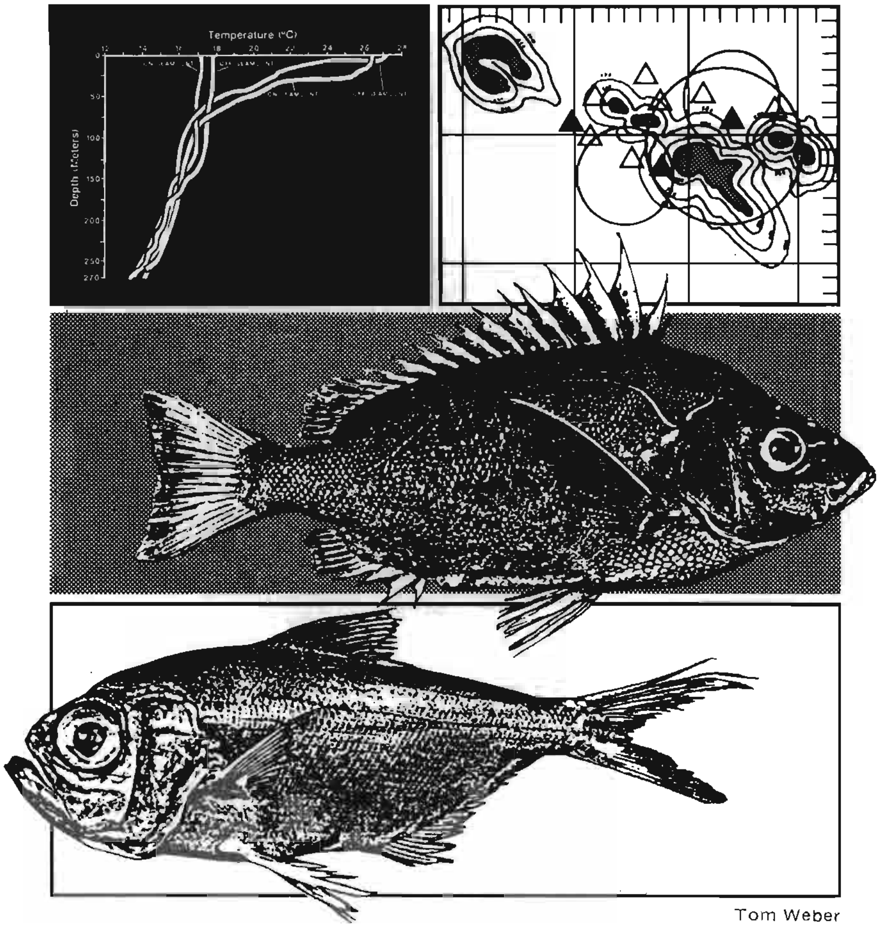
NOAA Technical Report NMFS 43 September 1986

Environment and Resources of Seamounts in the North Pacific

Richard N. Uchida, Sigeiti Hayasi, and George W. Boehlert *editors*



Tom Weber

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service

NOAA TECHNICAL REPORT NMFS

The major responsibilities of the National Marine Fisheries Service (NMFS) are to monitor and assess the abundance and geographic distribution of fishery resources, to understand and predict fluctuations in the quantity and distribution of these resources, and to establish levels for their optimum use. NMFS is also charged with the development and implementation of policies for managing national fishing grounds, development and enforcement of domestic fisheries regulations, surveillance of foreign fishing off United States coastal waters, and the development and enforcement of international fishery agreements and policies. NMFS also assists the fishing industry through marketing service and economic analysis programs, and mortgage insurance and vessel construction subsidies. It collects, analyzes, and publishes statistics on various phases of the industry.

The NOAA Technical Report NMFS series was established in 1983 to replace two subcategories of the Technical Reports series: "Special Scientific Report—Fisheries" and "Circular." The series contains the following types of reports: Scientific investigations that document long-term continuing programs of NMFS; intensive scientific reports on studies of restricted scope; papers on applied fishery problems; technical reports of general interest intended to aid conservation and management; reports that review in considerable detail and at a high technical level certain broad areas of research; and technical papers originating in economics studies and from management investigations. Since this is a formal series, all submitted papers receive peer review and those accepted receive professional editing before publication.

Copies of NOAA Technical Reports NMFS are available free in limited numbers to governmental agencies, both Federal and State. They are also available in exchange for other scientific and technical publications in the marine sciences. Individual copies may be obtained from: U.S. Department of Commerce, National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161. Although the contents have not been copyrighted and may be reprinted entirely, reference to source is appreciated.

1. Synopsis of biological data on the Blue Crab, *Callinectes sapidus* Rathbun, by Mark R. Millikin and Austin B. Williams. March 1984, 39 p.

2. Development of hexagrammids (Pisces: Scorpaeniformes) in the Northeastern Pacific Ocean, by Arthur W. Kendall, Jr., and Beverly Vinter. March 1984, 44 p.

3. Configurations and relative efficiencies of shrimp trawls employed in southeastern United States waters, by John W. Watson, Jr., Ian K. Workman, Charles W. Taylor, and Anthony F. Serra. March 1984, 12 p.

4. Management of northern fur seals on the Pribilof Islands, Alaska, 1786-1981, by Alton Y. Roppel. April 1984, 26 p.

5. Net phytoplankton and zooplankton in the New York Bight, January 1976 to February 1978, with comments on the effects of wind, Gulf Stream eddies, and slope water intrusions, by Daniel E. Smith and Jack W. Jossi. May 1984, 41 p.

6. Ichthyoplankton survey of the estuarine and inshore waters of the Florida Everglades, May 1971 to February 1972, by L. Alan Collins, and John H. Finucane. July 1984, 75 p.

7. The feeding ecology of some zooplankters that are important prey items of larval fish, by Jefferson T. Turner. July 1984, 28 p.

8. Proceedings of the International Workshop on Age Determination of Oceanic Pelagic Fishes: Tunas, Billfishes, and Sharks, by Eric D. Prince (convener and editor), and Lynn M. Pulos (editor). December 1983, 211 p.

9. Sampling statistics in the Atlantic menhaden fishery, by Alexander J. Chester. August 1984, 16 p.

10. Proceedings of the Seventh U.S.-Japan Meeting on Aquaculture, Marine Finfish Culture, Tokyo, Japan, October 3-4, 1978, by Carl J. Sindermann (editor). August 1984, 31 p.

11. Taxonomy of North American fish Eimeriidae, by Steve J. Upton, David W. Reduker, William L. Current, and Donald W. Duszynski. August 1984, 18 p.

12. Soviet-American Cooperative Research on Marine Mammals. Volume 1—Pinnipeds, by Francis H. Fay, and Gennadii A. Fedoseev (editors). September 1984, 104 p.

13. Guidelines for reducing porpoise mortality in tuna purse seining, by James M. Coe, David B. Holts, and Richard W. Butler. September 1984, 16 p.

14. Synopsis of biological data on shortnose sturgeon, *Acipenser brevirostrum* LeSueur 1818, by Michael J. Dadswell, Bruce D. Taubert, Thomas S. Squiers, Donald Marchette, and Jack Buckley. October 1984, 45 p.

15. Chaetognatha of the Caribbean sea and adjacent areas, by Harding B. Michel. October 1984, 33 p.

16. Proceedings of the Ninth and Tenth U.S.-Japan Meetings on Aquaculture, by Carl J. Sindermann (editor). November 1984, 92 p.

17. Identification and estimation of size from the beaks of 18 species of cephalopods from the Pacific Ocean, by Gary A. Wolff. November 1984, 50 p.

18. A temporal and spatial study of invertebrate communities associated with hard-bottom habitats in the South Atlantic Bight, by E. L. Wenner, P. Hinde, D. M. Knott, and R. F. Van Dolah. November 1984, 104 p.

19. Synopsis of biological data on spottail pinfish, *Diplodus holbrooki* (Pisces: Sparidae), by George H. Darcy. January 1985, 11 p.

20. Ichthyoplankton of the Continental Shelf near Kodiak Island, Alaska, by Arthur W. Kendall, Jr., and Jean R. Dunn. January 1985, 89 p.

21. Annotated bibliography on hypoxia and its effects on marine life, with emphasis on the Gulf of Mexico, by Maurice L. Renaud. February 1985, 9 p.

22. Congrid eels of the eastern Pacific and key to their Leptocephali, by Solomon N. Raju. February 1985, 19 p.

23. Synopsis of biological data on the pinfish, *Lagodon rhomboides* (Pisces:Sparidae), by George H. Darcy. February 1985, 32 p.

24. Temperature conditions in the cold pool 1977-81: A comparison between southern New England and New York transects, by Steven K. Cook. February 1985, 22 p.

25. Parasitology and pathology of marine organisms of the world ocean, by William J. Hargis, Jr. (editor). March 1985, 135 p.

26. Synopsis of biological data on the sand perch, *Diplectrum formosum* (Pisces: Serranidae), by George H. Darcy. March 1985, 21 p.

27. Proceedings of the Eleventh U.S.-Japan Meeting on Aquaculture, Salmon Enhancement, Tokyo, Japan, October 19-20, 1982, by Carl J. Sindermann (editor). March 1985, 102 p.

28. Review of geographical stocks of tropical dolphins (*Stenella* spp. and *Delphinus delphis*) in the eastern Pacific, by William F. Perrin, Michael D. Scott, G. Jay Walker, and Virginia L. Cass. March 1985, 28 p.

29. Prevalence, intensity, longevity, and persistence of *Anisakis* sp. larvae and *Lacistorhynchus tenuis* metacestodes in San Francisco striped bass, by Mike Moser, Judy A. Sakanari, Carol A. Reilly, and Jeannette Whipple. April 1985, 4 p.

30. Synopsis of biological data on the pink shrimp, *Pandalus borealis* Krøyer, 1838, by Sandra E. Shumway, Herbert C. Perkins, Daniel F. Schick, and Alden P. Stickney. May 1985, 57 p.

31. Shark catches from selected fisheries off the U.S. east coast, by Emory D. Anderson, John G. Casey, John J. Hoey, and W. N. Witzell. July 1985, 22 p.

32. Nutrient Distributions for Georges Bank and adjacent waters in 1979, by A. F. J. Draxler, A. Matte, R. Waldhauer, and J. E. O'Reilly. July 1985, 34 p.

33. Marine flora and fauna of the Northeastern United States. Echinodermata: Echinoidea, by D. Keith Serafy and F. Julian Fell. September 1985, 27 p.

34. Additions to a revision of the shark genus *Carcharhinus*: Synonymy of *Aprionodon* and *Hypoprion*, and description of a new species of *Carcharhinus* (Carcharhinidae), by J. A. F. Garrick. November 1985, 26 p.

35. Synoptic review of the literature on the Southern oyster drill *Thais haemastoma floridana*, by Philip A. Butler. November 1985, 9 p.

NOAA Technical Report NMFS 43

ENVIRONMENT AND RESOURCES OF SEAMOUNTS IN THE NORTH PACIFIC

PROCEEDINGS OF A WORKSHOP, MARCH 21-23, 1984 SHIMIZU, JAPAN

Richard N. Uchida
Sigeiti Hayasi
George W. Boehlert, Editors

Sponsored by:

Far Seas Fisheries Research Laboratory
Shimizu, Japan

Southwest Fisheries Center Honolulu Laboratory
National Marine Fisheries Service, NOAA
Honolulu, Hawaii

Japanese Society of Fisheries Oceanography
Tokyo, Japan

U.S. DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary
National Oceanic and Atmospheric Administration
Anthony J. Calio, Administrator
National Marine Fisheries Service
William G. Gordon, Assistant Administrator for Fisheries

CONTENTS

Session 1 **Review of oceanography in the vicinity of seamounts**
Discussion Leader, Gunnar I. Roden

Session 2 **Review of seamount fisheries**
Discussion Leader, Takashi Sasaki

Session 3 **Review of other seamount fisheries**
Discussion Leader, Richard W. Grigg

FOREWORD

RICHARD N. UCHIDA,
SIGEITI HAYASI,
GEORGE W. BOEHLERT

The trawl fishery for pelagic armorhead, *Pseudopentaceros wheeleri* (formerly referred to as *Pentaceros richardsoni*), and alfonsin, *Beryx splendens*, over the central North Pacific seamounts has a relatively short history. Before 1967, fishery scientists were generally unaware of the resources on seamounts; however, the discovery of commercial concentrations of pelagic armorhead on seamounts in the southern Emperor Seamounts by a Russian commercial trawler in November 1967 led to almost immediate exploitation of the species by the Soviets. Unconfirmed reports indicated that the schools of pelagic armorhead on the seamounts averaged 30 m thick and catches averaged from 3 to 50 metric tons on 10-20 min hauls (Sakiura 1972).

Japanese trawlers entered the fishery in 1969. To assist in the development of this fishery, Japanese research vessels conducted extensive surveys in 1972 on the distribution and potential for development of the pelagic armorhead and alfonsin resources. The results of their surveys to the central North Pacific and mid-Pacific seamounts showed that many had summits that were too deep for trawling. Those found suitable were concentrated in the southern Emperor-northern Hawaiian Ridge.

When the U.S. Magnuson Fishery Conservation and Management Act was implemented on March 1, 1977, the U.S. Government assumed exclusive management authority over all fishery resources within 200 mi of its territories except for highly migratory species (tunas). The resources on Hancock Seamounts, which are within the U.S. fishery conservation zone, in some years contributed significantly to the central North Pacific pelagic armorhead catch by the Japanese.

Despite the discovery of the pelagic armorhead resource over the central North Pacific seamounts some 17 years ago, not much is known about the life history, stock structure and identity, and population dynamics of the species. For example, in attempting an assessment of the pelagic armorhead stock, Wetherall (1978) noted a glaring lack of essential data and information on which to base his study.

Because of the inadequacy of information needed to understand the dynamics of the seamount population, the Honolulu Laboratory included seamounts in the massive Northwestern Hawaiian Islands investigation which began in October 1976. Because research on spiny lobster and bottom fish was given higher priority than seamount surveys, however, baseline data on seamount species remained inadequate for a meaningful evaluation and assessment of the stock. In 1982, the Honolulu Laboratory produced a planning document which proposed to upgrade the seamount project into a major seamount-groundfish initiative. This document reiterated the problem of inadequate data and proposed ways to obtain data essential for characterizing standing crop, productivity, trophic interactions, and population dynamics of the resource.

As the initiative developed, the Honolulu Laboratory found that there was a vital need to review the history of the fishery, to assess its present status, and to determine the direction of future research. Since it appeared that the greater part of the exploitation of the seamount groundfish involved Japanese trawling, the Honolulu Laboratory proposed in early 1983 to the Far Seas Fisheries Research Laboratory, Japan Fisheries Agency, in Shimizu, Japan, to convene a joint seamount workshop, which later expanded to include the Japanese Society of Fishery Oceanography of Tokyo, Japan, as a cosponsor. The objectives of the workshop were to review (1) what is known of the oceanography in the vicinity of seamounts, (2) the various fisheries associated with seamounts, and (3) the population characteristics and biology of seamount species (including a preliminary assessment of the stocks), and to develop hypotheses and models to guide the direction of future research.

The workshop was held on March 21-23, 1984 at the Orido Community Center, located near the Far Seas Fisheries Research Laboratory, and at the Government Port Building in Shimizu. This report includes the papers presented as well as summaries of each session prepared by the workshop cochairmen. Appendix lists the participants.

We would like to express our gratitude to two individuals who helped immensely with this volume. Dr. Hajime Yamanaka provided significant editorial work on several Japanese contributions, and Mr. Tamio Otsu translated several contributions from Japanese to English. This version, with all papers in a single language, would have been impossible without their help.

CITATIONS

SAKIURA, H. (translator).
1972. The pelagic armorhead, *Pentaceros richardsoni*, fishing grounds off the Hawaiian Islands, as viewed by the Soviets (So-Ren kara mita Hawaii oki kusakari tsubodai gyojyo). [In Jpn.] Suisan Shuho (The Fishing & Food Industry Weekly) 658:28-31, June 15, 1972. (Engl. transl. by T. Otsu, 1977, 7 p., Transl. No. 17; available Southwest Fish. Cent. Honolulu Lab., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396.)

WETHERALL, J. A.
1978. Assessment of the armorhead stock on the mid-Pacific seamounts. Southwest Fish. Cent. Honolulu Lab., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396. Admin. Rep. 1978, 19H, 11 p.

SEAMOUNTS: A BIOLOGICAL CONCOURSE IN THE OPEN SEA

An Introductory Statement

RICHARD S. SHOMURA
Southwest Fisheries Center Honolulu Laboratory
National Marine Fisheries Service, NOAA
Honolulu, Hawaii 96822-2396

In 1883, Sir Thomas Huxley expressed a view that river fisheries can be exhausted by man, but the seas held almost unlimited supplies of food (Foster and Lankester 1903). He noted that the important marine resources such as cod, herring, and mackerel were inexhaustible. A caveat in his inaugural address, which was given at the Fisheries Exhibition in London in 1883, was that these resources were inexhaustible "... in relation to our present modes of fishing." In the late 1800's it was not difficult to view the sea resources as very large and that man's fishing effort would only contribute a small fraction to the total mortality. However, today, after 100 years of fisheries exploration and expansion in the world's oceans, we know that the resources are not inexhaustible and that they can be overfished. Classic examples include the Peruvian anchovy and the Pacific sardine.

While history is proving Sir Thomas Huxley wrong on man's impact on the sea resources, his views on management of the river resources are certainly applicable to the high seas resources. He noted that river resources which have been exhausted by man's exploitation can usually be prevented because man's operations can be controlled. Thus, to optimize our harvest of the ocean resources we need to understand the dynamics of the system. This draws us to the reasons which led us to organize this workshop, "Environment and resources of seamounts in the North Pacific."

The bulk of the world's ocean resources comes from the coastal zones and the adjacent continental shelf. A small fraction comes from the pelagic areas and includes species such as the tunas, billfishes, sharks, and offshore squids. Until the 1960's seamounts were not considered of any consequence in fisheries. This changed in the late 1960's when Soviet trawlers were reported to land substantial quantities of finfishes from seamounts located in the central North Pacific (Sakiura 1972). A short while later references to a "phantom" fish began appearing in Japanese fisheries trade publications. These fish, whose scientific identity could not be ascertained because they were gutted and gilled at sea, were being caught by Japanese trawlers operating in the mid-Pacific. In the United States of America we were puzzled by the Soviet trawler activity in the waters just beyond the Hawaiian Archipelago and by the reports of "phantom" fish appearing in Japanese markets. Enlightenment on the subject came about during a talk given in Tokyo by Dr. Tokiharu Abe in 1970 when he described the "phantom" fish as the armorhead, *Pentaceros richardsoni* (= *Pseudopentaceros wheeleri*) (Abe 1972). Based on Dr. Abe's report it became apparent that the seamounts were the focus of a new fishery. Of interest is that until the development of the fishery, the armorhead was considered a rare species (Welander et al. 1957).

In comparison with the resources of the continental shelf and the open ocean, the seamounts are a direct source of only a small fraction of the world's marine catch. Details of the historical catch and present knowledge of seamounts will be presented during this workshop. It will suffice at this time to provide a brief description of seamounts.

A seamount is defined as an elevation rising 1,000 m or more from the sea floor, and of limited extent across the summit (U.S. Board of Geographic Names 1981). Although an accurate count of the number of seamounts in the Pacific is not available, the total number ranges in the tens of thousands (Scott and Rotondo 1983). Darwin suggested that the formation of islands, atolls and submerged reefs was the result of uplifting, subsidence, and coral growth (Hesse et al. 1937). Recent research in plate tectonics has provided the basis for a new explanation on the formation of seamounts (Scott and Rotondo 1983). The present view is that in the Pacific, fixed melting anomalies located some distance from the East Pacific Rise produced the volcanic island chains. The magmatic outpourings which break through the sea surface become islands; however, the majority of these igneous monoliths never reach the ocean surface and thus are preserved intact from subaerial weathering and erosion. Those that extend from the floor of the ocean upwards of 1,000 m become seamounts. Even the islands undergo changes with time such that the migration of the island chain into deeper waters westward combined with subaerial weathering and erosion results in an eventual drowning of these islands. These also become seamounts.

The question that needs to be addressed is what is the role of seamounts in the ocean? Are the resources on seamounts substantial? What is the mechanism that sustains and maintains these resources? Do seamounts have an indirect impact on pelagic resources, e.g., tunas and squids? Are all seamounts alike? In any event, seamounts are presently recognized as biological concourses in the open sea. We need to understand their importance.

I am looking forward to 3 days of interesting and informative discussions on seamounts, and I am confident that this workshop will lead to a better understanding of the dynamics of seamounts.

CITATIONS

ABE, T.

1972. Commercial fishing of berycoids and other fishes in previously unfished waters between Japan and the Midway Island. *In* The Kuroshio II. Proceedings of the Second Symposium on the Results of the Cooperative Study of the Kuroshio and the Adjacent Regions. Tokyo, Japan, September 28-October 1, 1984, p. 525-526. Saikon Publ., Co., Ltd., Tokyo.

FOSTER, M., and E. R. LANKESTER (editors).

1903. The scientific memoirs of Thomas Henry Huxley. Supplementary volume. McMillan and Co., Ltd., London, 90 p.

HESSE, R., W. C. ALLEE, and K. P. SCHMIDT.

1937. Ecological animal geography: An authorized rewritten edition based on Tiergeographie auf oekologischer grundlage. John Wiley & Sons, Inc., N.Y., 597 p.

SAKIURA, H. (translator).

1972. The pelagic armorhead, *Pentaceros richardsoni*, fishing grounds off the Hawaiian Islands, as viewed by the Soviets (So-Ren kara mita Hawaii oki kusakari tsubodai gyojyo). [In Jpn.] Suisan Shuho (The Fishing & Food Industry Weekly) 658:28-31, June 15, 1972. (Engl. transl. by T. Otsu, 1977, 7 p., Transl. No. 17; available Southwest Fish. Cent. Honolulu Lab., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396.)

SCOTT, G. A. J., and G. M. ROTONDO.

