and fauna.

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BIOLOGY AND CONSERVATION OF THE LAYSAN DUCK (ANAS LAYSANENSIS)*

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ABSTRACT

A two-summer study of Laysan Ducks (Anas laysanensis) resulted in a population estimate of 500 based on mark-recapture methods with over 90 percent of the population marked. The recommended estimation technique for non-banded populations is based on crepuscular or nocturnal rather than diurnal observations.

Nesting occurred in spring and early summer in spite of the subtropical climatic regime. Nests were mainly in clumps of the grass, Eragrostis, and hatching success was low, due in part to egg predation by Laysan Finches (Telespyza cantans). Only a small proportion of nesting hens seem successful in rearing young. Duckling mortality due to exposure is common during rainstorms, but no direct predation was noted. The species seems to be long-lived and with a low reproductive rate as is common in K-selected species.

Pair bond characteristics resemble those of continental populations of Mallards. Pairs are conspicuous in spring and bonds last until incubation is well along. Males tend to return to mates after brood-rearing or loss of brood or nest. Year-to-year mate switching occurs over half the time even when previous mates are alive. Males do not assist in care of the brood.

During spring and summer, ducks of all ages rely heavily on invertebrate foods. Radio-marked pairs

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*The complete paper has been accepted for publication in Condor and is currently in press.

consistently used the same upland areas during the day, where they may have fed on larvae and pupae of the moth, *Agrotis dislocata*, and other terrestrial invertebrates. At night, most ducks moved to the lake to feed, and to drink at freshwater seeps, which were communal areas.

Feeding and drinking activity is dominantly crepuscular and nocturnal at the lake, but laying hens or hens with broods sometimes fed throughout the day as well. Adult brine flies (*Neoscatella sexnotata*) on the mud flats around the lake were the major food of ducks of all ages, and a late summer shift to the uplands may have been due to reduced numbers of brine flies at the lake. Nevertheless, the lake is vital to the success of the species, and it is unlikely that a significant population could survive on terrestrial resources alone. The species make little use of tidal areas expect for bathing.

Conservation of the species requires monitoring of duck populations and habitat conditions, and surveillance for accidentally introduced predators such as rats. Intensive management will be necessary only if blowing sands fill the lake, predators become established, or the vegetation is seriously damaged in some way.

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ENCOUNTERS OF HAWAIIAN MONK SEALS WITH FISHING GEAR AT LISIANSKI ISLAND, 1982*

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ABSTRACT

During a 6 month field study at Lisianski Island in 1982, 10 of the 26 pups born there (38.5%) were observed to investigate or become entangled in lost or discarded netting or line. Four of these pups became entangled in debris, necessitating release by biologists. Twenty-one net fragments which washed ashore were cataloged and sampled, suggesting that such debris may be ubiquitous in the waters surrounding the Northwestern Hawaiian Islands. Presence of such debris, coupled with a general propensity of monk seal pups to explore the reef environment, could lead to mortality of Hawaiian monk seal pups.

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*The complete paper has been accepted for publication in Marine Fisheries Review and is currently in press.

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EFFECTS OF TAGGING ON MONK SEAL PUPS: PRELIMINARY RESULTS

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ABSTRACT

To assess potential effects of tagging on Hawaiian monk seal pups, one half (n=13) of the 1982 pup cohort at Lisianski Island were tagged and marked at weaning, while the remaining 13 were only marked. For 6 months the pups' presence and location on the island, duration of trips away from the island, and behavior while on the island were monitored. Preliminary analysis of the movement and haulout patterns revealed no significant difference between the tagged and non-tagged groups.

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RECOVERY PLAN FOR THE HAWAIIAN MONK SEAL, MONACHUS SCHAUINSLANDI

William G. Gilmartin

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ABSTRACT

This recovery plan is a "working plan" prepared by a knowledgeable team of scientists to guide research and management which will aid the recovery of the endangered Hawaiian monk seal. The plan presents available information concerning the background and present status of the species, identifies problems (both biological and human related), outlines a plan of research addressing these problems, and recommends management policies.

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FIRST OBSERVATION OF A FATAL SHARK ATTACK ON A HAWAIIAN MONK SEAL

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ABSTRACT

Sharks fatally attacked a Hawaiian monk seal on 28 May 1982 off Laysan Island, Northwestern Hawaiian Islands. Two species of sharks were present (tiger sharks, *Galeocerdo cuvier*, and gray reef sharks, *Carcharhinus amblyrhynchos*), and it is thought that tiger sharks initiated the attack. The victim of the attack was a subadult with dorsal injuries apparently inflicted by adult male seals at least 2 days prior to the shark attack.