1983. A model for the development of types of atolls and volcanic islands on the Pacific lithospheric plate. Atoll Res. Bull. 260:1-33.

U.S. BOARD ON GEOGRAPHIC NAMES.

1981. Gazetteer of undersea features. Names approved by the United States Board on Geographic Names. Defense Mapping Agency, Wash., D.C. 3d ed., var. pag.

WELANDER, A. D., R. C. JOHNSON, and R. A. HAJNY.

1957. Occurrence of the boar fish, *Pseudopentaceros richardsoni*, and the zeid, *Allocyttus verrucosus*, in the North Pacific. Copeia 1957:244-246.

Aspects of Oceanic Flow and Thermohaline Structure in the Vicinity of Seamounts[1]

GUNNAR I. RODEN
School of Oceanography, WB-10
University of Washington
Seattle, Washington 98195

ABSTRACT

Aspects of oceanic flow and thermohaline structure in the vicinity of seamounts are discussed on the basis of recent theoretical and observational findings. The results show that the effects of seamounts on flow and structure are complex and depend on a variety of parameters involving the rotation of the Earth, the stratification, the mean flow structure, and the shape and orientation of the seamounts. Depending on the parameters chosen, a variety of flow and structural patterns are obtained. Observations from the Emperor Seamounts region indicate that the interaction of large-scale flow with large-scale topography produces intense mesoscale features. The Kuroshio Extension is deflected anticyclonically by the southern Emperor Seamounts, which is seen in hydrographic and drifter data. A pronounced Taylor column, 50 km wide and 400 m high and indicated by bottom-intensified uplift of the isopycnals, was found over Suiko Seamount. A spectacular mesoscale eddy with an asymmetric dome-like density structure was encountered just to the west of Jingu Seamount. This dome was 800 m high, 200 km wide, and extended from the top of the seamount to the bottom of the seasonal pycnocline. A large sea level depression occurred at the center of the dome. There is some agreement between the theoretical results of flow over low amplitude topography in a stratified rotating fluid and the observations from the high amplitude Emperor Seamounts, but many of the observed details remain unexplained.

INTRODUCTION

Seamounts are ubiquitous features of the ocean floor. They have different shapes and heights and occur either individually or in groups, forming the peaks of underwater ridges and rises. Many seamounts have steep slopes and occupy a large fraction of the ocean's depth. The peaks of such seamounts penetrate deeply into the region of strong temperature and salinity gradients, there to interact with ocean currents of various scale, ranging from planetary to local.

The observational phenomena that result from seamount-current interaction are highly varied and depend on scale, stratification, rotation of the Earth, structure of the mean flow, and orientation of the seamount. In principle, an obstacle in a moving, rotating fluid distorts the flow field and leads to the formation of gradients of velocity and bottom stress. These in turn generate vorticity, deformation, and divergence in the flow field. Thus, one might expect to find current deflections, eddies, convergence zones, and wavelike features in the vicinity of seamounts. Moreover, trapped eddies over seamounts—Taylor columns—can occur. These eddies are often associated with strong upward velocities, carrying nutrients toward the surface. In a stratified fluid, the Taylor columns do not penetrate to the surface, but are bottom trapped, and the largest upward velocities are above the seamount top. The heights and longevity of Taylor columns are not well-known. Results of theoretical and modeling theories suggest that the heights decrease with increasing stratification (Hogg 1973) and that for certain flow conditions the columns become stationary (Huppert and Bryan 1976). Observational evidence indicates that over abyssal bumps, where the stratification is weak, Taylor column heights reach 2 to 3 km (Owens and Hogg 1980), whereas over the high Emperor Seamounts, where the stratification is stronger, the heights are of the order of several hundred meters (see below). The longevity of Taylor columns cannot be asserted from observations as yet, because of the paucity of information. Cheney et al. (1980) reported a satellite tracked drifter that became entrapped over a small seamount south of the Emperor Seamounts. This buoy performed anticyclonic loops for a month before moving on. In addition to trapped eddies which remain attached to seamounts and may be regarded as classical Taylor columns, other trapped, but unattached, eddies can occur in the vicinity of topography. Theoretical investigations by McCartney (1975) and Huppert and Bryan (1976) have shown that such eddies occur in the wake of seamounts. Observational evidence is scant. Although pronounced eddies are observed in the vicinity of some seamounts, it is not known whether these features are trapped or transient.

At present, the understanding of topography-flow interaction in a stratified, rotating fluid is incomplete. The purpose of this brief paper is to point out some of the more important theoretical results of flow around seamounts and to discuss the main observational findings from the Emperor Seamounts region.

THEORETICAL ASPECTS OF FLOW OVER TOPOGRAPHY IN A ROTATING FLUID

Theoretical studies dealing with flow-topography interactions in a rotating fluid indicate that large flow deflections take place in the vicinity of topography and that for certain parameter ranges closed vortical circulations—Taylor columns—occur near the top of an obstacle. This was first recognized in a pioneering article by Taylor

---

[1] Contribution No. 1596, from the School of Oceanography, University of Washington, Seattle, Washington.

(1923) though the name "Taylor column" was not used widely until Hide (1961) attributed the Great Red Spot of Jupiter to an irregularity in that planet's surface. Since that time, much attention has been paid to the possibility of finding Taylor columns in the ocean.

Most theoretical work has concentrated on regularly shaped seamounts, which have small amplitude when compared to the depth of the ocean. For such seamounts, it has been found that the details of flow-topography interaction depend strongly on the orientation of the seamount with respect to the oncoming flow, the horizontal and vertical shear of the oncoming flow, the stratification, and the variability of the Coriolis parameter with latitude. Depending upon the assumptions made, very different flow patterns are obtained. To illustrate this, three cases are examined briefly.

Flow around elliptically shaped seamounts spaced at an arbitrary angle against uniform oncoming flow when the Coriolis parameter is constant

This problem was solved analytically by Johnson (1982). His findings are shown in Figure 1. It is seen that the nature of flow deflection depends on the orientation of the seamount. In all cases, there is a basic anticyclonic deflection around the seamount. For a seamount oriented at right angles to the oncoming flow, the flow deflection is symmetrical, and the flow speeds on either side of the seamount are the same. For any other orientation, the deflection is asymmetrical, and the strongest flow speeds occur on the left side of the seamount, when looking in a downstream direction. Taylor columns, indicated by the looping of the isolines, occur in all cases, but their location depends on the orientation of the seamount with respect to the oncoming flow. Taylor columns and anticyclonic flow deflection around a hill were observed by Owens and Hogg (1980) and flow intensification on the left side of an abyssal bump was found by Gould et al. (1981). Similar features were observed over the large amplitude Emperor Seamounts by Roden et al. (1982) and Roden and Taft (1985).

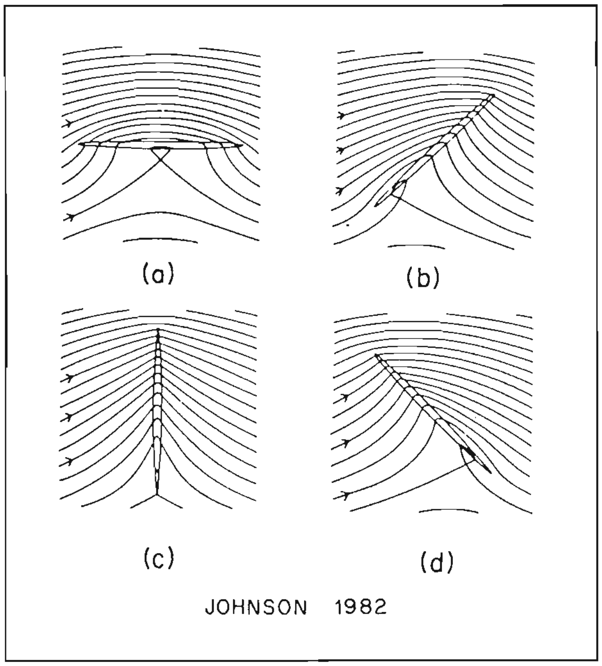


Figure 1.—Quasi-geostrophic flow over an elliptic cylinder inclined at an angle of (a) 0°, (b) 45°, (c) 90°, and (d) 135° to the oncoming flow (Johnson 1982).

Flow around a cylindrical seamount in a stratified fluid on a beta-plane

This theoretical study based on a two-layer fluid with variable Coriolis parameter was carried out by McCartney (1975). He found that stratification intensifies the disturbance due to the seamount in the lower layer and that the variable Coriolis parameter leads to asymmetry of the streamline patterns. This is shown in Figure 2 for the case when the mean flows in each layer are in the same direction. For westward mean flow, the deflection of the streamlines is anticyclonic, there is an anticyclonic Taylor column, and the disturbance is limited to the vicinity of the seamount. For eastward mean flow, the deflection and Taylor column rotation can be either anticyclonic (as shown here) or cyclonic, and a large meandering wake occurs behind the seamount. Embedded in this wake are stationary eddies. When the mean flows in the upper and lower layers are of opposite directions, even more complicated conditions exist and stationary Rossby waves can occur in the vicinity of the seamount.

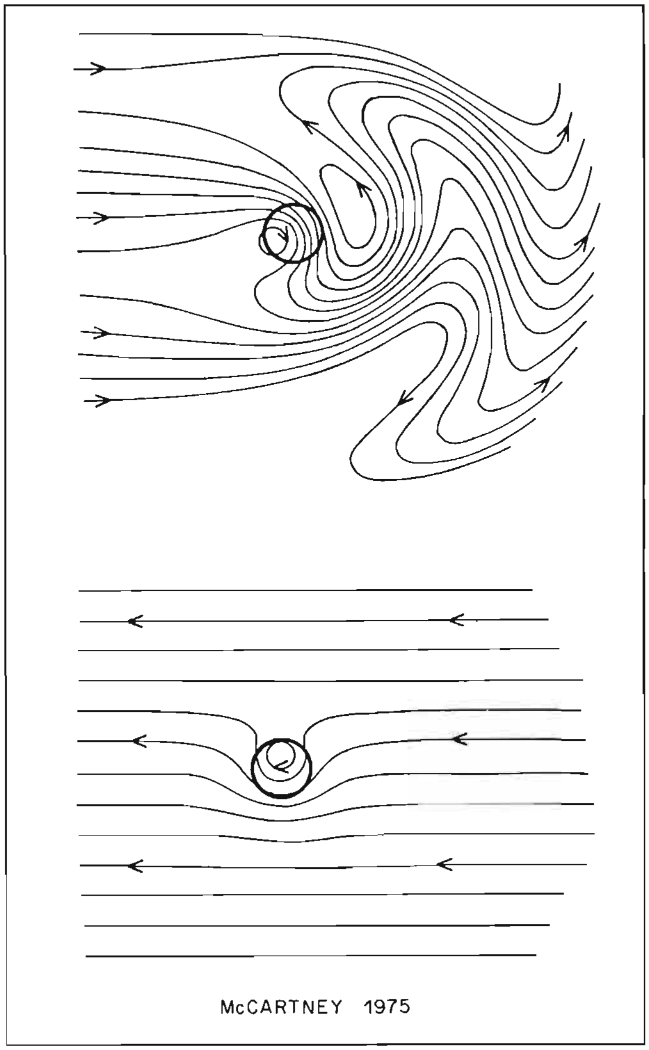


Figure 2.—Lower layer streamlines for eastward (top) and westward (bottom) flow past a circular cylindrical bump in a two-layer fluid with variable Coriolis parameter (McCartney 1975).

Zyryanov (1981) extended these investigations to a continuously stratified fluid on a beta-plane and investigated the case of two low amplitude cylindrical banks placed next to each other in an eastward flow. He found that the Taylor columns are curved cones and that their centers are displaced southwestward relative to the center of the banks. He also found that when the stratification is strong, the apex of the Taylor column cone shrinks and that under certain conditions, an oppositely rotating cone can occur above the Taylor column. The effect of the second bank upon the first is to reduce the strength of the Taylor column when compared to a Taylor column over a single bank. Moreover, the presence of two banks changes the position and shape of eddies in the wake behind the banks.

Evolution of topographically generated eddies—The above examples were for interaction of stationary mean flow with topography. When time variability of the mean flow is taken into account, the evolution of topographically generated eddies can be studied. This was done in a benchmark paper by Huppert and Bryan (1976) for a stratified fluid initiated from rest that interacts with an isolated low amplitude topographic feature for the case of a constant Coriolis parameter. The evolution of cold and warm eddies around a circular seamount and the final flow pattern above the seamount are shown in Figures 3 and 4, respectively.

The findings by Huppert and Bryan (1976) indicate that the time evolution of the mean flow leads to vorticity redistribution over topography. Anticyclonic vorticity remains trapped over topography, while cyclonic vorticity is shed from topography and drifts away, if the mean flow is strong enough. Associated with vorticity are regions of anomalous density and temperature. Both the high density cold core eddy, which corresponds to anticyclonic vorticity, and the low density, warm core eddy, which corresponds to cyclonic vorticity, are indicated by the closed isolines in Figure 3. At day 2.3 after initiation of the flow, cold and warm eddies appear over the seamount, occupying almost equal areas. After about a week, both eddies have moved in a clockwise sense, and the cold eddy occupies most of the seamount. After 2 weeks, the cold eddy has expanded and pushed the warm eddy off the seamount. The warm eddy then elongates and drifts away. What remains over the seamount is a cold anticyclonic eddy (Fig. 4), which can be regarded as a classical Taylor column. For the seamount shape chosen by these authors, the criterion for eddy formations above the seamount depends upon the parameter Nh/U, where N is the Väisälä frequency, h is the height of the seamount, and U is the mean velocity. When this ratio is much larger than 10, the mean flow is too weak to lift the fluid over the seamount and most of the flow will be around it. When the ratio is of order 10, the warm core cyclonic eddy will remain in the vicinity of the seamount. When the ratio is of order $\leqslant 1$, the warm eddy will drift away.

It cannot be emphasized too strongly that the above conclusions are dependent on the shape of the seamount and on the choice of the mean flow parameters. Huppert (1975) found, for example, that vertically faced seamounts, no matter how low, induce a Taylor column, which would not be there for a seamount of equal height but with nonvertical walls.

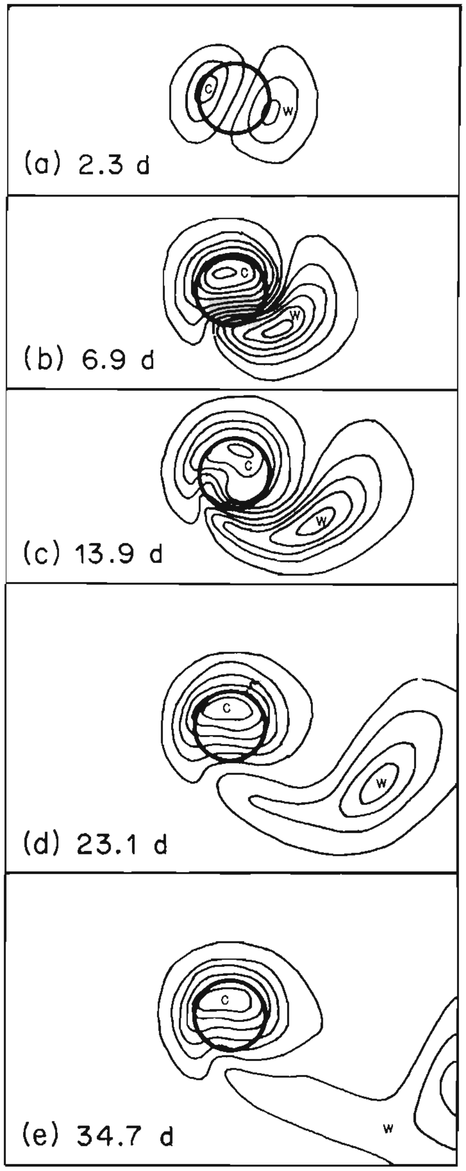


Figure 3.—Evolution of cold (C) and warm (W) eddies in flow past an isolated low amplitude seamount, with time measured in days (Huppert and Bryan 1976).

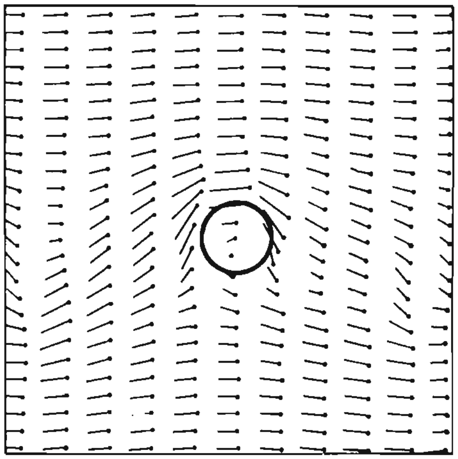


Figure 4.—Horizontal velocity vectors in flow past an isolated low amplitude seamount after 34.7 days (Huppert and Bryan 1976).

OBSERVATIONS OF THE THERMOHALINE STRUCTURE AND FLOW IN THE EMPEROR SEAMOUNTS REGION

The Emperor Seamounts are located in the North Pacific Ocean between lat. 32° and 53°N near long. 170°E and consist of several seamounts that rise abruptly from the deep ocean floor (Fig. 5). The seamounts are 3-5 km high, 50-100 km wide, and are of an irregular, elongated shape. Impinging upon the seamounts are two major ocean currents, the Kuroshio Extension and the Subarctic Current. The interaction of these currents with the seamount chain has a twofold effect: Deflection of the main flow and the generation of secondary flow features, which have large amplitudes but are of a limited horizontal extent. Because of the geographic variability of the mean flow and the variable shapes and orientations of the seamounts, the phenomena resulting from the flow-topography interactions are, in general, different for each seamount. Only when similar mean flows interact with seamounts of similar shape and orientation, can one expect to find common phenomena. The principal findings from the Emperor Seamounts region follow.

Deflection of thermohaline fronts and baroclinic flow by the seamount chain

The temperature, salinity, and dynamic height distributions in the vicinity of the seamount chain are shown in Figure 6. The 150 m depth was selected because the flow features around seamounts show up better at subsurface depths than at the surface, where radiative and mixing processes often diminish the horizontal gradients. The thermohaline fronts and the dynamic height contours all show large deflections around the seamounts. Though details of the deflection patterns vary from one seamount to the other, there is a tendency for the fronts and currents to be deflected northward and eastward. Anticyclonic loops are suggested over Kinmei and Nintoku Seamounts, involving the Kuroshio Extension and subarctic currents, respectively. Not all isolines are deflected equally; those over the shallower parts of the seamounts are deflected more than over the deeper parts. These results are in broad agreement with analytical (McCartney 1975; Johnson 1982) and modeling studies (Huppert and Bryan 1976) of flow deflection over low amplitude topography. This is surprising in a way because the Emperor Seamounts have high amplitudes, and it is not a priori clear that theoretical findings for low seamounts can be applied to them.

The tendency for anticyclonic flow deflection around the southern Emperor Seamounts is seen also in satellite-tracked, drifter trajectories, as shown in Figure 7. Drifters 1 and 2, according to McNally et al. (1983) and Vastano et al. (1985), moved eastward to about long. 170°E and then turned northward to perform anticyclonic loops near Jingu Seamount. Downstream of this seamount, the drifters moved in a generally southeastward direction in a meandering fashion. Drifters 3 and 4, according to records kindly furnished by Nitani (Roden et al. 1982), took different paths, but showed similar features in the vicinity of seamounts. Drifter 3 stayed in the region of the Kuroshio Extension, made an anticyclonic loop about the northern part of Kinmei Seamount, and then continued to move toward the southeast. Drifter 4, which experienced some tracking difficulties (indicated by straight dotted lines between fixes), turned anticyclonically across Jingu Seamount, but instead of continuing toward the southeast, as did the other buoys, it turned northward to end up near lat. 43°N, in the vicinity of the mean position of the subarctic front and current (Roden 1975), where it turned eastward.

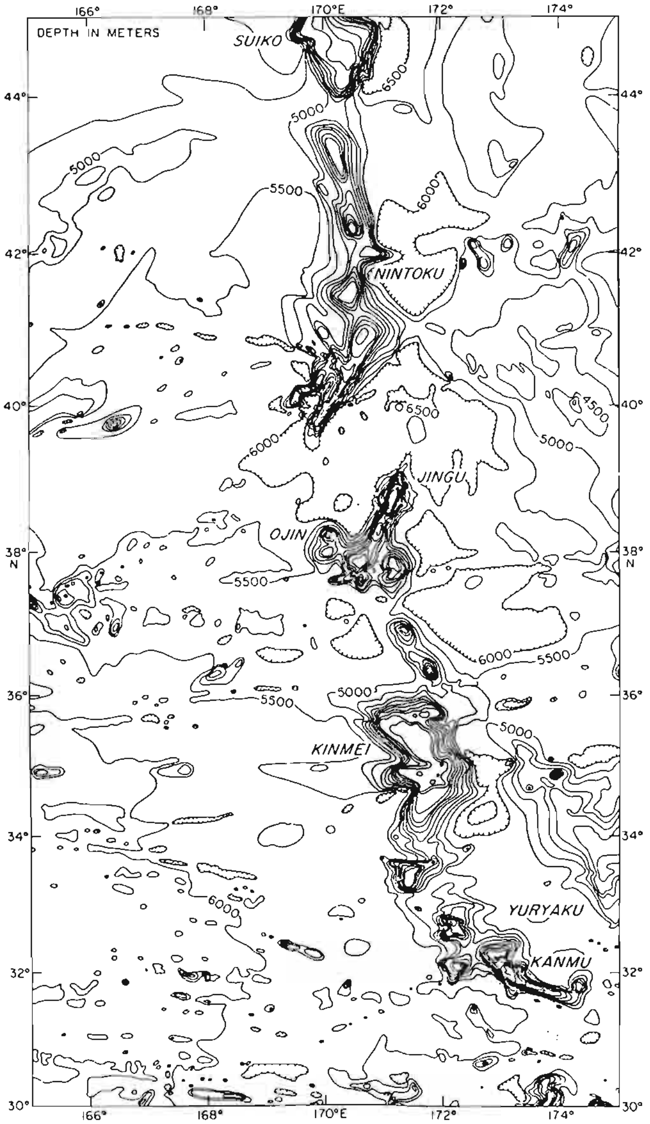


Figure 5.—Map showing topography of the Emperor Seamounts region (depths in meters).

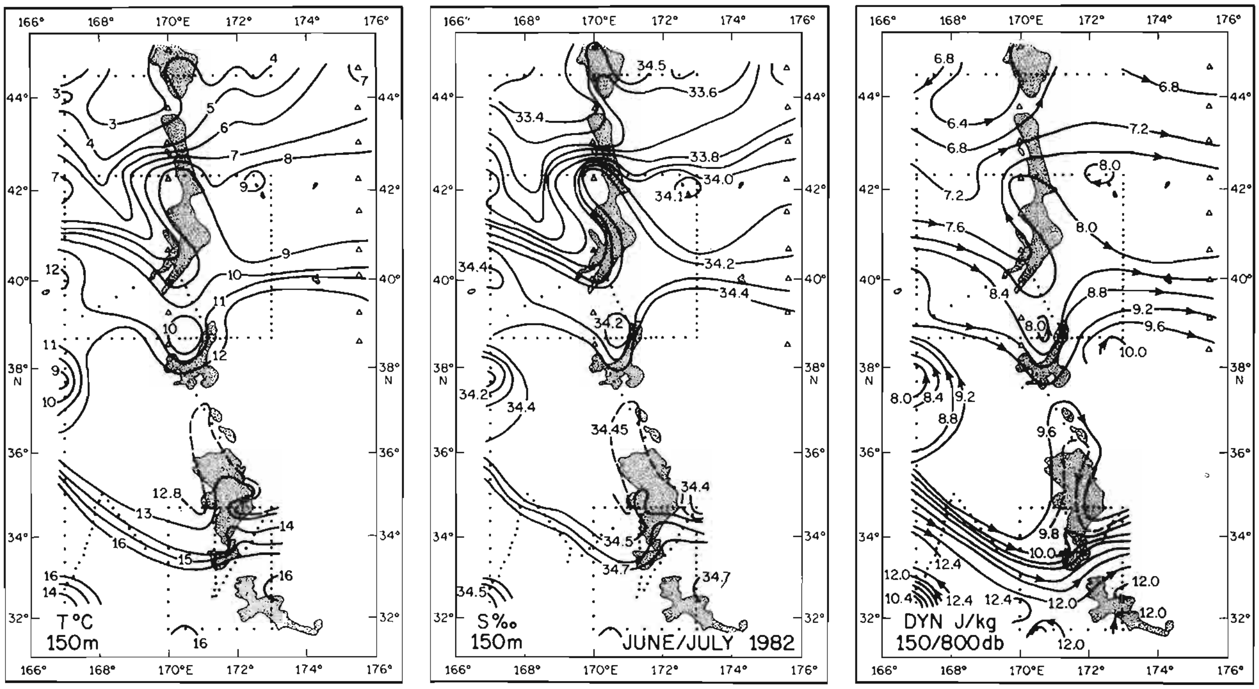


Figure 6.—Temperature, salinity, and dynamic height at 150 m in the vicinity of the Emperor Seamounts. Dots refer to station positions occupied by the RV *Thomas G. Thompson* in June and July 1982, triangles to stations occupied by the RV *Hokusei Maru* in July 1982 (Roden 1984).

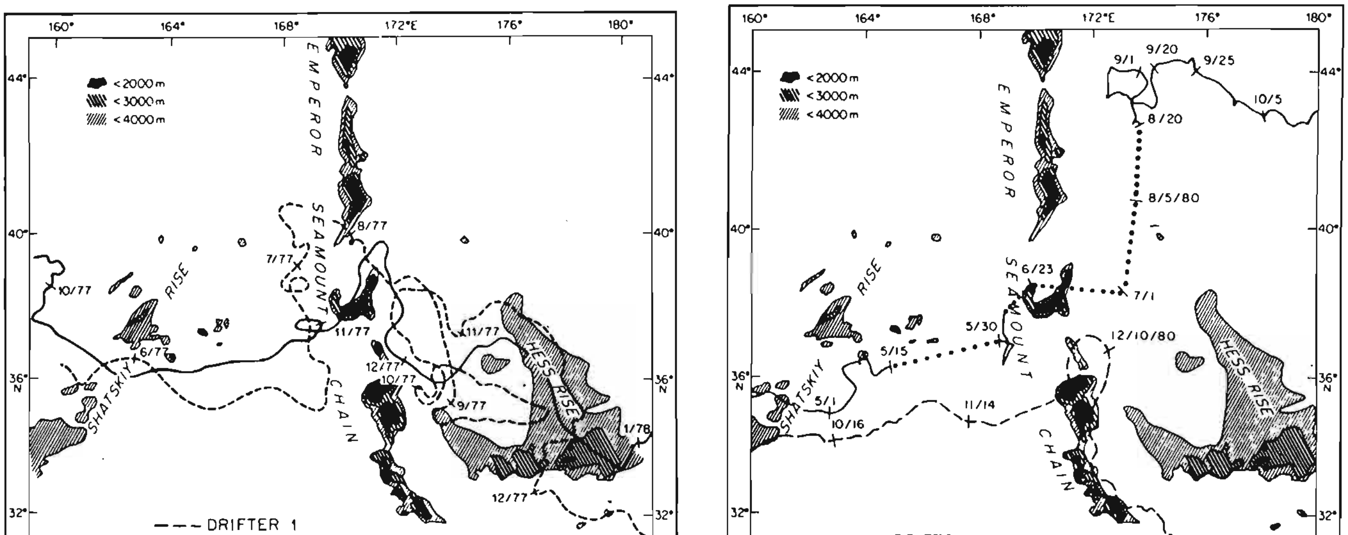


Figure 7.—Satellite-tracked drifter trajectories in the Emperor Seamounts region, based on investigations by McNally et al. (1983) and Vastano et al. (1985) (left), and Nitani (Roden et al. 1982) (right). Numbers refer to dates.

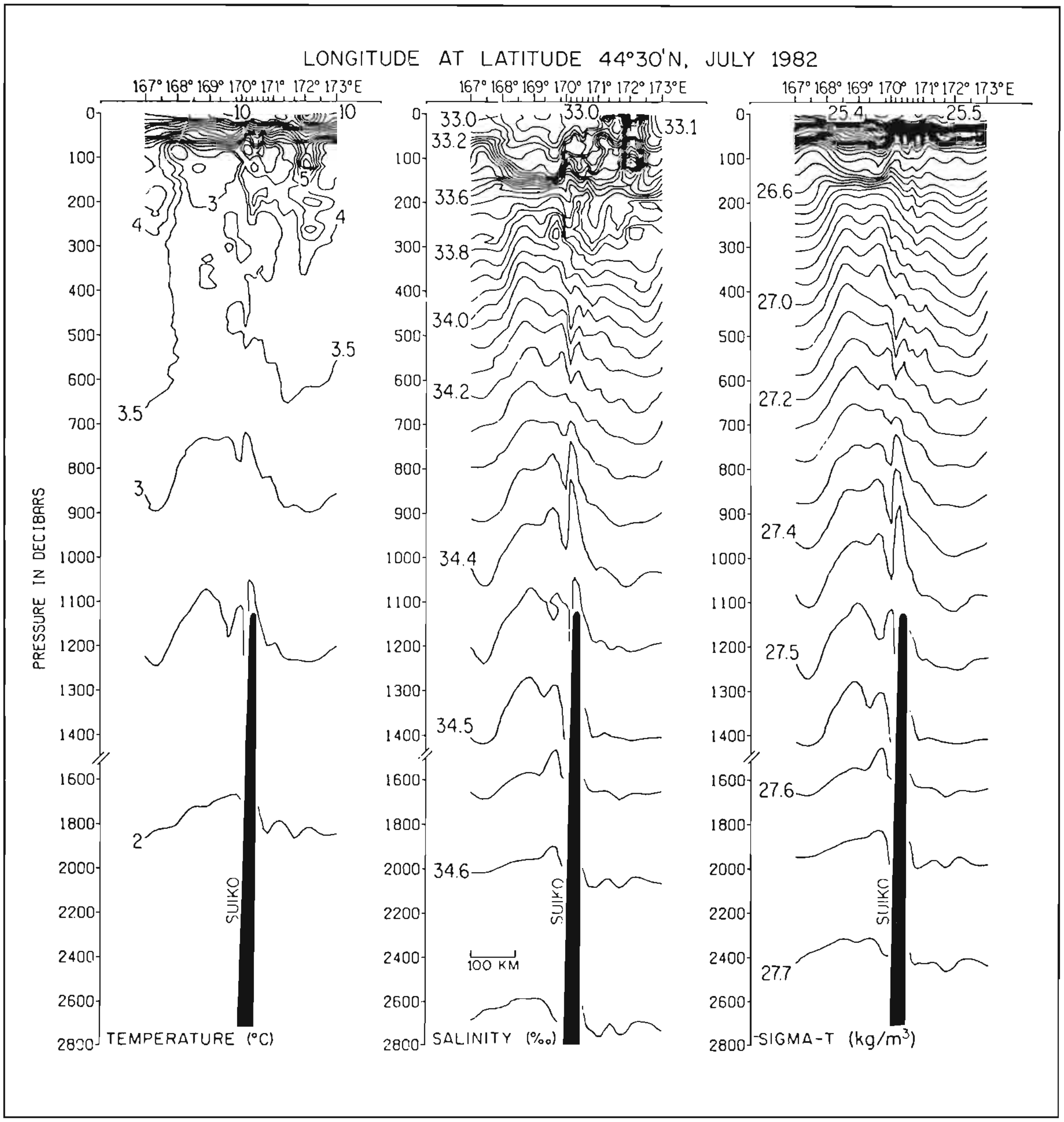


Figure 8.—Temperature, salinity, and density across Suiko Seamount in July 1982 (Roden and Taft 1985).

Taylor columns over the Emperor Seamounts

Theoretically, Taylor columns may be regarded as trapped regions of vorticity over a seamount top. For anticyclonic rotation in a stratified fluid, this would be recognizable by a bottom-intensified uplift of the isolines of density. The clearest expression of this was found over Suiko Seamount during the 1982 Emperor Seamount expedition. The temperature, salinity, and density distributions across the central section of this seamount are shown in Figure 8. Note the uplift of the isotherms, isohalines, and isopycnals directly above this seamount peak and note also that the amplitudes of the uplift decrease with distance from the peak. The width of the Taylor column is comparable to the width of the seamount, about 50 km, and the height of the column is approximately 400 m. These dimensions indicate that the Taylor column is a mesoscale feature. To detect such columns observationally, it is necessary to sample the ocean with a station spacing of not less than a fifth of the seamount's width; moreover, it is necessary to sample the ocean deeply because most Taylor columns do not extend to the surface.

Mesoscale eddies near the Emperor Seamounts

In addition to Taylor columns, pronounced mesoscale eddies occur in the vicinity of seamounts. The distinction between Taylor columns and other mesoscale eddies generated by flow-topography interaction is not always easily made. The interpretation made here is that when the eddies are attached to the seamount, have dimensions of the seamount's width, and have isoline displacements, the amplitudes of which decrease with distance from the seamount top, they will be regarded as Taylor columns. On the contrary when the eddies are not attached to the seamount, have large dimensions, and have

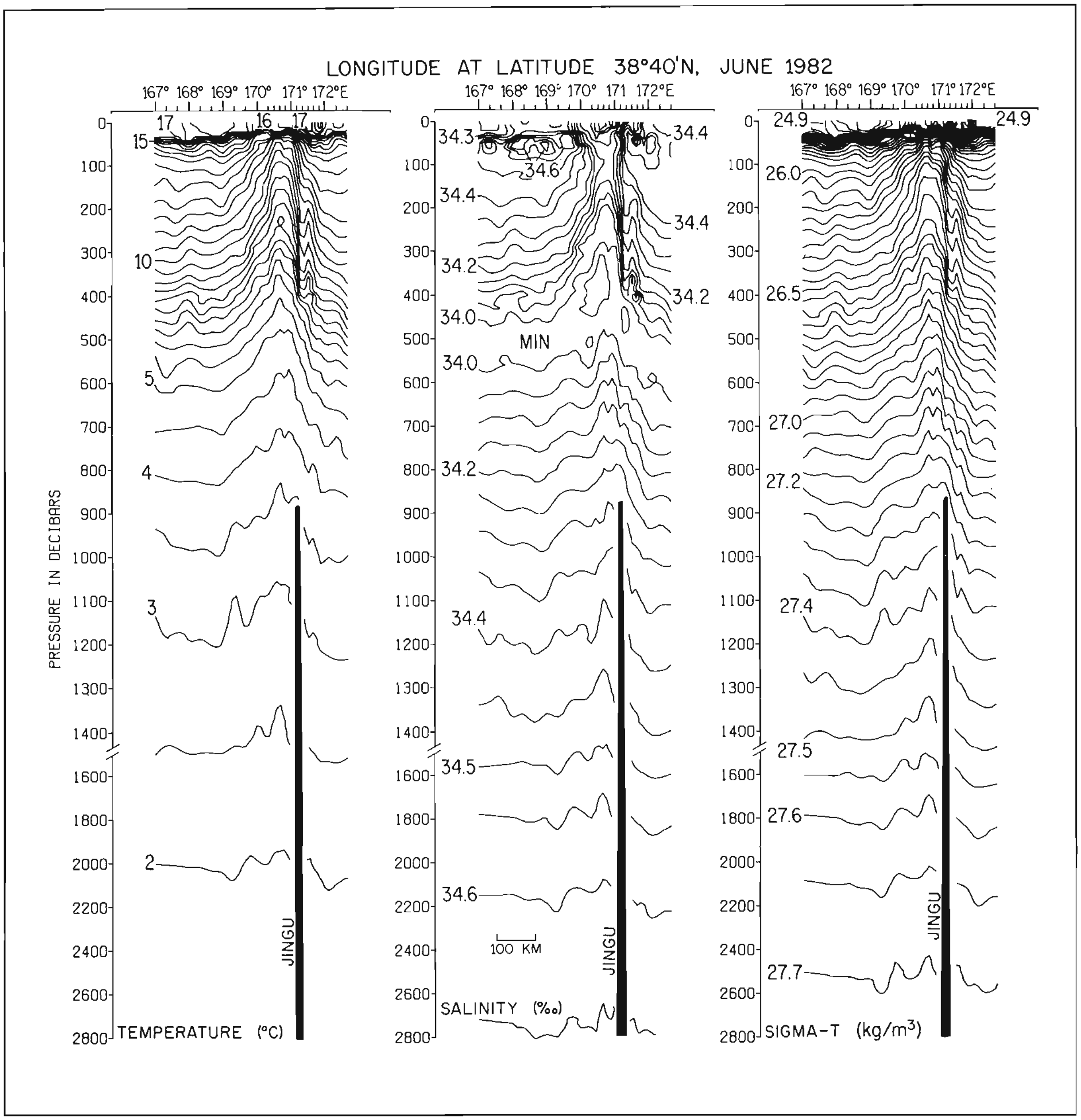


Figure 9.—Temperature, salinity, and density across Jingu Seamount in June 1982 (Roden and Taft 1985).

isoline displacements that increase rather than decrease from the seamount top, they will be regarded here as secondary eddies. Of course, some secondary eddies may have evolved from Taylor columns that drifted away from the seamount, as numerical modeling by Huppert and Bryan (1976) has shown.

A well-defined, dome-shaped, secondary eddy was found just west of Jingu Seamount (Fig. 9). This dome was about 200 km wide and extended from the seamount peak to the bottom of the intense shallow pycnocline, a total distance of 800 m. Maximum isoline displacements relative to the surroundings were about 300 m and occurred about 600 m above the seamount peak. The dome is flanked by strong fronts. The thermohaline fronts on the seamount side of the dome were stronger than on the far side, indicating baroclinic flow intensification on the seamount's left flank. Such flow intensification on the left side of topography when looking in a downstream direction has been predicted by Johnson (1982).

Dynamic height perturbations near seamounts

Associated with well-defined eddies and current meanders near seamounts are dynamic height perturbations. The perturbation associated with the large, secondary eddy west of Jingu Seamount is shown in Figure 10. The dynamic height relative to the 800 dB reference level is shown by a solid line and that relative to the 2,800 dB reference level is shown by a broken line. The shape of the curve is largely independent of the choice of the reference level. The V-shaped depression near Jingu is about 200 km wide and 0.3 m deep (obtained by dividing the dynamic height difference by the acceleration of gravity) and is large enough to be detected by satellite altimeter (Bernstein et al. 1982). Dynamic height perturbations were observed also near other seamounts of the Emperor Seamounts, though they did not have the dimensions or intensity of the one described above.

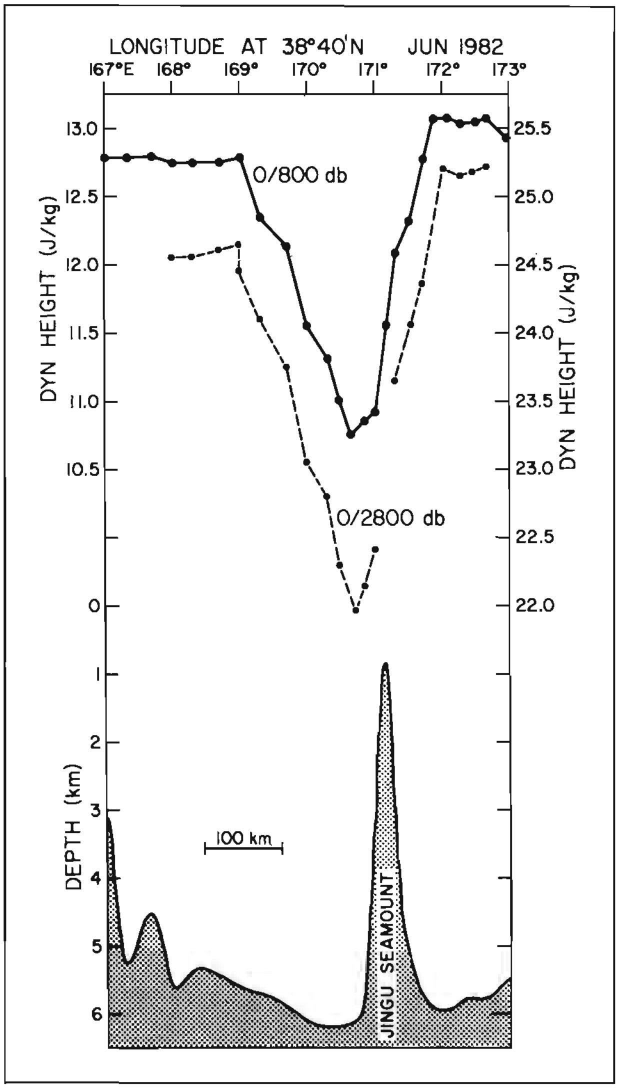


Figure 10.—Perturbation of dynamic height in the vicinity of Jingu Seamount in June 1982 (Roden and Taft 1985).

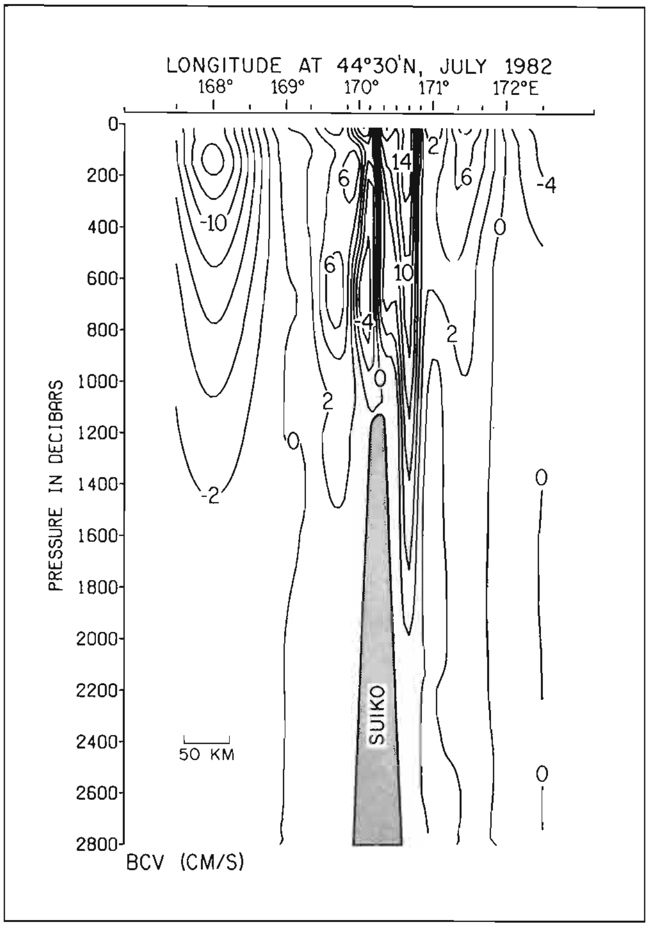


Figure 11.—Meridional component of baroclinic flow, relative to 2,800 dB, in the vicinity of Suiko Seamount in July 1982.

Baroclinic flow structure in the vicinity of seamounts

The vertical structure of baroclinic flow in the vicinity of seamounts is complex and is characterized by features with horizontal dimensions about the width of the seamount. Typical examples of the meridional flow component, relative to 2,800 dB, across Suiko and Kinmei Seamounts, are shown in Figures 11 and 12, respectively. At Suiko, the far field flow is southward. The flow along both flanks of the seamount is northward, while over the seamount itself there is a narrow region of southward flow at depths between 200 and 1,100 m. The northward flow along the eastern flank is deep and extends to about 2,000 m, when measured by the 2 cm s^{-1} isotach. At Kinmei, there is strong northward flow west and strong southward flow east of the seamount, extending to at least 2,200 m, which is connected with the anticyclonic loop of the Kuroshio Extension as indicated in Figure 6. Over the seamount, the flow is weaker and cells of oppositely directed meridional flow are observed southward between 0 and 300 m and northward between 400 and 600 m. In addition, there is a region of moderate southward flow on the upper west flank of this seamount. These flows are accompanied by strong vertical and horizontal shear.