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THE HAWAIIAN MONK SEAL, *MONACHUS SCHAUINSLANDI*, AT FRENCH FRIGATE SHOALS, 1982

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ABSTRACT

This report presents information collected during 1982 at French Frigate Shoals on the Hawaiian monk seal. Data are from 8 of the 12 low sandy islets, and include the following: identification of individuals (based on natural markings), census results, haulout patterns, reproduction, wounds, entrapments, deaths, and miscellaneous observations.

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HAWAIIAN MONK SEAL POPULATION RESEARCH, LISIANSKI ISLAND, 1982

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ABSTRACT

The absolute number of Hawaiian monk seal, *Monachus schauinslandi*, in the population at Lisianski Island was determined by identifying individuals on the basis of applied bleach numbers or natural marks, and conducting 98 island censuses 17 March to 14 September, and 26 October to 22 November, 1982. The alternate day censuses provided data on temporal and spatial haulout patterns for individual seals. Data were collected daily on pupping, weaning, molting, and other factors that may influence haulout patterns. Injuries, deaths, and entanglements in fishing gear and other debris were documented.

In addition to 28 pups of the year, 215 seals consisting of the following were identified: 18 male and 10 female juveniles, 24 male and 21 female subadults, and 101 male and 41 female adults. Only two of these seals (an adult female and adult male) were known to have moved to Lisianski Island from other islands during the study. Three pups died, and a subadult female disappeared and is presumed dead. There were three serious injuries: two adult females with dorsal wounds, and a shark-injured adult male. Four weaned pups had to be removed from entangling debris, and other entanglements were seen.

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SCAT AND SPEW ANALYSIS OF THE HAWAIIAN MONK SEAL, *MONACHUS SCHAUINSLANDI*

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ABSTRACT

Monk seal scats and spews were collected at five locations in the Northwestern Hawaiian Islands (Kure Atoll, Pearl and Hermes Reef, Lisianski Island, Laysan Island, and French Frigate Shoals). Preliminary identification of fish scales and cephalopod beaks has been made on materials collected through 1982, and a list of prey items is included in this report. A comprehensive analysis of monk seal food items is ongoing.

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FECUNDITY OF THE SPINY LOBSTER, *PANULIRUS MARGINATUS* (QUOY AND GAIMARD), IN THE NORTHWESTERN HAWAIIAN ISLANDS

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ABSTRACT

Fecundity estimates were made for the spiny lobster, *Panulirus marginatus*, based on 75 berried females collected in the Northwestern Hawaiian Islands. Eggs from 22 berried females ranging in size from 53.1 to 143.8 mm carapace length were examined for differences in egg size within the brood. Variation in fecundity of spiny lobsters from Necker Island and Maro Reef was examined also. The number of eggs carried (113,000 to 1,021,000) generally increased in relationship to an increase in carapace length.

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DETERMINATION OF SIZE AT MATURITY IN THE HAWAIIAN SPINY LOBSTER, *PANULIRUS MARGINATUS*, FROM CHANGES IN RELATIVE GROWTH

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ABSTRACT

The size (carapace length, CL) at maturity of two populations of *Panulirus marginatus* (Quoy and Gaimard 1825) from Oahu and Necker Islands, Hawaii, were studied. Three regression analysis procedures were used to estimate size at maturity from changes in the allometric growth of some pairs of the walking legs. Estimates of the size at maturity were 58.6 mm CL for the females around Oahu and 60.7 mm CL for those at Necker Island. The males' estimated size at maturity around Necker Island was 59.2 mm CL and 63.6 mm CL around Oahu. On the basis of these results, it appeared that there were no significant differences in size at maturity between either sex or locality studies. Several general models for allometric growth are discussed as well as methods for fitting them. The use of changes in allometric growth to estimate size at maturity versus the more commonly used method and probability plots of the proportions of mature specimens in given size classes, are also discussed.

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NOTES ON THE DIETS OF HERBIVOROUS FISHES FROM THE NORTHWESTERN HAWAIIAN ISLANDS

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ABSTRACT

Diets of suspected herbivorous and omnivorous fishes from Midway and French Frigate Shoals were examined as part of a larger study of the trophic relationships of inshore fishes. Algal gut contents were systematically analyzed from 189 specimens of 24 common species in nine families. These included almost all of the most numerous species that might be expected to be of greatest ecological significance as herbivores.