Upwelling and downwelling near seamounts

The patterns varied from seamount to seamount. At Suiko and Jingu (Figs. 8 and 9), there was clear evidence of upwelling over or adjacent to the seamount tops associated with a Taylor column and a strong mesoscale eddy, respectively. Along the flanks of these two seamounts, upwelling was suggested on the east and downwelling on the west sides. The width of the upwelling and downwelling regions near the flanks was of the order of the Rossby radius of deformation, or about 59 km. Upwelling, as defined by the uplift of the isolines, did not penetrate to the sea surface, but was confined to depths below the sharp seasonal pycnocline near 50 m. At other seamounts, less well-defined upwelling and downwelling patterns were observed.

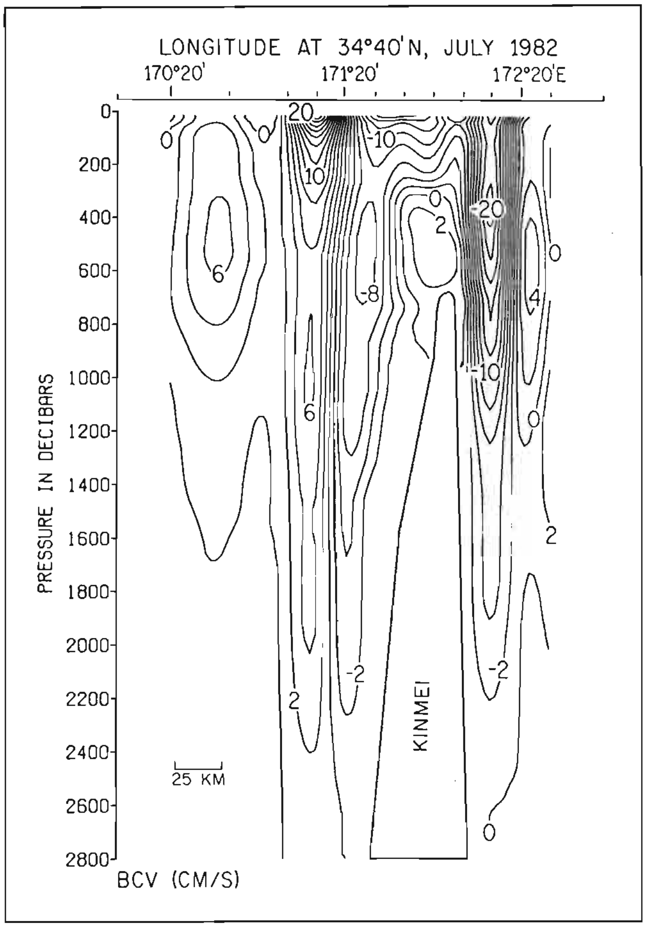


Figure 12.—Meridional component of baroclinic flow relative to 2,800 dB, in the vicinity of Kinmei Seamount in July 1982.

CONCLUSIONS

The following conclusions can be drawn from the theoretical and observational findings discussed above:

1. The effect of seamounts on oceanic flow is complex and depends on a variety of parameters involving the rotation of the Earth, stratification, structure of the approaching flow, and the height, shape, and orientation of the seamounts. Depending on the parameters chosen, a variety of flow patterns are obtained.
2. Simple models of stratified flow over low amplitude topography indicate—for certain parameter ranges—anticyclonic flow deflection and the appearance of trapped, bottom-intensified vortices—Taylor columns—over topography. More elaborate models of flow over low amplitude topography find additional trapped and transient eddies in the region of a seamount. The applicability of these findings to high amplitude seamounts is not immediately clear, from a theoretical perspective.
3. Observations of the thermohaline structure and drifter trajectories in the vicinity of the high amplitude Emperor Seamounts reveal a great variety of mesoscale features, some of which are in agreement with theoretical findings of flow over low amplitude topography.
4. Baroclinic flow and drifter trajectories indicate that the Kuroshio Extension makes an anticyclonic loop around the southern Emperor Seamounts.
5. Over Suiko Seamount, bottom-intensified uplift of the isotherms, isohalines, and isopycnals indicates the presence of a Taylor column 400 m high. The width of this Taylor column is about the width of the seamount, about 50 km.
6. To the west of Jingu Seamount, a pronounced dome-shaped eddy is found which is about 200 km wide, 800 m high, and which extends upward to the shallow pycnocline. The eddy is flanked by strong thermohaline fronts, which are stronger on the seamount side, suggesting baroclinic flow intensification.

More theoretical and observational work is needed before the interaction of seamounts with flow is fully understood. On the theoretical side, the need is for investigating the interaction of strongly sheared and geographically variable mean flow with large amplitude seamounts and seamount chains. Because analytical solutions are hard to obtain under such circumstances, numerical modeling approaches may be needed. On the observational side, it is necessary to obtain adequate resolution for defining mesoscale features, such as Taylor columns. This requires horizontal station spacing of not more than about one-fifth the width of the seamount near its top as well as deep sampling, because many of the features are bottom-intensified. Moreover, there is an urgent need to determine the temporal variability of the mesoscale features to distinguish the trapped from the transient ones. The larger scale flow in the region around the seamount must also be known because theoretical and observational experience has shown that the interaction of large-scale flows with large-scale topography can give rise to secondary circulations which are intense, but of limited horizontal extent.

ACKNOWLEDGMENTS

This paper is based on a presentation made by the author at the Workshop on Environment and Resources of Seamounts in the North Pacific held at the Far Seas Fisheries Research Laboratory in Shimizu, Japan, 21-23 March 1984. The work reported here was supported by National Science Foundation Grant 81-17047 and by the Office of Naval Research Contract N00014-84-C-0252.

CITATIONS

BERNSTEIN, R. L., G. H. BORN, and R. H. WHRITHNER.
1982. SEASAT altimeter determination of ocean current variability. J. Geophys. Res. 87:3261-3268.
CHENEY, R. E., P. L. RICHARDSON, and K. NAGASAKA.
1980. Tracing a Kuroshio ring with a free drifting buoy. Deep-Sea Res. 27:641-654.
GOULD, W. J., R. HENDRY, and H. E. HUPPERT.
1981. An abyssal topographic experiment. Deep-Sea Res. 28:409-440.
HIDE, R.
1961. Origin of Jupiter's Great Red Spot. Nature 190:895-896.
HOGG, N. G.
1973. On the stratified Taylor column. J. Fluid Mech. 58:517-537.
HUPPERT, H. E.
1975. Some remarks on the initiation of inertial Taylor columns. J. Fluid Mech. 67:397-412.
HUPPERT, H. E., and K. BRYAN.
1976. Topographically generated eddies. Deep-Sea Res. 23:655-679.

JOHNSON, E. R.
1982. Quasigeostrophic flow over isolated elongated topography. Deep-Sea Res. 29:1985-1995.

MCCARTNEY, M.
1975. Inertial Taylor columns on a beta plane. J. Fluid Mech. 68:71-95.

MCNALLY, G. J., W. C. PATZERT, A. D. KIRWAN, and A. C. VASTANO.
1983. The near surface circulation of the North Pacific using satellite tracked drifting buoys. J. Geophys. Res. 88:7507-7518.

OWENS, W. B., and N. G. HOGG.
1980. Oceanic observations of stratified Taylor columns near a buoy. Deep-Sea Res. 27:1029-1045.

RODEN, G. I.
1975. On North Pacific temperature, salinity, sound velocity and density fronts and their relation to wind and energy flux fields. J. Phys. Oceanogr. 5:557-571.
1984. Mesoscale oceanic fronts of the North Pacific. Ann. Geophysicae 2:399-410.

RODEN, G. I., and B. A. TAFT.
1985. Effect of the Emperor Seamounts on the mesoscale thermohaline structure during the summer of 1982. J. Geophys. Res. 90:839-855.

RODEN, G. I., B. A. TAFT, and C. C. EBBESMEYER.
1982. Oceanographic aspects of the Emperor Seamounts region. J. Geophys. Res. 87:9537-9552.

TAYLOR, G. I.
1923. Experiments of motions of solid bodies in rotating fluids. Proc. R. Soc. Edinb. Sect. A (Math. Phys. Sci.) 104:213-218.

VASTANO, A. C., D. E. HAGAN, and G. J. MCNALLY.
1985. Lagrangian observations of surface circulation at the Emperor Seamount chain. J. Geophys. Res. 90:3325-3331.

ZYRYANOV, V. N.
1981. A contribution to the theory of Taylor columns in a stratified ocean. Izv. Atmos. Oceanic Phys. 17:793-800.

Oceanographic Studies of Seamounts[1]

HAJIME YAMANAKA
Division of Oceanography
Far Seas Fisheries Research Laboratory
Shimizu, Shizuoka, 424 Japan

ABSTRACT

This paper describes the results of various investigations into the association of fish schools with oceanographic features in the vicinity of seamounts and other undersea configurations. There has been no definitive study on the fish aggregating mechanisms of seamounts and shoals.

Hypotheses developed from early studies indicated that the influence of upwelling and eddies in aggregating fish is dependent on many factors including size and shape of seamount, the depth to the summit, type of bottom, water quality, and current strength.

Examples of good fishing in the vicinity of seamounts are cited. Near the Emperor Seamounts, studies indicated the possible presence of bluefin tuna down to a depth of 400 m over the seamount slopes. In general, tuna fishing grounds usually develop upstream of seamounts; however, the reason for this phenomenon is not clear.

Unique bottom topography near Crozet and Kerguelen Islands in the southern Indian Ocean has been identified as being responsible for variations in oceanographic conditions which subsequently lead to accumulation of antarctic krill and whales.

Undersea ridges also produce changes in surface currents which ultimately influence the transport and dispersion of fish eggs and larvae. The Izu-Ogasawara Ridge, which cuts across the path of the Kuroshio, affects the transport of the current; the resulting circulation pattern, including the formation of an eddy, appears to be beneficial for the dispersion of eggs and larvae.

Studies on currents near artificial reefs demonstrated that the influence of such structures extends for distances roughly 1.5 times their width in the perpendicular direction, and 6 times their width in the direction of the flow. Changes were also noted in current speed and direction, and in development and dissipation of eddies. Although small compared with seamounts, artificial reefs may serve as models in the study of circulation over and around seamounts.

INTRODUCTION

It has long been known that tuna fishing grounds are commonly found near seamounts, shoals, and islands. Tominaga (1957) reported that good fishing grounds for skipjack tuna, *Katsuwonus pelamis*, are found around the eddies and backwashes (yodomi) that develop near islands and shoals. Uda and Ishino (1958) found from model experiments that eddies develop downstream of seamounts, shoals, and islands and that localized upwellings and convergences are subsequently formed. Uda (1961) reported that these oceanographic conditions are related to the formation of good fishing grounds.

Regarding the fish aggregating mechanism of seamounts and shoals, the following explanation has been given: According to views expressed by Nathansohn (1906), upwelling may result from certain configurations in the bottom topography. Such upwelling brings nutrient-rich water to the surface, which results in a phytoplankton bloom, followed by an increase in zooplankton. Small fish gather to feed on the zooplankton and they, in turn, attract the larger predators such as the tunas. Eddies may form from current-topography interactions to provide an environment suitable for the aggregation of tunas (Uda 1961). However, no definitive studies have been conducted on the fish aggregating mechanism of these seamounts and shoals to verify the above theory. Numerous questions still remain unanswered at present.

Van Arx et al. (1954), as well as Mao and Yoshida (1955), carried out studies on the physical oceanography around Bikini and adjacent atolls, and Bennett and Schaefer (1960) conducted environmental studies related to physical, chemical, and biological oceanography near the Revilla Gigedo islands. They also examined fish aggregating mechanisms. Hanamoto et al. (1964) and Hanamoto (1971) reported on the relationship between bottom topography and the formation of tuna fishing grounds. Nakao et al. (1973) surveyed a bank (Yamato-tai) in the Sea of Japan, Nasu (1973) the central Pacific seamounts, and Tawara and Koga (1974) the Seychelles Islands area. Yamanaka and Yukinawa (1976), as part of a special oceanographic study of oceanic banks, carried out a detailed survey of Hunter Bank in the western Pacific Ocean. Also, Morita and Yamanaka (1978) examined the oceanographic environment within the reef line.

Studies were subsequently carried out on the transport, diffusion, and survival of fish eggs and larvae in relation to the environment (Otsuka 1976; Fujimoto 1977; Nakao 1977; Tokyo University, Ocean Research Institute 1979). In relation to the transport and dispersion of eggs and larvae by the Kuroshio, the influence of the Tokara and Izu ridges was studied. Oceanographic studies were also carried out at Seno-umi in Suruga Bay (Nakamura and Sawada 1971; Nakamura 1972) and the mackerel, *Scomber japonicus*, fishing grounds near the Izu Archipelago (Nakamura 1981). The Fishery Department of Kagoshima University carried out a 3-year study in the Ryukyu Archipelago as part of a comprehensive program to develop fishing grounds on the continental shelf slope. The studies included detailed examination of the various oceanographic features such as upwelling, eddies, and productivity related to shoals and islands, and results of the oceanographic conditions near a seamount (lat. 30°N, long. 138°30'E) were summarized by Fukazawa (1979). In addition, tracking of the Kuroshio was carried out using the Argos buoy (Ishii 1981) which resulted in information on the current in the vicinity of the Shatskiy Rise. It was found that a cold water mass breaks off in the vicinity of the Kinan Shoals, located near the apex of the Kuroshio meander (Hasunuma 1978; Nishiyama et al. 1980; Konaga et al. 1981). With the development of satellite

---

[1] Translated from the Japanese by Tamio Otsu, November 1983.

remote sensing, it has also become possible to observe coastal upwellings (Kishi and Konaga 1977). Furthermore, many artificial reefs have been installed in Japanese coastal waters and various environmental studies have been carried out on these reefs. Although not of a size or scale comparable to the seamounts, these artificial reefs have served as models for numerous studies including current flow, plankton distribution, and plankton swarming. Current meters capable of functioning for as long as 6 months to a year, and instruments to measure various characteristics of seawater have now been developed. Thus, much new information on the oceanographic conditions on the seamounts and their influence on the living marine resources can now be anticipated.

Seamounts as fishing grounds and their oceanographic condition

The relationship between seamounts and oceanographic conditions has been discussed earlier, but Uda (1961) reported that the influence of upwelling and eddies in aggregating fish is dependent on many factors such as the size and shape of the seamounts, the depth at the shallowest point, and the type of bottom, water quality, and strength of the currents in the vicinity of seamounts; there still are large gaps, however, in knowledge regarding these various factors. Furthermore, Uda (1961) stated that in the fishing grounds of "island-associated" fish schools, skipjack tuna (which are strong swimmers) are sometimes seen upstream of the island where the currents diverge. In general, however, fish schools tend to gather downstream of islands near the convergences that occur in the vicinity of upwelling. Such areas seem to be especially attractive to fish schools.

Areas of rapid currents over shallow shoals develop considerable wave action and are therefore unsuitable for aggregating fish. However, many good fish habitats (shoals) can be found farther offshore in waters 100-300 m deep. These so-called fish habitats may be classified according to their origin into volcanic or coralline types (Niino 1967), the volcanic types considered to be excellent fishing grounds. In fact, tuna fishermen as well as coral harvesters are said to consider these volcanic shoals as "mother lodes." Inoue (1969) reported that excellent tuna fishing grounds are formed in the central North Pacific Ocean along the central North Pacific ridge.

Tuna fishing grounds—Hanamoto (1971, 1974, 1977a, 1977b, 1978), Machida (1972, 1974), Tawara and Koga (1974), and Konagaya (1978) reported on the seamounts, and the relationship between tuna fishing grounds and bottom topography. Their reports may be summarized as follows:

A shoal is located within a short distance south of Cargados Carajos Shoals in the Indian Ocean. Upwelling occurs upstream of it where the bottom topography is quite complex, and also over the submarine canyon east of the shoal. A good tuna fishing ground is situated upstream of this shoal. The hook rate averaged 8% in the immediate vicinity of the shoal, and 4.3% farther away. The catch made directly over the shoal consisted of 45% yellowfin tuna, *Thunnus albacares*, and 5% albacore, *T. alalunga*, whereas the catch from some distance away was made up of 75% albacore and 14% yellowfin tuna.

The waters near the Emperor Seamounts in the North Pacific are considered to be good fishing grounds for bluefin tuna, *T. thynnus*. Fish-finder records have revealed the presence of what appeared to be bluefin tuna down to 400 m over the seamount slopes. Excellent fishing grounds for striped marlin, *Tetrapturus audax*, and southern bluefin tuna, *T. maccoyii*, have also been found over steeply sloping bottoms in waters east of Australia. However, in the waters of the southeastern Indian Ocean (lat. 35°-50°S, long. 80°-110°E), the Indian Antarctic Ridge traverses latitudinally, and the current curves to the left when it approaches the ridge, and again to the right after passing it. The surface temperature also varies in a similar pattern. A fishing ground for southern bluefin tuna develops upstream of the ridge. Although tuna fishing grounds generally develop upstream of seamounts or shoals, the reason for this is not clear.

Yamanaka and Yukinawa (1976) carried out a detailed study of Hunter Bank which is located on the northern part of the Yap Ridge. The shallowest point on Hunter Bank (30 m) was selected as the midpoint from which the surrounding area within a 5-nmi radius was studied in detail. Bathythermograph casts, NORPAC net tows, and TX-V_2 current measurements were carried out at 1-nmi intervals in a detailed survey of the environment. A total of 113 stations were occupied. The results showed that the northward flowing current predominated over the bank. A northward flowing current was the main component on the western side of the bank, while an easterly current predominated on the eastern side. The isotherms were quite disorderly near the bank. Features such as convergences, divergences, and upwelling were indistinct. A cold water eddy developed directly over the bank, while warm water eddies appeared to be present at the northwestern and southeastern edges of the bank. Plankton volume was high on the western side. Skipjack tuna were absent and only a few were seen 3-4 nmi from the bank on the northwestern side.

Whaling grounds—Machida (1972, 1974) reported that there is an intimate relationship between whaling grounds and the bottom topography. Near Crozet and Kerguelen Islands in the South Indian Ocean, the Antarctic circumpolar current curves northward near the island ridges. As a result, the cold water from the south protrudes northward just above the ridges, whereas warm water pushes southward on the east. There are localized temperature fronts along the boundary between the warm and cold water masses. Also, a clockwise eddy develops where there is a northward protrusion of cold water. On the other hand, there seems to be a counterclockwise eddy at the southward intrusion of warm water just to the east of the island ridge. This type of variation in oceanographic condition appears to bear a close relationship to the distribution of antarctic krill and whales.

Others—Shimomura (1967) reported on the relationship between fishing grounds and bottom topography in the Sea of Japan, and Kojima (1967) described the relationship between bottom topography and the "shiirazuke" (fishing for dolphinfish under rafts) fishing grounds. Nasu (1973), and Nasu and Kikuchi (1974) reported on the occurrence of a circular current flowing in a clockwise direction over Milwaukee Seamounts (located south of the Emperor Seamounts). This current has also been verified by Geomagnetic Electrokinetograph measurements. It has been reported that in March-April 1969, the Soviets carried out oceanographic studies in this area and also reported on the presence of this eddy.

The density of chlorophyll *a* (μg/L) is high on the eastern side of seamounts, as is the volume of zooplankton. However, phosphates are low (under 0.6 μg/L) directly over seamounts and somewhat higher (0.8 μg/L) near banks.

Kuroshio and the seamounts as well as submarine ridges

The relationship between bottom topography, currents, and waves was reported on by Yoshida (1967) and others, but there are many unanswered questions on this subject. Between August and September 1971, an oceanographic survey was carried out at Yamato-tai in the Sea of Japan. The four current meters installed for this study revealed the presence of an eddy in the vicinity of Yamato-tai. The polar frontal zone in the Sea of Japan lay directly over Yamato-tai, and the current meandered sharply at the northern end of the bank as it turned southward. A large eddy (warm water mass) with a clockwise circulation developed over Yamato-tai, but it was noted that a cold water mass existed deeper than 150 m, while a warm water mass moved in a clockwise direction shallower than 150 m in a double-layered structure at the apex of Yamato-tai. It was believed that a good fishing ground would develop in this area where the warm water mass comes together with the cold water mass, and where upwelling supplies nutrient-rich water (Hirao and Sawamoto 1973; Kawana 1973; Nakao et al. 1973; Nakata et al. 1973; Okazaki 1973).

To gain an understanding of the transport and dispersion of fish eggs and larvae by the Kuroshio and its branches, and to learn about their survival rates, studies on the current were carried out by the release of dyes, drift bottles, and drift cards, as well as by tracking current panels and radar buoys, and simultaneous collections of eggs and larvae and measurements of vital environmental parameters. The results of these studies may be summarized as follows: The current panels and radar buoys revealed relatively little dispersion within the limits of the main flow of the Kuroshio. They tended to repeat a series of convergences and divergences as they gradually dispersed, but they hardly, if ever, dispersed at right angles to the flow of the current. The drifting objects were transported a long distance when the current flowed strongly at a speed greater than 1 knot, whereas, the transport distance was very short when the current speed was under 1 knot. The drifting material moved virtually in a straight line between the Ryukyu Ridge and the Izu-Ogasawara ridge. However, when the drifting material proceeded beyond the Izu-Ogasawara ridge, the speed was only around 3 nmi per day. The speed decreased just as the Kuroshio approached the Izu ridge. An eddy, in which eggs and larvae tended to disperse, developed downstream of this ridge but remained in the vicinity.

From the above, it is believed that the Izu-Ogasawara ridge, which cuts across the path of the Kuroshio, may affect not only the transport of the current, but also provides a good influence on the reproduction of resources (Fujimoto 1977; Tokyo University, Ocean Research Institute 1979). On the other hand, the relationship between the movements of water masses, as indicated by movements of current panels, and the changes in the distribution of eggs and larvae, as indicated by sampling, are not easy to verify. It has been reported that improvements in research methods are necessary to carry out such studies.

Recently, an oceanographic and biological survey was carried out in the vicinity of the Ryukyu Archipelago by the Fishery Department of Kagoshima University. The results of these studies (Chaen et al. 1979; Sakurai and Maeda 1979; Saizho et al. 1980; Takahashi et al. 1980; Hidaka et al. 1981; Yamazaki et al. 1981) may be summarized as follows: Based on the distribution of marine bacteriophage, it was concluded that the waters of the Ryukyu Islands are poor in nutrients and that nutrient salts, zooplankton, and phytoplankton volumes are greatest over the continental shelf in the East China Sea, and very low within the main Kuroshio and the Tsushima warm current. They were lowest in offshore Kuroshio waters.

Upwelling resulting from the nature of the bottom topography was found near the continental shelf slope at Hozan Sone near Miyako Island, Tokara ridge, and near the island shelf of Amami Oshima. Furthermore, within the waters related to the Kuroshio, zooplankton volume (copepods were most plentiful, comprising 45% of the total count) was greatest within the main current of the Kuroshio and on the rise located to the east of Amami Oshima. Nutrient salts were also high in waters over the latter rise.

The productivity in this area is not always great, but it is, nevertheless, quite high compared with waters farther offshore.

In relation to the formation of mackerel fishing grounds in the coastal waters of Izu Archipelago, studies were carried out on the flow of the Kuroshio near the Izu ridge (Otsuka 1976), and on the characteristics of the oceanographic structure within the fishing grounds (Nakamura 1981). Oceanographic studies were also conducted in the adjacent waters of Suruga Bay (Nakamura and Sawada 1971; Nakamura 1972; Sea Sphere Institute 1974), and the presence of upwelling near Seno-umi has been confirmed.

In May 1977 it was observed for the first time that the cold water mass off Kinan Shoals was split into two parts near long. 130°10′E off Tokaido, and at lat. 32°20′N, long. 136°10′E near Shionomisaki. (This cold water mass was subsequently named Harukaze after the RV *Harukaze* of the Kobe Marine Meteorological Observatory.) Hasunuma (1978) observed that this cold water mass proceeds westward and reunites with the Kuroshio. In August 1979, Nishiyama et al. (1980) found a detached cold water mass at the same location as the Harukaze, and postulated that this cold water mass may have some relationship with the Kinan Seamounts.

The Hydrographic Department of the Maritime Safety Agency used Argos buoys to study the currents in a survey that began in January 1980. The buoys were released within the Kuroshio and tracked. Although much interesting information was obtained, many questions regarding the flow of the currents in the open sea remain. For example, the results indicated that if the buoys were within the Kuroshio when the current passed the Izu ridge, they continued on with the current. However, if they passed near lat. 30°N south of Torishima, the buoys moved in a southeast-south southeasterly direction. The buoys that drifted in between these routes seemed to remain stationary until they came under the influence of the continuing flow of the Kuroshio running to the east of the archipelago, or the Kuroshio countercurrent. Also, when passing the Shatskiy Rise (Northwest Pacific Rise) they revolved in a counterclockwise direction for about 2 months, after which they remained stationary for the next 4 months. When the buoy approached the rise, it moved northward once, and then to the south, and appeared to follow the depth contour line (isobath). These findings indicated that ridges and rises do have some influence on surface currents.

Oceanographic and fishing conditions at artificial reefs

When an artificial reef is installed on the sea bottom, it has been estimated that its influence on the current extends a distance of roughly 1.5 times its width in the perpendicular direction, and a distance of about 6 times its width in the direction of the flow. Actually, changes take place both in current direction and speed. There are also changes in development and dissipation of eddies (Hirose et al. 1977). Katoh and Itosu (1980) conducted biological and oceanographic studies at an artificial reef installed near Hachijyo

Island. In addition, the Japan Fishery Resource Conservation Association published Marine Aquaculture Series 26 and 27 (1981a, 1981b) in which many authors contributed papers on the theoretical and practical aspects of artificial reefs. Although the artificial reefs are nowhere the size and scale of natural seamounts, they appear to be excellent models for the study of seamounts.

FUTURE PROBLEMS

There are many questions remaining to be answered regarding the influence of seamounts on the oceanographic environment, biological productivity, and reproduction. For future studies of the seamounts, the following method may be considered: Infrared temperature sensors have recently been used from aircraft and satellites to measure surface water temperatures and to observe coastal upwelling. This technology should be applied in carrying out long-term oceanographic observations in the vicinity of seamounts. The surface environment (upwellings, eddies) can be observed over an extended period, and measurements may be obtained of the various environmental variables. Finally, these studies should be supplemented by a systematic survey of the seamount area from a research vessel equipped with the latest oceanographic instrumentation.

CITATIONS

BENNETT, E., and M. B. SCHAEFER.

1960. Studies of physical, chemical and biological oceanography in the vicinity of the Revilla Gigedo islands during the "Island Current Survey" of 1957. Bull. Inter-Am. Trop. Tuna Comm. 4(5):219-317.

CHAEN, M., S. HIGASHIGAWA, S. ARIMA, and M. AZUMA.

1979. Oceanographic conditions in the vicinity of the southern Ryukyu Island. [In Jpn.] Fish. Dep., Kagaoshima Univ., 1978 Res. Prog. Rep. 8-18.

FUJIMOTO, M.

1977. STD measurements in and around the East China Seas in July 1973. [In Jpn.] Bull. Tokai Reg. Fish. Res. Lab. 90:77-82.

FUKAZAWA, M.

1979. Oceanographic conditions in the vicinity of seamounts. [In Jpn.] Kaiyo Kagaku (Mar. Sci.) 11(3):214-225.

HANAMOTO, E.

1971. Relation between the southern bluefin tuna fishing ground and submarine topography off the coast of eastern Australia and in New Zealand region. [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 19:117-122.

1974. Tuna fishing grounds in relation to the submarine rises. [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 24:165-166.

1977a. Fishery oceanography of striped marlin—I. Fishing season, fishing ground and movement pattern of the fish in the southern Coral Sea. [In Jpn.] Bull. Jpn. Soc. Sci. Fish. 43:649-657.

1977b. Fishery oceanography of striped marlin—II. Spawning activity of the fish in the southern Coral Sea. [In Jpn.] Bull. Jpn. Soc. Sci. Fish. 43:1279-1286.

1978. Fishery oceanography of striped marlin—III. Relation between fishing ground of striped marlin and submarine topography in the southern Coral Sea. [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 32:19-26.

HANAMOTO, E., K. KAMIJO, and Y. NAKAMURA.

1964. An example of a shoal in the Indian Ocean tuna fishing grounds. [In Jpn.] Maguro Gyojo (Tuna Fishing Ground) 27:54-58.

HASUNUMA, K.

1978. The detached circular current rejoins the Kuroshio. Fiscal year 1977 Ministry of Education Science and Culture Grant-in-Aid for Co-operative Research. [In Jpn.] Res. Rep. p. 76-80.

HIDAKA, T., K. SAKITA, Y. UENO, T. NISHIYAMA, and M. MATSUURA.

1981. Distribution of marine bacteriophage in the waters west of the northern Ryukyu Islands. [In Jpn.] Fish. Dep., Kagoshima Univ., 1980 Res. Prog. Rep. 60-64.

HIRAO, T., and S. SAWAMOTO.

1973. Species composition and distribution of plankton on Yamato-tai (I). [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 22:146-149.

HIROSE, M., M. AMIO, S. TAWARA, K. UCHIDA, and Y. FUJII.

1977. On the fish schools and the environment of fishing grounds in the vicinity of artificial gravel fish reef. [In Jpn.] J. Shimonoseki Univ. Fish. 26:57-78.

INOUE, M.

1969. Perspective on exploitation of fishing grounds for skipjack and young yellowfin tuna in the western tropical Pacific. [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr., Spec. No. (Prof. Uda Commemorative Papers), p. 235-242.

ISHII, H.

1981. Tracking the Kuroshio with an Argos buoy. [In Jpn.] Kaiyo Kagaku (Mar. Sci.) 13(5):338-345.

JAPAN FISHERY RESOURCE CONSERVATION ASSOCIATION.

1981a. A review of artificial fishreef research—I. Primary subjects of artificial fishreef study. [In Jpn.] Mar. Aqua. Ser., 26, Ishizaki Shoten, Tokyo, 119 p.

1981b. A review of artificial fishreef research—II. Present status in research of artificial fishery. [In Jpn.] Mar. Aqua. Ser., 27, Ishizaki Shoten, Tokyo, 126 p.

KATOH, J., and C. ITOSU.

1980. Study on artificial reefs from the viewpoint of environmental hydraulic engineering. [In Jpn.] Bull. Jpn. Soc. Sci. Fish. 46:1445-1456.

KAWANA, K.

1973. Measurement of underwater illumination in the sea on Yamato-tai. [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 22:144-145.

KISHI, M., and S. KONAGA.

1977. Observations on coastal upwellings. [In Jpn.] Kaiyo Kagaku (Mar. Sci.) 9(6):20-25.

KOJIMA, S.

1967. Shiira-zuke fishing ground and bottom topography. [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 11:91-93.

KONAGA, S., H. ISHIZAKI, and K. NISHIYAMA.

1981. The 1934-43 Kuroshio meander and the pattern of oceanic circulation in the western North Pacific. [In Jpn.] Kaiyo Kagaku (Mar. Sci.) 13(14):271-277.

KONAGAYA, T.

1978. Pelagic fishery resources (particularly albacore) in the vicinity of the Emperor Seamounts. [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 33:67-69.

MACHIDA, S.

1972. Note on whaling ground in relation to sea-bottom topography in northwestern Pacific. [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 20:121-122.

1974. Some oceanic features in the Crozet and the Kerguelen Ridges region. [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 24:166-176.

MAO, H. L., and K. YOSHIDA.

1955. Physical oceanography in the Marshall Islands area, Bikini and nearby atolls, Marshall Islands. Prof. Pap. U.S. Geol. Surv., 260-R, p. 645-684.

MORITA, J., and H. YAMANAKA.

1978. On the diurnal variations in surface temperatures (based on intake-pipe temperature) inside of the reef in the vicinity of Cape Lambert in New Britain Island. [In Jpn.] Bull. Far Seas Fish. Res. Lab. 16:51-57.

NAKAMURA, Y.

1972. Oceanographic studies of Suruga Bay (I): Characteristics of the oceanographic structure during the fall season. [In Jpn.] Shizuoka Pref. Fish. Exp. Stn. Rep. 5, 20 p.

1981. The fishing grounds for the Pacific mackerel in the coastal Kanto waters, and their characteristic oceanographic features. [In Jpn.] Tokyo, Kanagawa, Shizuoka and Chiba Pref. Fish. Exp. Stns. Rep. 99-126.

NAKAMURA, Y., and T. SAWADA.

1971. Report on the oceanographic survey of Suruga Bay (1): Characteristics in the oceanographic structure during the fall season of 1969. [In Jpn.] Shizuoka Pref. Fish. Exp. Stn., 36 p.

NAKAO, T.

1977. Oceanic variability in relation to fisheries in the East China Sea and the Yellow Sea. J. Fac. Mar. Sci. Tech., Tokai Univ., Spec. Rep. 199-367.

NAKAO, T., M. UDA, and S. KUDO.

1973. Oceanographical condition on the Yamato-tai and its neighborhood in the summer of 1971. [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 22:125-138.

NAKATA, K., M. ONITSUKA, and K. ISHIKAWA.

1973. Velocity of ocean current on the Yamato-tai. I. [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 22:127-131.

NASU, K.

1973. Surveys on mid-Pacific seamounts by the R/V *Kaiyo Maru*. 1. Oceanography. [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 23:57-62.

NASU, K., and T. KIKUCHI.

1974. The 16th symposium on whaling. 1. Current in the vicinity of Milwaukee Bank. [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 24:153-156.

NATHANSOHN, A.

1906. Uber die bedeutung der vertikaler wasserbewegungen fur die produktion des planktons in Meer. Kgl sachs d wiss abb 29 (5).

NIINO, H.
1967. Fishing reef, submarine valley and marine living resources. [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 11:51-54.
NISHIYAMA, K., S. KONAGA and H. ISHIZAKI.
1980. The cold water eddy observed far south of Shikoku in September 1979. Oceanogr. Mag. 31(1-2):27-32.
OKAZAKI, M.
1973. Velocity of ocean current on the Yamato-tai II. [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 22:131-135.
OTSUKA, K.
1976. Path of the Kuroshio near Izu Archipelago. [In Jpn.] Kaiyo Kagaku (Mar. Sci.) 8(4):35-41.
SAIZHO, T., Y. IMOTO, and T. TERASHI.
1980. On the distribution of zooplankton in the vicinity of Amami Island. [In Jpn.] Fish. Dep., Kagoshima Univ., 1979 Res. Prog. Rep. 96-99.
SAKURAI, M., and A. MAEDA.
1979. Detailed water temperature structure in the waters in the vicinity of the southern Ryukyu Islands. [In Jpn.] Fish. Dep., Kagoshima Univ., 1978 Res. Prog. Rep. 40-43.
SEA SPHERE INSTITUTE.
1974. Report on the 1973 survey of the bottom topography of Seno-umi in Suruga Bay. [In Jpn.] Sea Sphere Institute, 49 p.
SHIMOMURA, T.
1967. Bottom topography and fishing ground in the Sea of Japan and adjacent waters to the west part of Japan. [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 11:54-58.
TAKAHASHI, T., M. CHAEN, H. ICHIKAWA, T. NISHI, S. ARIMA, and K. TAKATA.
1980. Variations in current velocity and water temperatures off Kasarizaki, Amami Oshima. [In Jpn.] Fish. Dep., Kagoshima Univ., 1979 Res. Prog. Rep. 68-73.
TAWARA, S., and S. KOGA.
1974. On the fishing grounds and oceanographic condition in the vicinity of the Seychelles Islands. [In Jpn.] J. Shimonoseki Univ. Fish. 23(1):1-24.
TOKYO UNIVERSITY, OCEAN RESEARCH INSTITUTE.
1979. Environmental research pertaining to the transport, dispersion, and survival of fish eggs and larvae. . . Research results as well as collection of basic data. [In Jpn.] Tokyo Univ., Ocean Res. Inst., 50 p.
TOMINAGA, S.
1957. Skipjack tuna. . . behavior and fishing method. [In Jpn.] Ishizaki Shoten, Tokyo, 156 p.
UDA, M.
1961. On fish shoals. Kaiyo gjojogaku (Study of oceanic fishing grounds). [In Jpn.] Koseisha Koseikaku, Tokyo, p. 101-111.
UDA, M., and M. ISHINO.
1958. Enrichment pattern resulting from eddy systems in relation to fishing grounds. J. Tokyo Univ. Fish. 44(1-2):105-118.
VAN ARX, W. S., W. H. MUNK, M. C. SARGENT, and M. K. ROBINSON.
1954. Bikini and nearby atolls. Part 2. Oceanography (physical). Geol. Surv. Prof. Pap. 260-B, C, D, p. 265-281.
YAMANAKA, H., and M. YUKINAWA.
1976. A study on the oceanographic features in the vicinity of the Hunter Bank. [In Jpn.] Far Seas Fish. Res. Lab., Res. Rep. 14:123-162.
YAMAZAKI, S., T. MAKITA, W. NAGATA, F. IKEDA, and H. HIRATA.
1981. On the distribution of phosphates and nitrates in the waters west of the northern Ryukyu Islands. [In Jpn.] Fish. Dep., Kagoshima Univ., 1980 Res. Prog. Rep. 50-59.
YOSHIDA, K.
1967. Bottom topography, sea current and waves. [Abstr.] [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 11:64.

Session 1. Summary

RICHARD N. UCHIDA and SIGEITI HAYASI

Two papers were presented during the session. The first by Roden dealt primarily with the effects that seamounts have on the ocean's thermohaline structure and generated an active exchange of opinions during the discussion. The behavior of this structure and the circulation depend on several factors including speed and sheer of the oncoming flow, shape and orientation of the seamount, vertical stratification, and rotation of the earth. When conditions are favorable, stationary water masses called Taylor columns may form near seamount peaks, whereas under other conditions eddies may be shed from the seamount. Not all Taylor columns reach the sea surface. Those that do are more easily observed in winter by their low temperatures; in summer, the temperature contrast is minimal at the sea surface because the Taylor column may not extend above the mixed layer. The duration and frequency with which Taylor columns form have not been researched.

Yamanaka presented the second paper which reviewed results of investigations into the association of fish schools with oceanographic conditions in the vicinity of seamounts and other undersea features. He cited studies which showed that size and shape of seamounts, depth of the summit, bottom topography, water quality, and current strength all contribute to the formation of eddies and upwelling which aggregate fish. In these eddies, water color and transparency change and productivity is high near the summit. Many phenomena in the vicinity of seamounts need to be clarified. For example, one study showed that tuna usually aggregated upstream of seamount eddies whereas prey were found downstream. Unique bottom conditions around Crozet and Kerguelen Islands have been reported to be responsible for accumulating Antarctic krill and whales. Undersea ridges, which alter surface circulation, have influenced the transport and dispersion of fish eggs and larvae.

Yamanaka reported that even artificial reefs, although small compared with seamounts, also influence currents, to some extent, and may serve as models in the study of circulation over and around seamounts.

In the discussion that followed, Roden emphasized that to properly investigate the influence of seamounts on the oceanic environment, three-dimensional sampling would be required. Sampling stations should be spaced not more than 20 km apart for large seamounts and 5 km apart for small ones. Combination of ship, satellite, and satellite-tracked drifter measurements should produce results superior to single measurements. Accurate navigation and precision depth recording are also essential, and hydrographic stations should be conducted to depths of 3,000 m and preferably to the bottom.

Discussion also brought out that the height of the Taylor column is associated with the strength of the vertical stratification, that is, the stronger the stratification, the shorter the column. Furthermore, whether a Taylor column can be detected on the sea surface depends on weather conditions. Differences in water color and transparency can be seen over, and adjacent to, seamounts to some extent. On cyclonic and anticyclonic eddies in the vicinity of seamounts, the discussion centered on Yamato Bank located at the division of two current systems. Observations at this bank showed current speed in the southern part of the bank was twice as fast as that in the northern sector.

On a question of whether information on topography and other parameters could be used to develop models for other seamounts, Roden replied that a generalized model will be quite difficult to construct, explaining that some models will provide answers some of the time, but no generalized model is possible for all seamounts.

Another point brought up was the depth profile of chlorophyll *a* in the vicinity of seamounts. Yamanaka responded that because his presentation was an overview of other investigations, he was not able to describe its depth distribution. The question of why aggregations of small fish appear on the downstream side and large fish such as tunas occur on the upstream side was brought up but remained unanswered for lack of research information.

Development and Present Status of Japanese Trawl Fisheries in the Vicinity of Seamounts

TAKASHI SASAKI
Far Seas Fisheries Research Laboratory
Shimizu, Shizuoka, 424 Japan

ABSTRACT

A large-scale trawl fishery over seamounts in open waters of the central North Pacific began in 1967 when Soviet trawlers first exploited the pelagic armorhead stocks. In 1969, Japanese trawlers commenced exploratory trawling on the same stocks. At present, two to three vessels, ranging in size from 1,500 to 4,000 gross tons, operate annually in the Japanese seamount trawl fishery. The pelagic armorhead catch reached peak levels of 22,000-35,000 metric tons (MT) in 1972-76 but declined drastically in 1977 to only 3,500 MT. Catch per unit of effort (CPUE) began to show a declining trend as early as 1972-73, before expansion of the fisheries reached very low levels in 1978, and has remained low since then. The catch of alfonsin in recent years constituted a large proportion of the total catch in the seamount fishery. Although CPUE of alfonsin rose sharply in 1979, there were no indications of further rise or decline even after 3 or 4 years of intensive exploitation. Examples of rapid decline in demersal seamount stocks after exploitation by trawlers have been observed in rockfish stocks on Cobb Seamount in the northeastern Pacific and in sea bass stocks on Norfolk Ridge in the South Pacific Ocean.

Trawl fisheries developed mainly to exploit large stocks such as cod and plaice distributed over very wide continental shelves and slopes. The high fishing efficiency of the gear can often deplete smaller stocks in limited habitats around seamounts or banks in the open oceans. Past experiences in Japanese trawl fisheries indicate the necessity to conduct biological research in advance of operations by large trawlers to define initial stock sizes and understand the factors affecting turn-over rates such as reproduction, recruitment, growth, and movement. The size of the trawling fleet should be kept at a low but economically feasible operating level until sufficient biological information is obtained.

INTRODUCTION

It has long been known that seamounts, banks, and isolated islands provide fertile grounds for fishing migratory and demersal fishes. There are a number of banks and seamounts utilized for various types of fisheries in waters adjacent to Japan (Sato 1979, 1981, 1982, 1983). These banks and seamounts have two features: First, they are located close to the Japanese islands or the Asian Continent, and second, the fishing grounds, most of which are narrow, have low concentrations of exploitable fish stocks, thus discouraging the development of trawl fisheries. One exception is the fishable stock at Yamato Ridge. To harvest the resources over the seamounts close to Japanese islands, angling from small vessels <50 gross tons (GT) is the only practical fishing method (Ikeda 1980). There are a number of banks and seamounts located in the open sea far from the continental shelf, where some Japanese fishermen handline for alfonsin, *Beryx splendens* Lowe (Masuzawa et al. 1975).

Success of Soviet trawlers in harvesting seamount fisheries resources in 1967 led to a change in the belief that seamount stocks could be exploited only by angling. The Soviet fleet discovered and profitably harvested densely distributed pelagic armorhead, *Pseudopentaceros wheeleri* (Smith), over seamounts in the southern Emperor Seamounts and the northern Hawaiian Ridge (SE-NHR) (Sakiura 1972). In 1969, Japanese trawlers commenced exploratory fishing operations near Milwaukee Seamounts (Bank) (Takahashi and Sasaki 1977). A search was also conducted for other unexploited seamount resources in the central and eastern North Pacific, the central South Pacific, the Indian Ocean, and the South Atlantic Ocean. This report reviews the historical development and current status of the Japanese trawl fisheries in the central North Pacific Ocean, and presents a brief summary of the results of trawl surveys conducted by the Japanese over seamounts distributed in other parts of the world's oceans.