Surgeonfishes (Acanthuridae) were found to contain a wide variety of brown, red, and green algae. The phaeophyte, *Lobophora variegata*, was a dominant, identifiable algal species, which occurred in the guts of *Acanthurus nigroris*, *A. leucoparieus*, *A. olivaceus*, *Naso unicornis*, and *N. lituratus*. In 20 specimens examined of the two Naso species, *L. variegata* comprised about 90 percent of the gut contents. The chlorophyte, *Boodlea composita*, also occurred widely among the diets of acanthurid species. Two balistid species, *Melichthys niger* and *M. vidua*, were heavy algal consumers. Their gut contents were dominated by brown, green, and red algae, especially greens and corallines. The nenue, *Kyphosus bigibbus*, fed primarily on algae (browns, reds, and especially greens), with *Lobophora variegata* and large quantities of *Halimeda opuntia* identified. Guts of three parrotfish (Scaridae) species contained a milky chyme consisting of fine calcium carbonate particles and digested algae. This is consistent with the common observation of scarids feeding by scraping algae from coral surfaces. *Boodlea composita*, *Acanthophora spicifera*, *Laurencia sp.*, *Grateloupia sp.* and *Siphonocladus tropicus* were

identifiable in these contents. The latter two algae also occurred among the acanthurids.

Of four species of butterflyfishes examined, only *Chaetodon fremblii* contained significant algae. All identifiable food in its guts was green algae, including *Halimeda*. Among the damselfishes (Pomacentridae), only *Abudefduf abdominalis* and the abundant *Dascyllus albisella* were analyzed. Over 60 percent of *Abudefduf* specimens contained algae, including browns, reds, and greens. Less than 20 percent of *Dascyllus* specimens contained algae, including browns, greens, and some filamentous forms. Both these pomacentrids contained small crustaceans as well; for *Dascyllus* this animal prey seemed to dominate the diet. *Centropyge potteri*, the only abundant pomacanthid species, appeared to consume considerable algae (mostly greens) and very little else. Of all the specimens of the common puffer, *Canthigaster jactator*, that contained food, algae (primarily reds and particularly corallines) occurred in a little less than 40 percent, mixed with a variety of benthic invertebrates. Additional fish species examined that contained traces of algae were *Flammeo sammara*, *Thalassoma ballieui*, *T. duperrey*, *Parupeneus pleurostigma*, *Priacanthus meeki*, and *Pervagor spilosoma*.

In total, at least 20 species of fish out of 129 species examined appeared to eat substantial quantities of algae. It is probably reasonable to characterize 18 species as obligate herbivores, even though some amount of animal food may be taken as well. Several of the herbivorous species, especially some of the acanthurids and scarids, are quite widespread and abundant, although they appear subjectively to be less so than in similar high island situations. Based on the number of predator individuals within which various prey types occurred and the relative species composition of the complete fish community as determined by quantitative collections of patch reefs, algae directly provide about 8 percent of the food base for the entire fish community. Fish herbivory is clearly an important trophic pathway in these reef communities.

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FOOD AND FEEDING HABITS OF THE WAHOO, ACANTHOCYBIUM SOLANDRI, IN THE NORTHWESTERN HAWAIIAN ISLAND WATERS

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ABSTRACT

Wahoo, *Acanthocybium solandri*, stomachs collected from fish caught during 1976-82 in the Northwestern Hawaiian Islands (NWHI) were examined for food contents and stomach parasites. Approximately 85% of the stomachs contained food items. Wahoo feed on fish, cephalopods, and to a small extent, crustaceans. Fish were the major prey items and *Decapterus* sp., Monocanthidae, Scombridae, and Acanthuridae occurred most frequently in the stomachs. Cephalopods consisted mostly of Teuthoidea. Crab megalops and Squillidae represented the small crustacean portion of wahoo diet. Although wahoo feed on a wide variety (approximately 30 families) of prey items, in the NWHI they feed heavily on a relative few, primarily littoral, species such as *Decapterus* sp. and monocanthids. *Decapterus* sp. was the major prey item in every season except summer, during which tine monocanthids were more important followed by *Decapterus* sp. Gastric parasites included trematodes, nematodes, and cestodes. A large trematode, *Hirudinella ventricosa*, occurred in 100% of the stomachs. Cestodes of the order Trypanorhynca occurred in 10.7%. Unidentified nematodes occurred in 2.2% of stomachs. Wahoo in the NWHI probably patrol the outer reefs and banks for the majority of their food, feeding on prey in depths ranging from near the surface to close to the bottom.