MATERIALS AND METHODS

Fishery statistics and length-frequency data on pelagic armorhead and alfonsin in the central North Pacific seamounts, which were used in this paper, were compiled by the Far Seas Fisheries Research Laboratory in Shimizu based on operation records submitted to the Fisheries Agency of Japan from commercial fishing vessels in accordance with their obligation. Data are included for the period from 1969 to 1982. The length-frequency data were reinforced by the data obtained from research vessels and biological measurements at the laboratory. The fishery statistics are arranged by month, statistical block (long. 1° × lat. 30°), fishing gear, and species. Units of catch and fishing effort for stern trawl vessels are metric ton and hour, respectively. Catch per unit of effort (CPUE) was calculated from monthly or yearly effort and monthly or yearly catch by species. The Japanese fishing fleet operating in the central North Pacific seamounts area, for which the statistics are available, consists of several different sized stern trawlers. Fishing power may, therefore, be a little different among the vessels but no standardizations were applied. Also, it is possible that some modification of fishing gear and tactics were made to target alfonsin as the abundance of pelagic armorhead declined. It is unknown, however, if a change in fishing gear or tactics actually took place, so the same index of effort was used to calculate CPUE values for both species in this paper.

In addition to the above materials, trawl survey reports from the Fisheries Agency of Japan, the Japan Marine Fishery Resource

Research Center (JAMARC), Hokkaido University, and other research organizations were reviewed to describe the living resources not only in the North Pacific seamounts, but also in the seamounts in other oceans.

RESULTS

Fishing grounds around seamounts in the central North Pacific Ocean

Development and present status—Only limited information is available on the pioneering trawling operations of the Soviet vessels over seamounts in the SE-NHR. Sakiura (1972) reported that the vessels captured as much as 133,400 metric tons (MT) of pelagic armorhead during the early years of the fishery. Japanese exploratory surveys have demonstrated that profitable trawling grounds are limited to only a few seamounts, including Kimmei, Milwaukee, Colahan, and Hancock among the many found in waters in the vicinity of the SE-NHR (Fig. 1) (Iguchi 1973; Kuroiwa 1973; Fisheries Agency of Japan 1974; JAMARC 1974; Miyagi Prefectural Office 1975; Aomori Prefecture Fisheries Experimental Station 1976; Hokkaido Prefectural Office 1977; Hokkaido University 1978, 1979, 1980, 1981).

The large Japanese trawlers that have operated in the seamount fishery range from 1,500 to 4,000 GT and usually participate in the North Pacific trawl fisheries. Two to five trawlers have operated in the seamount fishery every year since 1969. With the exception of catches made in 1969 (7,500 MT) and 1971 (5,800 MT), the total landings were usually large, ranging from 22,800 to 35,100 MT during the first 8 years of the fishery (Table 1). By 1977, the total catch had dropped to 5,800 MT and further declined in 1978 to 3,400 MT, indicating a drastic reduction in the pelagic armorhead stock. Owing to the increasing catches of alfonsin, total landings recovered to 13,700 MT in 1980, but subsequent catches further declined and by 1982 only 9,900 MT were landed (Table 1).

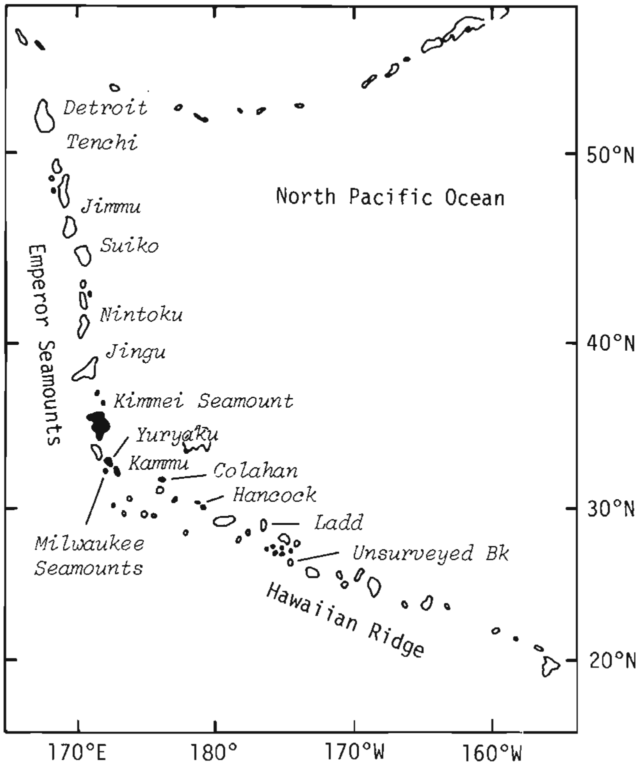


Figure 1.—Major seamounts within the Emperor Seamounts and northern Hawaiian Ridge (shaded seamounts provide fertile trawling grounds).

Table 1.—Catch in metric tons of major species by Japanese trawlers in the Emperor Seamounts and northern Hawaiian Ridge, 1969-82.

Year	Pelagic armorhead	Alfonsin	Other fish	Total catch
1969	7,410	45	1	7,456
1970	26,262	600	75	26,937
1971	5,546	68	164	5,778
1972	34,826	81	234	35,141
1973	28,355	12	191	28,558
1974	26,284	—	999	27,283
1975	21,746	—	1,096	22,842
1976	24,829	1,726	4,535	31,090
1977	3,448	1,941	424	5,813
1978	875	1,645	895	3,415
1979	499	5,383	975	6,857
1980	1,837	8,632	3,198	13,667
1981	1,211	7,916	1,991	11,118
1982	524	8,582	763	9,869

Thus, in the 12 years that the seamount trawl fishery has been in existence, there has been a shift in dominant catch from pelagic armorhead to alfonsin. Whereas pelagic armorhead comprised more than 90% of the total catch in 1969-75, the species represented only 80% in 1976, 59% in 1977, 26% in 1978, and only 5 and 13% since then (Table 1). The catches of alfonsin by trawlers were insignificant until 1976 when landings of this species were relatively large, reaching 1,700 MT and constituting 6% of the total seamount fishery production. Since then, alfonsin catches have been rather significant, rising rapidly in the face of declining pelagic armorhead catches. By 1982, alfonsin represented 87% of the total seamount fishery landings. The cause of this increase of alfonsin catch is not yet determined. Even incidental species, which represented <5% of the catch before 1975, comprised 7-8% in 1977 and in 1982, and varied between 15 and 26% in 1976 and 1978-81.

Implementation of the Magnuson Fishery Conservation and Management Act in 1977 resulted in exclusion of Hancock Seamounts from free access to non-U.S. fishing vessels. Japanese trawlers did not enter the Hancock Seamount area in 1977. In 1978 and 1979, only one vessel applied for and received a permit to fish at the Hancock Seamounts, whereas, two vessels were permitted from 1980 to 1982. The quota allotted to Japan was 1,000 MT of whole demersal fish from the Hancock Seamount area; the actual catch, however, has never reached the quota, and ranged between 210 MT in 1979 and 800 MT in 1980. Pelagic armorhead usually comprised more than 90% of the total catch except in 1979 (65%) and 1982 (70%). The details of the fishery at Hancock Seamounts are reported by Uchida and Tagami (1984).

Description of four major seamounts

Kimmei Seamount—The area of the top of Kimmei Seamount at depths <366 m is 452 km^2, making this the largest among the Emperor Seamount group. There are two peaks with a minimum depth of 270-280 m in the south and 212-220 m in the north (JAMARC 1974; Aomori Prefectural Fisheries Experimental Station 1976; Nakano 1978). The major trawling grounds extend between depths of 300 and 600 m, and temperatures at the bottom vary from 9.8° to 11.0°C (Kuroiwa 1973). The species composition at this seamount includes pelagic armorhead, alfonsin, Japanese beardfish, *Polymixia japonica* Steindachner, broad alfonsin, *Beryx decadactylus* Cuvier, Japanese butterfish, *Hyperoglyphe japonica* (Döderlein), mirror dory, *Zenopsis nebulosa* (Temminck et Schlegel), skilfish, *Erilepis zonifer* (Lockington), and honeycomb rockfish, *Hozukius emblemarius* (Jordan et Starks) (Kuroiwa 1973; JAMARC 1974; Aomori Prefectural Fisheries Experimental Station 1976; Suzuki and Takahashi 1978; Yamamoto et al. 1978).

Milwaukee Seamounts—A group which includes Yuryaku and Kammu Seamounts and located at the southern tip of the Emperor Seamounts is collectively called Milwaukee Seamounts. At Yuryaku, the minimum depth is 388-390 m (JAMARC 1973, 1974), and the fishing grounds extend from 400 to 600 m where the temperature ranges from 5.0° to 11.0°C (Kuroiwa 1973). There are three flat tops over Kammu, the shallowest being 335-370 m (Fisheries Agency of Japan 1974). Trawlers usually operate over grounds 350-600 m deep where temperatures range between 4.5° and 13.0°C (Kuroiwa 1973). Species composition of the catch is almost identical with that at Kimmei Seamount (Kuroiwa 1973; Sasaki 1973; Fisheries Agency of Japan 1974; JAMARC 1974).

Colahan Seamount—This is a single seamount located at the northern tip of the Hawaiian Ridge. The minimum depth is 270 m (JAMARC 1973; Nakano 1978). Trawlers operate at 270-400 m where temperatures vary from 11.0° to 13.0°C (Kuroiwa 1973). Major species are almost identical with those at Kimmei and Milwaukee Seamounts (Kuroiwa 1973; JAMARC 1974).

Hancock Seamount—There are several peaks in the Hancock group, two of which are located at the northwestern and southeastern tips. Shallowest levels are 263 m below the sea surface at the northwestern rise and 265 m at the southeastern rise. The apex is flat and very narrow, occupying 9 km^2 at depths <500 m at the northwestern end, and 3 km^2 at depths <300 m at the southeastern end (JAMARC 1973, 1974; Fisheries Agency of Japan 1974). Trawlers operate at 265-300 m at the northwestern rise and at 200-300 m at the southeastern rise. The bottom temperature ranges between 9.0° and 13.5°C at the former and 8.0° and 13.0°C at the latter (Kuroiwa 1973). In addition to the major species taken at the previously described seamounts, the catch at Hancock Seamount comprises four species or groups of species including mackerel scad, *Decapterus russellii* (Rüppell), bigeye driftfish *Ariomma lurida* Jordan et Snyder, bonnetmouth, *Erythrocles schlegeli* (Richardson), and sea basses, Serraninae (Kuroiwa 1973; Sasaki 1973; Fisheries Agency of Japan 1974; JAMARC 1974).

Amount of fishing effort—Japanese trawlers have expended most of their effort in the fishing grounds around Kimmei Seamount and Milwaukee Seamounts (Table 2). There are wide fluctuations in the effort expended at these two fishing grounds. Fishing intensity, which peaked relatively early in the fishery (1970), reached 460 trawling hours at Kimmei Seamount and 2,050 h at Milwaukee Seamounts. After a decline in effort at Kimmei Seamount in 1971 and in 1973 at Milwaukee Seamounts, there was an appreciable increase to a second peak which exceeded 1,000 h at both fishing grounds in 1976 and 1977. The effort at Kimmei Seamount gradually declined to 480 h in 1980 and then showed a slight recovery. A similar trend in fishing effort was observed at Milwaukee Seamounts, except for an extraordinarily high level of 1,150 h in 1980. The two other grounds were not intensively exploited and the effort was <500 h; however, there has been an increase in effort at Hancock Seamount since 1979.

Catch—Table 2 shows the catches of pelagic armorhead at Kimmei, Milwaukee, Colahan, and Hancock Seamounts since the beginning of the fishery in 1969, until 1982. It is clear that catches of pelagic armorhead and the total trawl landings in the seamount fishery fluctuated in a similar fashion until 1978. At Milwaukee Seamounts, considered the most productive ground, the catch increased in the even-numbered years until 1976, and the highest catch of 18,300 MT was obtained in 1974. The catch decreased to 2,000 MT in 1977 then declined to low levels, reaching 200 MT in 1982. This species has been less productive on the Kimmei Seamount trawling ground, especially in the early years of exploitation in 1971-72. Here, the catch peaked twice—once in 1969 when the catch reached 7,100 MT and again in 1976 when 6,300 MT were landed. The catch then decreased to 1,200 MT in 1977, and since 1978 has remained at very low levels between 30 and 200 MT. At Colahan Seamount, the catch of pelagic armorhead showed a single peak in 1972 at 14,200 MT whereas at Hancock Seamount, one peak occurred in 1973 at 8,000 MT. At both grounds, the decline in the catch has been almost continuous.

Landings of alfonsin were made up mostly from catches at Kimmei and Milwaukee Seamounts (Table 3). At Kimmei Seamount, the catches of alfonsin have shown a relatively steady upward trend and reached 4,600 MT in 1982, whereas, at Milwaukee Seamounts, the catches rose sharply to a peak in 1980 at 6,500 MT, declined in 1981, then rose again slightly in 1982.

Fishing season

Pelagic armorhead—Fishing effort aimed at pelagic armorhead in the SE-NHR remained stable for 4 years in 1973-76 after much information on the fishing grounds was accumulated. Figure 2 shows the seasonal changes in fishing effort, catch, and CPUE of pelagic armorhead during these years. Fishing intensity in the seamount trawl fishery usually remained low in January-March, increased in April, peaked in May, declined again to low levels in June-July, reached a second peak in August, before declining once again to low levels in October. There was a slight rise in fishing activity in November before it returned once again to low levels. Despite such wide fluctuations in fishing effort, catch remained fairly stable, usually varying between 2,100 and 2,900 MT, except in October when only 1,600 MT were caught. Accordingly, CPUE, which fluctuated inversely with trawling effort, was especially low in May, only 13 MT/h, but high in March, April, and December when catch rates were 33, 34, and 32 MT/h, respectively. Thus, apparent fishing efficiency for pelagic armorhead rose in those months when fishing intensity was low.

Alfonsin—For this species, seasonal changes in fishing activity were examined for 1979-82. Figure 3, which shows the monthly averages of catch, trawling hours, and CPUE, indicates that trawling effort for alfonsin fluctuated widely during the year. From a low level of about 100 h in January, effort rose in February, peaked to about 200 h in March, declined in April, then rose steadily thereafter to a peak of 320 h in September before declining sharply in October to about the January level. The effort then rose precipitously to a second peak of about 270 h in November and declined to a low level of about 70 h in December.

The alfonsin catch paralleled trawling effort during the year, rising to an early peak of 840 MT in February before declining to a low level in April. Catches then increased almost steadily throughout the summer, peaked to 1,350 and 1,300 MT in August and

Table 2.—Trawling effort in hauling hours, catch in metric tons, and catch per unit of effort (CPUE) in ton per hour of pelagic armorhead by Japanese trawlers in the major four seamounts in the Emperor Seamounts and northern Hawaiian Ridge, 1969-82.

Fishing grounds		1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
Kimmei	Effort	298	458	57	97	90	293	472	1,204	1,230	1,120	728	478	567	724
	Catch	7,080	5,138	95	2,017	893	4,015	3,789	6,277	1,205	180	200	73	80	29
	CPUE	23.8	11.2	1.7	20.8	9.9	13.7	8.0	5.2	1.0	0.2	0.3	0.2	0.2	0.0
Milwaukee	Effort	12	2,052	814	326	283	844	755	1,162	1,117	936	586	1,147	451	677
	Catch	330	19,600	3,514	14,828	11,269	18,267	12.686	15,609	2,023	179	86	528	124	182
	CPUE	27.5	9.6	4.3	45.5	39.8	21.6	16.8	13.4	1.8	0.2	0.1	0.5	0.3	0.3
Colahan	Effort	—	128	207	170	177	65	140	103	35	149	128	179	117	108
	Catch	—	916	1,188	14,166	4,918	1,406	1,789	758	74	95	75	433	208	32
	CPUE	—	7.2	5.7	83.3	27.8	21.6	12.8	7.4	2.1	0.6	0.6	2.4	1.8	0.3
Hancock	Effort	—	45	23	43	237	29	80	85	29	33	254	331	408	312
	Catch	—	320	81	3,482	8,002	771	1,322	808	70	407	136	735	595	273
	CPUE	—	7.1	3.5	81.0	33.8	25.6	16.5	9.5	2.4	12.3	0.5	2.2	1.5	0.9
Others	Effort	—	53	123	8	107	53	109	157	48	94	7	42	87	40
	Catch	—	289	668	336	3,278	1,828	2.159	1,378	77	15	4	69	195	8
	CPUE	—	5.5	5.4	42.0	30.6	34.5	19.8	8.8	1.6	0.2	0.6	1.6	2.2	0.2
All areas[1]	Effort	310	2,736	1,224	644	894	1,284	1,556	2,711	2,459	2,332	1,703	2,177	1,630	1,861
	Catch	7,410	26,263	5,546	34,829	28,360	26,287	21,745	24,830	3,449	876	501	1,838	1,211	524

[1] Discrepancies between catches shown in Table 1 and here are due to rounding.

Table 3.—Trawling effort in hauling hours, catch in metric tons, and catch per unit of effort (CPUE) in ton per hour of alfonsin by Japanese trawlers in the major four seamounts in the Emperor Seamounts and northern Hawaiian Ridge, 1969-82.

Fishing grounds		1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
Kimmei	Effort	298	458	57	97	90	293	472	1,204	1,230	1,120	728	478	567	724
	Catch	43	84	5	22	—	—	—	1,589	424	673	1,967	1,634	3,375	4,630
	CPUE	0.1	0.2	0.1	0.2	0.0	0.0	0.0	1.3	0.3	0.6	2.7	3.4	6.0	6.4
Milwaukee	Effort	12	2,052	814	326	283	844	755	1,162	1,117	936	586	1,147	451	677
	Catch	1	439	63	49	10	—	—	38	1,453	730	3,233	6,472	3,042	3,555
	CPUE	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.0	1.3	0.8	5.5	5.6	6.7	5.3
Colahan	Effort	—	128	207	170	177	65	140	103	35	149	128	179	117	108
	Catch	—	66	—	7	1	—	—	—	23	78	147	352	842	198
	CPUE	—	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.5	1.1	2.0	7.2	1.8
Hancock	Effort	—	45	23	43	237	29	80	85	29	33	254	331	408	312
	Catch	—	11	—	4	—	—	—	54	—	3	25	36	30	82
	CPUE	—	0.2	0.0	0.1	0.0	0.0	0.0	0.6	0.0	0.1	0.1	0.1	0.1	0.3
Others	Effort	—	53	123	8	107	53	109	157	48	94	7	42	87	40
	Catch	—	1	—	—	—	—	—	46	43	161	9	139	629	120
	CPUE	—	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.9	1.7	1.3	3.3	7.2	3.0
All areas[1]	Effort	310	2,736	1,224	644	894	1.284	1,556	2,711	2,459	2,332	1,703	2,177	1,630	1,861
	Catch	44	601	68	82	11	—	—	1,727	1,943	1,645	5,381	8,633	7,918	8,585

[1] Discrepancies between catches shown in Table 1 and here are due to rounding.

September, respectively, and sharply declined in October. The considerable amount of trawling pressure brought to bear on the stock in November produced a peak identical to that seen earlier in August. The catch then declined sharply once again to the lowest level of the year in December. Because changes in effort and catch were similar, CPUE generally fell within a fairly narrow range between 3.5 MT/h in January and 5.0 MT/h in November. The exceptions were in April when a very low value of 1.7 MT/h was recorded and in December when the catch rate reached only 2.8 MT/h. Thus, the alfonsin stocks available to the seamount trawl fishery have stayed at a fairly constant level throughout the year.

Trends in the available stock—The short history of the fishery precludes a detailed assessment of the pelagic armorhead and alfonsin stocks and limits analysis to data on CPUE. Information is also lacking for assessing stocks of other species.

Pelagic armorhead—Table 2 and Figure 4 show a general decline in CPUE during the very early years of the fishery through 1971 and a dramatic rise in 1972 at Milwaukee, Colahan, and Hancock Seamounts. The index for Kimmei Seamount also showed an increase in 1973 after the initial decline. Peak CPUE was particularly high at Colahan and Hancock Seamounts compared with indices from other grounds. After 1972-73, CPUE declined rapidly, falling to negligible values in 1978 at Kimmei, Milwaukee, and Col-

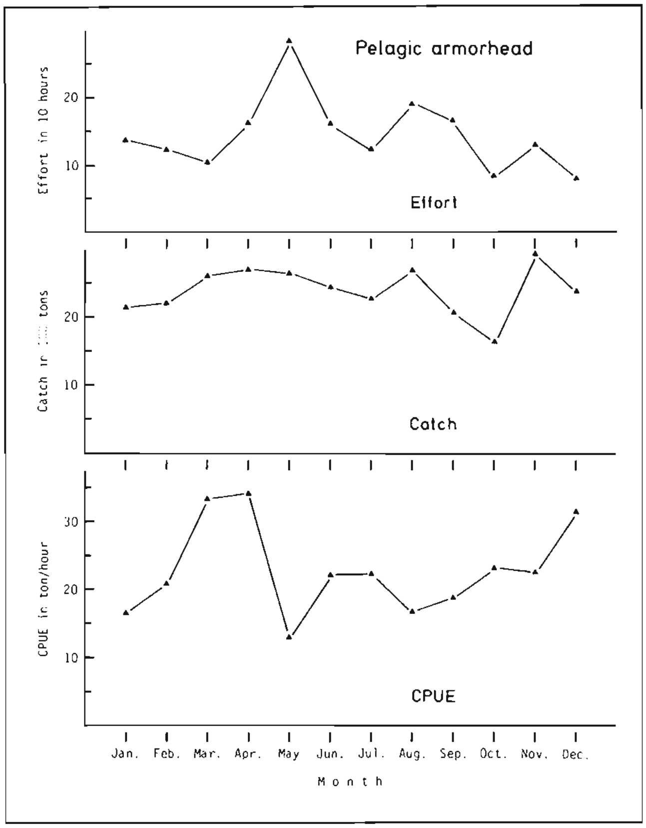


Figure 2.—Monthly averages of trawling effort in hauling hours, catch in metric tons, and CPUE in ton per hour of pelagic armorhead by Japanese trawlers in the Emperor Seamounts and northern Hawaiian Ridge, 1973-76.

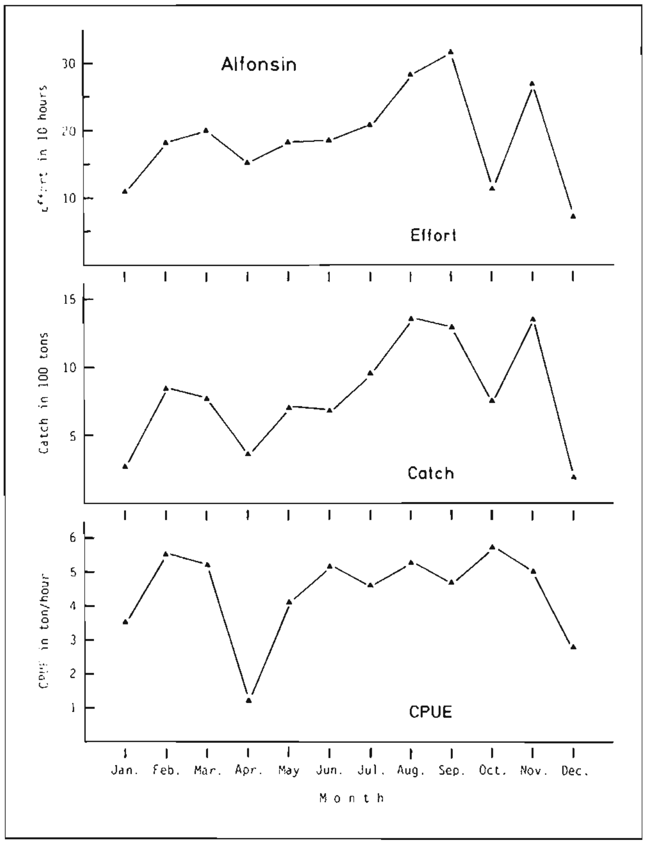


Figure 3.—Monthly averages of trawling effort in hauling hours, catch in metric tons, and CPUE in ton per hour of alfonsin by Japanese trawlers in the Emperor Seamounts and northern Hawaiian Ridge, 1979-82.

ahan Seamounts, and in 1979 at Hancock Seamounts. The catch remained relatively high until 1976 despite a drastic decline in CPUE since 1972-73 at all the grounds. It is obvious that the rapid increase in fishing effort in the last 3 or 4 years (Table 2) made possible maintaining a high level of catch and resulted in severe depletion of the pelagic armorhead stock.

Size composition of pelagic armorhead taken by Japanese trawlers shows a peculiar year-to-year change (Fig. 5). Fish of 28-32 cm fork length (FL) dominated the catch in 1969; however, by 1972, the dominant class consisted of fish in the 27-28 cm size group. In subsequent years, the proportion of large fish in the catch rose and the mean length has exceeded 30 cm since 1978. It is also quite noticeable that small fish (<25 cm FL) were not significantly represented in the catch.

Alfonsin—Since 1976, CPUE of alfonsin rose rapidly in the three grounds around Milwaukee, Kimmei, and Colahan Seamounts from <2 MT/h to over 6 MT/h (Table 3 and Fig. 4). The relative abundance index in 1982 was still high at Milwaukee and Kimmei Seamounts whereas it declined to earlier levels at Colahan Seamount. No rise was found at Hancock Seamounts (Fig. 4). It should be noted that CPUE had already declined in one of the three major grounds over a period of only 4 years of intensive exploitation.

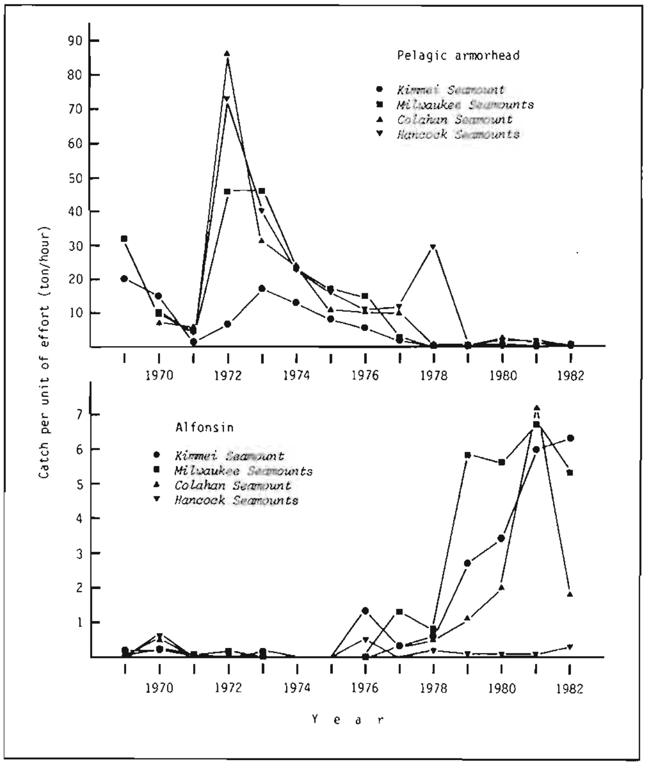


Figure 4.—Yearly average CPUE in ton per hour of pelagic armorhead and alfonsin exploited by Japanese trawlers in four major seamounts of the Emperor Seamounts and northern Hawaiian Ridge, 1969-82.

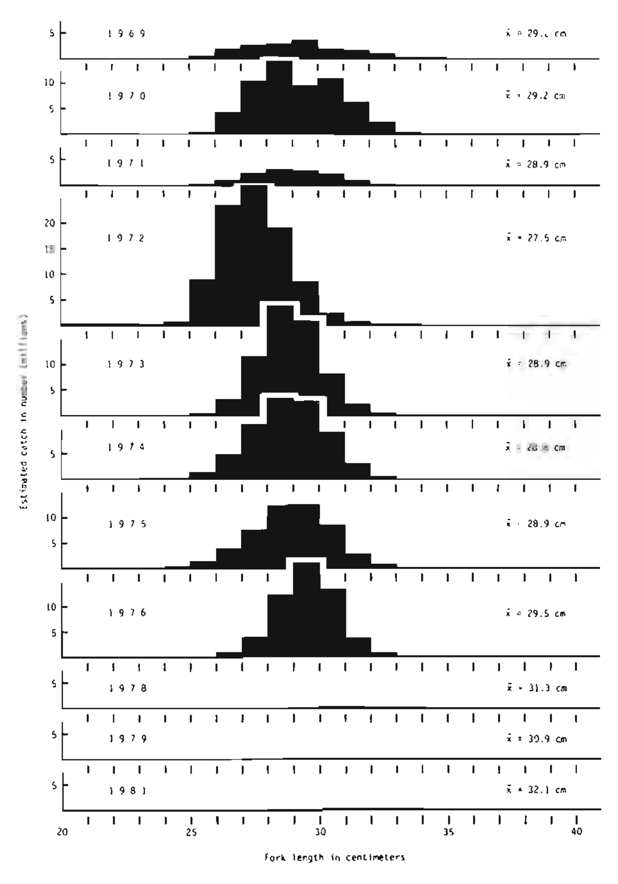


Figure 5.—Size composition of pelagic armorhead caught by Japanese commercial trawlers at seamounts of the Emperor Seamounts and northern Hawaiian Ridge, 1969-81. Size composition data are not available in 1977 and 1980.

Japanese surveys of fishery resources over other seamounts

The Fisheries Agency of Japan and JAMARC have conducted trawl fishery surveys at a number of seamounts in the Pacific, Indian, and South Atlantic Oceans. Major areas surveyed include the mid-Pacific, off Alaska, offshore waters of the northeastern Pacific, off Baja California, waters in the north-south belts from the Samoa Islands to New Zealand, and those of the east-west belt from the eastern coast of Australia to Austral Seamounts, located at long. 145°W in the South Pacific Ocean. The areas surveyed in the Indian Ocean include Saya de Malha Bank, Madagascar Bank, and others north of lat. 35°S, the Kerguelen and Crozet Islands, and Ob' Bank and Lena Tablemount (Bank) near the Antarctic Seas. The survey was also caried out over seamounts and banks between lat. 30° and 42°S in the South Atlantic Ocean.

North Pacific Ocean—In addition to the SE-NHR seamounts, others existing either singly or in groups, were surveyed by Japanese trawlers. The exploratory areas are shown in Figure 6.

Mid-Pacific seamounts—Trawl surveys in this area covered only the deep zones of 1,200-1,500 m. The exploratory trawling surveys caught only small quantities of low-quality fishes including brotulas (Brotulidae), longfin cutthroat eel, *Synaphobranchus affinis* Günther, Grays cutthroat eel, *S. kaupii* Johnson, slickheads (Alepocephalidae), grenadiers (Macrouridae), sawpalate (Serrivomeridae), and dogfish shark (*Etmopterus*) (Fisheries Agency of Japan 1974). Large-scale trawl exploitation of the resource was not expected to be feasible in this area, although angling operations may be profitable for alfonsin, crimson snapper, *Pristipomoides sieboldii* Bleeker, ruby snapper, *Etelis carbunculus* Cuvier, if seamounts with summits of 500-600 m or shallower can be located.

Seamounts in the Gulf of Alaska—Experimental fishing at Patton and Pratt Seamounts produced limited quantities of demersal fish dominated by sablefish, *Anoplopoma fimbria* (Pallas), smaller amounts of rougheye rockfish, *Sebastes aleutianus* (Jordan et Evermann), and shortspine thornyhead, *Sebastolobus alascanus* Bean (Chikuni 1971; Kuroiwa and Funato 1980; Shigeno 1981).

The U.S. survey in 1979 captured sablefish, two species of king crabs including the deep-sea red king crab, *Lithodes couesi* Benedict and the golden king crab, *L. aequispina* Benedict, and Tanner crab, *Chionoecetes tanneri* Rathbun, at 200-475 m on eight of the nine seamounts surveyed (Hughes 1981). Sablefish density was comparable to that on the continental shelf in the Gulf of Alaska (Alton 1986).

Seamounts in the central northeastern Pacific Ocean—Only limited amounts of sablefish were caught by trawls at Warwick Seamount located off the northwestern coast of Canada at lat. 48°04'N, long. 132°48'W (Kuroiwa and Funato 1980; Shigeno 1981). The shallow zone <300 m is widest at Cobb Seamount located southeast of Warwick. The major species taken were harlequin rockfish, *Sebastes variegatus* Quast, red-stripe rockfish, *S. proriger* (Jordan et Gilbert), rosethorn rockfish, *S. helvomaculatus* Ayres, and black rockfish, *S. melanops* Girard, together with jack mackerel, *Trachurus symmetricus* (Ayres) (Sasaki 1974a; Kuroiwa and Funato 1980; Shigeno 1981). In July 1978, the catch rate averaged 2,584 kg/h but the 1979 catch rate was only a quarter of that in the previous year, reaching 680 kg/h (Kuroiwa and Funato 1980; Shigeno 1981).

At seamounts in the area including Cobb, the catch and the size of individual fish declined during continuous harvesting in 1978-79.

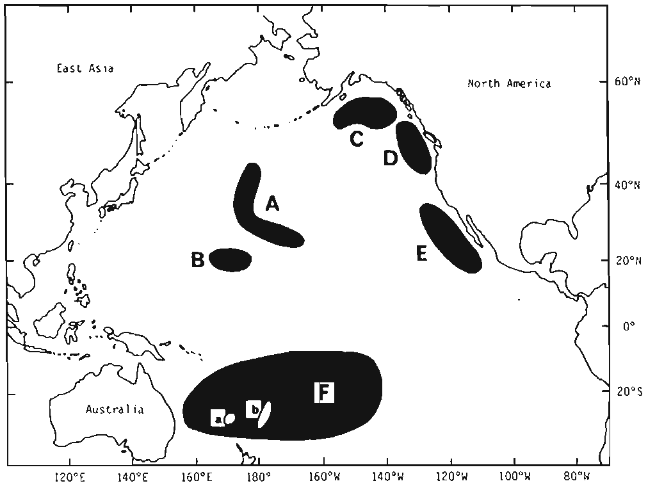


Figure 6.—Six Pacific Ocean areas of seamounts and ridges covered by Japanese trawl fishing resource surveys, 1972-80. A = Emperor Seamounts and northern Hawaiian Ridge; B = Mid-Pacific seamounts; C = seamounts in the Gulf of Alaska; D = seamounts in the central northeastern Pacific Ocean; E = seamounts off Baja California; F = seamounts and ridges in the South Pacific Ocean including Norfolk Ridge (a) and Kermadec Ridge (b).

Such adverse phenomena indicate that because the stocks inhabiting the seamount areas can be easily reduced by harvesting, it would be difficult to concentrate trawling in one particular seamount area.

Seamounts off Baja California—No fertile trawling ground was located off Baja California where seamounts are deep and have narrow tops. Economically valuable species were not caught during exploratory trawling; the catch usually consisted of dogfish shark (*Etmopterus*), chimaera, *Hydrolagus purpurescens* Gilbert, cat shark, *Apristurus brunneus* (Gilbert), morid cod (*Lepidion*), and grenadiers (Coryphaenoides) (Fisheries Agency of Japan 1979; Kuroiwa and Funato 1980).

South Pacific Ocean—The area surveyed by Japanese trawlers in the South Pacific extends over a broad sector between lat. 10°-30°S and long. 155°E-145°W (Fig. 6). Generally, the ichthyofauna showed geographic variation east and west of the Tonga and Kermadec Trenches, and had a remarkable resemblance to that in shallow-water zones <100 m of the western Pacific and Indian Oceans (Fisheries Agency of Japan 1977). Many species found at 200-300 m in the eastern part were similar to those in the SE-NHR in the North Pacific Ocean, with the exception of the pelagic armorhead and alfonsin, which were very scarce in the South Pacific Ocean.

At Norfolk and Kermadec Ridges, relatively high values of CPUE were obtained during initial exploratory trawling; however, heavy fishing reduced the catch rate considerably. At Norfolk Ridge, for example, a high CPUE of 4.6 MT/h was recorded at 100-200 m in January 1976. Dominant species were Blainville's dogfish, *Squalus blainvillei* (Risso), argentine (*Glossanodon*), berycoid fish, *Centroberys affinis* (Günther), dory (*Zenion*), sea bass, *Caprodon longimanus* (Günther), tarakihi, *Nemadactylus macropterus* (Bloch and Schneider), and porcupinefish, *Allomycterus pilatur* Whitley. Sea bass appears to have high commercial value, although porcupinefish was most abundant in the catch (Fisheries Agency of Japan 1976). Density of sea bass in the experimental operations was 1.7 MT/h in January 1976, but only 0.2 MT/h in December of the same year (Fisheries Agency of Japan 1976, 1977). Harvest of 1,000 MT by a large 2,500-GT class trawler might have been responsible for the rapid decline of CPUE. An analysis with the DeLury method suggested that the initial stock size of sea bass was 1,200 MT and production of 1,000 MT within 47 trawling days might have reduced the stock to one-sixth its initial size (Fisheries Agency of Japan 1977).

At Kermadec Ridge, the sea bed was rough and unsuitable for trawling. Bottom fishing with various types of angling gear produced few economically valuable species including yellowtail, *Seriola lalandi* Valenciennes, tarakihi, and jack (*Caranx*) (Fisheries Agency of Japan 1977).

Indian Ocean—Demersal fish stocks were found in four seamount areas in the Indian Ocean (Fig. 7): Saya de Malha Bank, which produced 700 MT in 1977 and 350 MT in 1978; banks around the Crozet Islands, which yielded 1,300 MT in 1978; those around Kerguelen Islands, which produced catches of 1,600 MT in 1977, and Ob' Bank and Lena Tablemount with catches of 734 MT in 1977 and 640 MT in 1979 (Kuroiwa 1978; Suzuki et al. 1978; Hasegawa 1980). The major species were scad (*Decapterus*), lizardfish, *Saurida undosquamis* (Richardson), and butterfly bream, *Nemipterus personii* (Block), around Saya de Malha Bank in the low latitudes, and antarctic giant fish, *Dissostichus eleginoides* Smith, antarctic cods, *Notothenia squamifrons* Günther and *N. rossii* Richardson, and icefishes, *Champsocephalus gunnari* Lonberg and *Chaenichthys rhinoceratus* Richardson, in the higher latitudes. These fishes brought relatively low prices in the Japanese market. Furthermore, the long distance from Japan to the Indian Ocean precludes commercial exploitation of seamount-associated resources in the Indian Ocean.

South Atlantic Ocean—Six seamount areas were surveyed in 1978 and 1979 (Fig. 8). Exploratory trawling in 1978 covered the waters around the R.S.A. Seamount and the McNish Seamount. Thirteen hauls in the former area landed 4 MT of fish, whereas 9 hauls in the latter produced 2.4 MT. Six hauls at Discovery Tablemount (Discovery Seamount), which has a deep summit, landed only a small quantity of economically low quality fishes consisting of several grenadiers (*Coryphaenoides*). Ten hauls were conducted in the Bromely Plateau, but the catch was insignificant in quality and quantity (Suzuki et al. 1978). Dominant species in both areas consisted of sancord, *Helicolenus dactylopterus* (De La Roche), rosy snapper, *Lutjanus lutjanus* Bloch, and rockfishes (*Sebastes*). In 1979, 24 hauls caught 54 MT of fish dominated by pelagic armorhead, *Pseudopentaceros richardsoni*, and sancord in the vicinity of the Valdivia Southeast Seamount, and 7 hauls produced 14 MT of butterfish (*Hyperoglyphe*) and others in waters around the Crowford Seamount (Tokusa 1981). However, the long distance from Japan and the low prices of these fish in the markets make extensive operation in the South Atlantic Ocean less feasible for the Japanese trawlers.

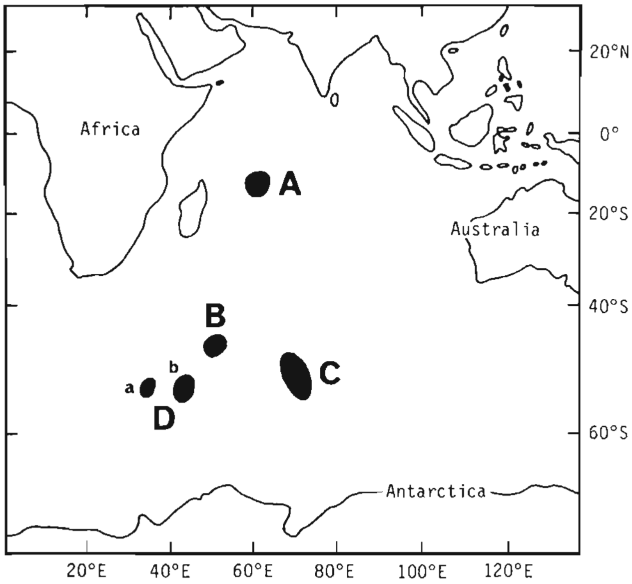


Figure 7.—Four bank areas in the Indian Ocean covered by Japanese trawl fishing resource surveys, 1977-79. A = Saya de Malha Bank; B = banks around Crozet Islands; C = banks around Kerguelen Islands; D = banks, including Ob' Bank (a) and Lena Tablemount (b).

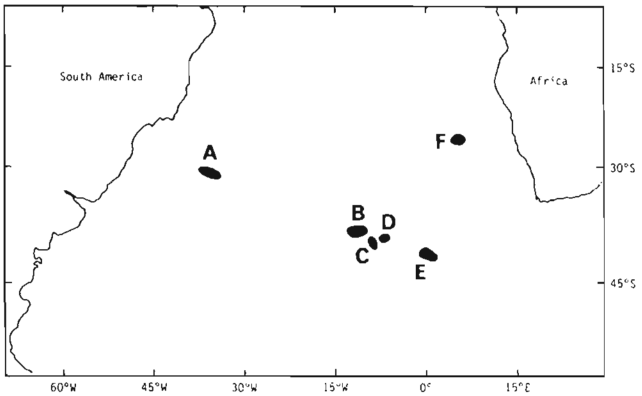


Figure 8.—Six seamount or bank areas in the South Atlantic Ocean covered by Japanese trawl fishing resource surveys, 1978 and 1979. A = Bromely Plateau; B = Crowford Seamounts; C = McNish Seamount; D = R.S.A. Seamount; E = Discovery Tablemount and Shannon Seamount; F = Valdivia Seamount.

DISCUSSION AND CONCLUSIONS

Detailed information has not been available from the Soviet trawl fleet, which first exploited pelagic armorhead in the seamount area. However, total catch of the Japanese and Soviet fleets might well have exceeded 140,000 MT at least in 1969 when unconfirmed reports indicated that the Soviet trawlers harvested 133,400 MT of this species (Sakiura 1972).

According to Borets (1979), the major group of 26-32 cm FL fish are 6-10 years old. Sasaki (1974b) noted that the dominant group includes sexually mature adults that spawn most actively in January and February. Borets (1979) found larvae and juveniles 2-20 mm in total length densely distributed in the surface layers of the waters around the seamounts in February-March. It is well known that fish of various sizes from young of 12 cm FL to adults over 30 cm FL are widely distributed over surface waters in the North Pacific, particularly in the northeastern part of the ocean (Welander et al. 1957; Neave 1959; Clemens and Wilby 1961; Wagner and Bond 1961; Follett and Dempster 1963; Honma and Mizusawa 1969; Chikuni 1970; Hart 1973). Young pelagic armorhead appear to spend their first 4 to 5 years in offshore surface waters before being recruited into the adult population which aggregates primarily over and around seamounts. Thus, much of the somatic growth occurs in the pelagic environment before recruitment to the seamount fishing grounds. Size composition data suggest that there is no evidence of recruitment of a strong year-class and recruitment has generally been very poor since 1973.