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AHERMATYPIC SCLERACTINIA FROM THE HAWAIIAN ISLANDS

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ABSTRACT

Eleven hundred fifty specimens of ahermatypic ("deep-water") Scleractinia were examined from 185 stations made throughout the Hawaiian Islands. Forty-two of these stations were made by the National Marine Fisheries Service vessels Townsend Cromwell and David Star Jordan. A total of 54 ahermatypic species are now known from the Hawaiian Islands, 19 of which are new records. Twenty-one species extend to the Northwestern Hawaiian Islands or have been taken only from there. Eight new species are described in the genera: Fungiacyathus, Caryophyllia, Premocyathus, Deltocyathus, Troch-ocyathus, Coenosmilia, Flabellum, and Cladopsammia. Forty-two species of hermatypic ("reef") Scleractinia are known from the Hawaiian Islands (Grigg and Wells, 1981), bringing the scleractinian fauna to 96. Clearly, there are more species of deep-water corals than shallow, a ratio also found in the Atlantic Ocean but not in the Indo-West Pacific, where hermatypes are so prolific.

Zoogeographically, the Hawaiian deep-water Scleractinia are an attenuated Indo-Pacific fauna, with no relationship to the eastern Pacific. Seventeen percent of the fauna is cosmopolitan, 15 percent Indo-West Pacific, 17 percent is found throughout the central and western Pacific, and 48 percent is endemic (one species has a disjunct distribution in the eastern Atlantic). The percentage of endemism, cited as 70 percent by Vaughan and Wells (1943), will probably continue to fall as the Indo-West Pacific fauna becomes better known. Hawaiian ahermatypes have been collected between 29 and 2,056 m; however, they are most common between 200 and 500 m.

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TRAPPING SURVEYS FOR THE DEEPWATER CARIDEAN SHRIMPS, *HETEROCARPUS LAEVIGATUS* AND *H. ENSIFER*, IN THE NORTHWESTERN HAWAIIAN ISLANDS

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ABSTRACT

Baited traps were used to assess the geographical and depth distribution of the deepwater caridean shrimps, *Heterocarpus laevigatus* and *H. ensifer*, in the Northwestern Hawaiian Islands. Traps were set in depths ranging from about 290 to 880 m. Both species occurred throughout the length of the chain. Catch rates varied markedly with depth. Highest catches of *H. laevigatus* were made in 500-800 m, and the mean catch rate was 0.91 kg per trap-night. For *H. ensifer* optimum trapping depths were 350-600 m, and the mean catch rate was 1.66 kg per trap-night. For both species mean catch rates were the same for spring-summer and fall-winter seasons.

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GROUNDFISH FISHERIES AND RESEARCH IN THE VICINITY OF SEAMOUNTS IN THE NORTH PACIFIC OCEAN

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ABSTRACT

The trawl fishery over the central North Pacific seamounts expanded rapidly after exploratory fishing by Soviet trawlers in 1967 demonstrated commercial concentrations of pelagic armorhead, *Pentaceros richardsoni*, and smaller quantities of alfonsin, *Beryx splendens*. In 1969, Japanese trawlers entered the fishery but experienced wide catch fluctuations in 1969-71. After 1971, the fishery stabilized and the catch peaked to 34,538 metric tons (MT) in 1974.

Hancock Seamounts, which fall within the U.S. Fishery Conservation Zone around the Hawaiian Archipelago, were fished in 1972-76 by Japanese trawlers which produced annual catches from 653 to 8,518 MT. In 1978-81, United States observers accompanied three Japanese trawlers that made six trips to Hancock Seamounts. Observer data indicated that the pelagic armorhead stock had recovered to some extent from the intense fishing prior to 1977. The catch per unit of effort in 1980 and 1981 improved and showed an upward trend.

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CURRENT TRENDS IN HAWAIIAN FISHERIES

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ABSTRACT

Existing data of commercial fishery landings in the State of Hawaii for the years 1961 to 1981 are presented. Historically, practically all of the fishery landings in the past were of species harvested in close proximity to the main Hawaiian Islands; however, in recent years waters around the Northwestern Hawaiian Islands have become increasingly important as major commercial fishing areas to the State of Hawaii. The current status and description of the major fisheries and the newly developing fisheries are also presented.

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FISHERY ATLAS OF THE NORTHWESTERN HAWAIIAN ISLANDS

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ABSTRACT

This atlas contains historical background and descriptions of the islands, atolls, banks, reefs, and seamounts in the Northwestern Hawaiian Islands. Also included are descriptions of the climatic, oceanographic, and biological characteristics of the area, and descriptions of fishing gears used to sample the marine resources. Of the species in 109 families of crustaceans, molluscs, and fishes found in the waters of the area, only a few are thought to be of any commercial value. The atlas also provides information on geographic and depth distributions, biology, and ecology of commercially important species and an extensive literature citation.