Although pelagic armorhead and alfonsin inhabit the summit and slope of seamounts, and both species migrate vertically past the summit daily, their diurnal behavior appears to be different. Pelagic armorhead rise above during the day and descend below the summit during the night (Sakiura 1972; Kitani and Iguchi 1974; Humphreys et al. 1984), whereas alfonsin remain on the slope area during daylight and in the upper water layers during darkness (Masuzawa et al. 1975). Therefore, making good use of the difference of behavior, fishing gear, and tactics might have been changed to target alfonsin; thus, CPUE of pelagic armorhead may be slightly underestimated in recent years. Even if a change in fishing gear or tactics actually took place, it is positive that the change began taking advantage of the depletion of pelagic armorhead stocks.

Changes in CPUE and size composition of pelagic armorhead suggest that the recruitment of an extremely strong year-class occurred in 1972 and that fishing up of the year-class resulted in the subsequent decline in CPUE since that time. It is difficult, however, to evaluate this hypothesis because the age composition data are not available and recruitment patterns are also not elucidated thoroughly. On the other hand, it is undeniable that the consistent decrease in spawning stock size may have resulted in the recent poor recruitment. In either case, it is obvious that the fishable biomass decreased rapidly since 1972 and has remained at a very low level of abundance since 1979. It is not expected that the stocks will recover in the near future. Future research on the seamount fisheries should attempt to delineate recruitment patterns in these areas and interrelations of stocks among the seamounts. It is also important to understand the age and growth of the fish.

Seamounts in the open oceans are not sufficiently productive to support large-scale operations of trawl fisheries. The only exceptions, thus far, are the seamounts in the SE-NHR in the central North Pacific Ocean. Heavy fishing pressure at these seamounts has seriously depleted the stocks associated with them in a fairly short time. Pelagic armorhead exhibited one of the typical examples of such reduction. Total production of pelagic armorhead which was sustained at a high level of 20,000-30,000 MT for 5 years (1972-76), declined sharply to only 3,500 MT in 1977. The CPUE exhibited a decline as early as 1972 just before the expansion of the fisheries (Sasaki 1978). Although the stock was first discovered in 1967, it can be seen how easily the resource was depleted in a matter of a few years. Even the remarkable reduction in fishing effort since 1978 did not result in recovery of the stock through 1982. Rapid decline of seamount-associated demersal stocks after the commencement of trawl fisheries also occurred in rockfish on Cobb Seamount in the northeastern Pacific and sea bass on Norfolk Seamount in the South Pacific Ocean.

Trawl fisheries have been developed mainly for exploiting large stocks such as cod and plaice which are distributed over wide continental shelves and slopes. High fishing efficiency of gear can often deplete smaller stocks in a limited habitat around seamounts or banks in the open oceans. The history of Japanese trawl surveys and subsequent commercial exploitation indicate the necessity to conduct biological research in advance of operations by large trawlers so that it would be possible to define initial stock sizes and understand factors affecting turnover rates of the stocks such as reproduction, recruitment, growth, and movement. The size of the trawling fleet should be retained at a low but economically feasible level until sufficient biological information is obtained. Failure, such as that witnessed in the pelagic armorhead seamount fishery in the central North Pacific Ocean, should not be repeated.

ACKNOWLEDGMENTS

I wish to express my deep felt gratitude to Sigeiti Hayashi, Director of the Tohoku Regional Fisheries Research Laboratory, and Hideo Otaki, Chief of Groundfish Resources Division of the Far Seas Fisheries Research Laboratory, who kindly reviewed the manuscript. I am also deeply indebted to Richard N. Uchida and George W. Boehlert, Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, for their kind editorial works of the English version of the manuscript and their efforts made to publish the paper.

CITATIONS

ALTON, M. S.

1986. Fish and crab populations of Gulf of Alaska seamounts. *In* R. N. Uchida, S. Hayasi, and G. W. Boehlert (editors), Environment and resources of seamounts in the North Pacific, p. 45-51. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 43.

AOMORI PREFECTURAL FISHERIES EXPERIMENTAL STATION.

1976. Survey report on the fishing grounds in the Emperor Seamounts, 1976. [In Jpn.] Aomori Prefectural Fisheries Experimental Station, 27 p.

BORETS, L. A.

1979. The population structure of the boarfish, *Pentaceros richardsoni*, from the Emperor Seamounts and the Hawaiian Ridge. J. Ichthyol. 19:15-20.

CHIKUNI, S.

1970. The "phantom fish," "kusakari tsubodai"—an outline. Enyo (Far Seas) Fish. Res. Lab. News 3:1-4. [In Jpn.] (Engl. transl. by J. H. Shohara, 7 p.; Natl. Mar. Fish. Serv., NOAA, Terminal Island, CA 90731.)

1971. Groundfish on the seamount in the North Pacific. [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 19:1-14. (Engl. transl. by K. Tatara, 1972, 12 p. Transl. No. 2130; available Fish. Res. Board Can.)

CLEMENS, W. A., and G. V. WILBY.

1961. Fishes of the Pacific coast of Canada. 2d ed. Bull. Fish. Res. Board Can. 68, 443 p.

FISHERIES AGENCY OF JAPAN.

1974. Survey of the North Pacific seamounts. Report of *Kaiyo Maru* survey cruises, 1972 season. [In Jpn.] Fish. Agency Jpn., 136 p. (Engl. transl. of selected portions of the report by T. Otsu, 1981, 55 p., Transl. No. 54; available Southwest Fish. Cent. Honolulu Lab., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396.)

1976. Survey of the coastal waters of the Australia and the Norfolk Ridge. Report of R/V *Kaiyo Maru* survey cruises, 1975 season. [In Jpn.]. Fish. Agency Jpn., 239 p.

1977. Survey of the central South Pacific Seamounts. Report of R/V *Kaiyo Maru* survey cruises, 1976 season. [In Jpn.] Fish. Agency Jpn., 259 p.

1979. Survey of the eastern North Pacific seamounts. Report of R/V *Kaiyo Maru* survey cruises, 1978 season. [In Jpn.] Fish. Agency Jpn., 173 p.

FOLLETT, W. I., and L. J. DEMPSTER.

1963. Relationships of the percoid fish *Pentaceros richardsoni* Smith, with description of specimen from the coast of California. Proc. Calif. Acad. Sci. Ser. 4, 32:315-338.

HART, J. L.

1973. Pacific fishes of Canada. Bull. Fish. Res. Board Can. 180, 740 p.

HASEGAWA, M.

1980. Survey report on the trawl fishery for commercialization of the fishing grounds in the southwestern Indian Ocean, 1978. [In Jpn.] Jpn. Mar. Fish. Resour. Res. Cent. (JAMARC) Rep. 7, 1978, 227 p.

HOKKAIDO PREFECTURAL OFFICE.

1977. Survey report on the fishery for commercialization of the fishing grounds in the Emperor Seamounts, 1976. [In Jpn.] Dep. Fish., Hokkaido Prefectural Office, 27 p.

HOKKAIDO UNIVERSITY.

1978. The "Hokusei Maru" cruise 3 (1-2) to the sea area off Hokkaido and sea area of the Emperor Seamount, northwest Pacific Ocean in June-August 1977. Data record of oceanographic observations and exploratory fishing 21:80-153.

1979. The "Hokusei Maru" cruise 6 (1-3) to the sea area off Hokkaido and sea area of the Emperor Seamounts, northwest Pacific Ocean in June-August 1978. Data record of oceanographic observations and exploratory fishing 22:72-178.

1980. The "Hokusei Maru" cruise 9 (1-3) to the sea area off Hokkaido and sea area of the Emperor Seamounts, northwest Pacific Ocean in June-August 1977. Data record of oceanographic observations and exploratory fishing 23:109-249.

1981. The "Hokusei Maru" cruise 12 (1-3) to the sea area off Hokkaido and sea area of the Emperor Seamounts, northwest Pacific Ocean in June-August 1980. Data record of oceanographic observations and exploratory fishing 24:111-212.

HONMA, Y., and R. MIZUSAWA.

1969. A record of the young of boar fish, *Pentaceros richardsoni*, from North Pacific. [In Jpn., Engl. summ.] Jpn. J. Ichthyol. 15(3):134-136.

HUGHES, S. E.

1981. Initial U.S. exploration of nine Gulf of Alaska Seamounts and their associated fish and shellfish resources. Mar. Fish. Rev. 43(1):26-33.

HUMPHREYS, R. L., Jr., D. T. TAGAMI, and M. P. SEKI.

1984. Seamount fishery resources within the southern Emperor-northern Hawaiian Ridge area. *In* R. W. Grigg and K. Y. Tanoue (editors), Proceedings of the Second Symposium on Resource Investigations in the Northwestern Hawaiian Islands, Vol. 1, May 25-27, 1983, University of Hawaii, Honolulu, Hawaii, p. 283-327. UNIHI-SEAGRANT-MR-84-01.

IGUCHI, K.

1973. Research by trawl fishery for commercialization of the fishing grounds by Japan Marine Fisheries Resource Research Center. II. Outline of trawl fishery investigation for commercialization in the central North Pacific. [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 23:47-56. (Partial Engl. transl. by W. G. Van Campen, 1983, 12 p., Transl. No. 96; available Southwest Fish. Cent. Honolulu Lab., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396.)

IKEDA, I.

1980. Groundfish resources in the seamounts and banks. [In Jpn.] *In* T. Aoyama, (editor) Groundfish resources, p. 331-342. Shin Suisan Gaku Zenshu 10. Koseishakoseikaku, Tokyo.

JAPAN MARINE FISHERIES RESOURCES RESEARCH CENTER (JAMARC).

1973. Survey report on the trawl fishery for commercialization of the fishing grounds in the central North Pacific Ocean, 1972. [In Jpn.] JAMARC Rep. 7, 1972, 89 p. (Partial Engl. transl. by T. Otsu, 1977, 22 p., Transl. No. 19; available Southwest Fish. Cent. Honolulu Lab., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396.)

1974. Survey report on the trawl fishery for commercialization of the fishing grounds in the central North Pacific Ocean, 1973. [In Jpn.] JAMARC Rep. 7, 1973, 159 p.

KITANI, K., and K. IGUCHI.

1974. Some observations on the feature of fishing ground on the seamount in the central North Pacific Ocean as surveyed through the trawl operation. (In Jpn., Engl. abstr.) Bull. Far Seas Fish. Res. Lab. (Shimizu) 11:33-36.

KUROIWA, M.

1973. Research by trawl fishery for commercialization of the fishing grounds by Japan Marine Fishery Resource Research Center. . . Outline of trawl fishery investigation for commercialization in the central North Pacific Ocean—I. [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 23:42-47. (Engl. transl. by T. Otsu, 1984, 7 p., Transl. No. 95; available Southwest Fish. Cent. Honolulu Lab., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396.)

KUROIWA, M.

1978. Survey report on the trawl fishery for commercialization of the fishing grounds in the southwest and east Indian Ocean and central North Pacific Ocean, 1977. [In Jpn.] JAMARC Rep. 8, 1977, 251 p.

KUROIWA M., and K. FUNATO.

1980. Survey report on the trawl fishery for commercialization of the fishing grounds in the seamounts of the east North Pacific Ocean, 1978. [In Jpn.] JAMARC Rep. 6, 1978, 297 p.

MASUZAWA, H., Y. KURATA, and K. ONISHI.

1975. Population ecology of Japanese alfonsin and other demersal fishes. Results of group study on population of demersal fishes in waters from Sagami Bay to southern Izu Islands. [In Jpn.] Suisan Kenkyu Sosho 28, 105 p. Jpn. Fish. Resour. Conserv. Assoc., Tokyo.

MIYAGI PREFECTURAL OFFICE.

1975. Report on the groundfish survey by *Shin Miyagi Maru* (far seas fishery guiding vessel) in the Emperor Seamounts, 1975. [In Jpn.] Dep. Fish., Miyagi Prefectural Office, 13 p.

NAKANO, S.

1978. Survey report on the bottom longline fishery for commercialization of the new fishing grounds, 1977. [In Jpn.] JAMARC Rep. 9, 1977, 215 p.

NEAVE, F.

1959. Records of fishes from waters off the British Columbia coast. J. Fish. Res. Board Can. 16:383-384.

SAKIURA, H. (translator).

1972. The pelagic armorhead, *Pseudopentaceros richardsoni*, fishing grounds off the Hawaiian Islands, as viewed by the Soviets. [In Jpn.] Suisan Shuho (The Fishing & Food Industry Weekly) 658:28-31, June 15, 1972. (Engl. transl. by T. Otsu, 1977, 7 p., Transl. No. 17; available Southwest Fish. Cent. Honolulu Lab., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396.)

SASAKI, T.

1973. Survey on the seamounts in the central North Pacific by R/V *Kaiyo Maru*. (2). Biology. [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 23:62-70.

1974a. Report on the biological research of ground fish in the northeastern Pacific by *Chosui Maru* in 1972. [In Jpn.] Far Seas Fish. Res. Lab., 88 p.

1974b. The pelagic armorhead, *Pentaceros richardsoni* Smith, in the North Pacific. [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 24:156-165. (Engl. transl. by T. Otsu, 1977, 13 p., Transl. No. 16; available Southwest Fish. Cent. Honolulu Lab., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396.)

1978. The progress and current status on exploration of seamounts fishing grounds. [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 33:51-53. (Engl. transl. by T. Otsu, 1979, 6 p., Transl. No. 35; available Southwest Fish. Cent. Honolulu Lab., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396.)

SATO, M.

1979. Discoveries of fish reefs in Ogasawara fishing grounds. [In Jpn., Engl. summ.] J. Fac. Mar. Sci. Technol., Tokai Univ. 12:293-307.

1981. Discoveries of fish reefs in Nansei Shoto Islands fishing grounds. [In Jpn., Engl. summ.] J. Fac. Mar. Sci. Technol., Tokai Univ. 14:379-397.

1982. Discoveries of fish reefs in fishing grounds in the Sea of Japan. [In Jpn., Engl. summ.] J. Fac. Mar. Sci. Technol., Tokai Univ. 15:403-418.

1983. Discoveries of sea mountains and fish reefs in fishing grounds in the sea off the eastern coast of Japan. [In Jpn., Engl. summ.] J. Fac. Mar. Sci. Technol., Tokai Univ. 16:265-280.

SHIGENO, M.

1981. Survey report on the trawl fishery for commercialization of the fishing grounds in the seamounts of the east North Pacific Ocean, 1979. [In Jpn.] JAMARC Rep. 6, 1979, 83 p.

SUZUKI, H., T. INADA, and T. NAKAO.

1978. Survey report on the trawl fishery for commercialization of the fishing grounds in the west Indian Ocean. 1977. [In Jpn.] JAMARC Rep. 12, 1977, 375 p.

SUZUKI, U., AND T. TAKAHASHI.

1978. Topographies and fisheries resources in the Emperor Seamounts [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 33:54-56.

TAKAHASHI, Y., and T. SASAKI.

1977. Trawl fishery in the central North Pacific seamounts (Kita Taiheiyo chubu kaizan ni okeru tororu gyogyo). Northern waters groundfish fishery—data (3) (Hokuyo soko-uo gyogyo—Shiryo (3)). [In Jpn.] Div. Northern Waters Groundfish Resour., Far Seas Fish. Res. Lab., 45 p. (Engl. transl. by T. Otsu, 1977, 49 p., Transl. No. 22; available Southwest Fish. Cent., Natl. Mar. Fish Serv., NOAA, Honolulu HI 96822-2396.)

TOKUSA, K.

1981. Survey report on the trawl fishery for commercialization of the fishing grounds in the South Atlantic seamounts and the sea area off southwest coast of the Africa, 1979. [In Jpn.] JAMARC Rep. 11, 1979, 101 p.

UCHIDA, R. N., and D. T. TAGAMI.

1984. Groundfish fisheries and research in the vicinity of seamounts in the North Pacific Ocean. Mar. Fish. Rev. 46(2):1-17.

WAGNER, E. J., and C. E. BOND.

1961. The percoid fish *Pseudopentaceros richardsoni* from Oregon waters. Fish. Comm. Oregon, Res. Briefs 8(1):71-73.

WELANDER, A. D., R. C. JOHNSON, and R. A. HAJNY.

1957. Occurrence of the boar fish, *Pseudopentaceros richardsoni* and the zeid, *Allocyttus verrucosus*, in the North Pacific. Copeia 1957:244-246.

YAMAMOTO, S., K. ISHII, S. SASAKI, and T. MEGURO.

1978. Outline of fisheries investigation on the Emperor Seamounts by the R/V *Hokusei Maru* in 1977 and some technical problems. [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 33:56-64.

Review and Present Status of Handline and Bottom Longline Fisheries for Alfonsin

MICHAEL P. SEKI
DARRYL T. TAGAMI
Southwest Fisheries Center Honolulu Laboratory
National Marine Fisheries Service, NOAA
Honolulu, Hawaii 96822-2396

ABSTRACT

The pelagic armorhead, *Pseudopentaceros wheeleri*, and the alfonsin, *Beryx splendens*, are the principal target species in the central North Pacific seamount groundfish fishery. The present fishery, executed predominantly by the Japanese, uses bottom trawls to harvest the resource, although in the past a hook-and-line fishery was also active at the seamounts primarily targeting the more valuable alfonsin.

The beginning of the Japanese hook-and-line fishery for alfonsin dates back to 1875, when vessels restricted operations to nearby fishing grounds off Chiba Prefecture and Shimoda. The fishery has since grown and now includes vessels over 100 tons which operate in waters near the Nansei Islands and the Zunan area. The fishing ground around Midway, which was also fished by hook-and-line boats, has been abandoned in recent years.

Since 1976, the Southwest Fisheries Center Honolulu Laboratory has conducted limited exploratory resource surveys at the seamounts of the southern Emperor-northern Hawaiian Ridge, with emphasis at Hancock Seamounts. Vertical handlines were used to assess the resources of the seamount slopes and other untrawlable areas. Pelagic armorhead dominated the handline catch, and alfonsin, dogfish, *Squalus* sp., and medai, *Hyperoglyphe japonica*, were the most abundant of the other species taken. The surveys indicated that the alfonsin caught on the slopes with handlines were larger than those taken on the summit by trawling. For pelagic armorhead, the sizes of handline- and trawl-caught fish were similar.

Test marketing of four species of frozen seamount groundfishes through the Honolulu fish auction and retail outlets indicated that product promotion would be necessary to develop a commercially feasible domestic fishery for the various species.

INTRODUCTION

The central North Pacific seamount groundfish fishery exploits a complex of species, principally the pelagic armorhead or kusakari tsubodai, *Pseudopentaceros wheeleri*, and the alfonsin or kinmedai, *Beryx splendens*. Since 1969, the major effort expended at the seamounts by the Japanese and the Soviets to exploit the resource has involved trawling. Although alfonsin represents the second species of importance in the seamount trawl fishery, it constitutes only a small percentage of the catch and is considered an incidental species (Humphreys et al. 1984). Furthermore, due to the rough and steep topography of the summits and slopes, many of the seamount areas inhabited by alfonsin are untrawlable even with modern techniques and gear. Vertical handlines and bottom longlines can fish in areas inaccessible to trawlers and have thus been the main fishing methods for alfonsin (Masuzawa et al. 1975; Sasaki 1978). This report reviews the available information, and presents the status of current research activity, on the hook-and-line fisheries for alfonsin.

TARGET SPECIES

Fishes of the genus *Beryx* (Fig. 1) are valued as food in Tokyo and neighboring prefectures. The most common and valued of the *Beryx* species is the alfonsin, *B. splendens*. This bright red fish which inhabits rocky bottom several hundred meters deep is the primary target species in the seamount bottom longline and handline fisheries (Abe 1969; Uchida and Tagami 1984). The Pacific distribution of this species includes the central North Pacific seamounts (from Koko Seamount to Seamount 11 within the southern Emperor-northern Hawaiian Ridge (SE-NHR)) and in the South Pacific along the Lau (South Fiji) Ridge (Sasaki 1978; Humphreys et al. 1984). In the western Pacific where the largest alfonsin fishery exists, its distribution includes Sagami Bay and Kashima Nada, the Izu Islands, the Kinan Seamounts, and the Kyushu-Palau Ridge (Chikuni 1971; Sasaki 1978). The optimum temperature range for alfonsin is reported to be 6° to 18°C (Onishi and Sato 1970).

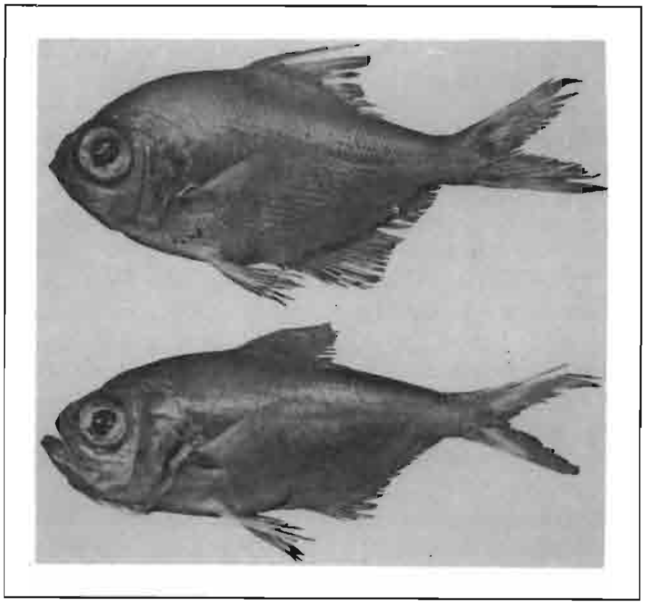


Figure 1.—Specimens of alfonsin, genus *Beryx*. Upper specimen is *B. decadactylus* and the lower specimen, *B. splendens*.

The broad alfonsin or nanyokinme, *B. decadactylus*, is also bright red and appears to inhabit areas similar to those inhabited by *B. splendens*. This species has often been taken with *B. splendens* but in much smaller numbers. *Beryx decadactylus* can be distinguished from *B. splendens* by its deeper body, larger, rougher scales, and prominent preorbital spine (Uchida and Uchiyama 1986). The Pacific distribution of this species also includes the seamounts within the SE-NHR; however, unlike *B. splendens*, *B. decadactylus* can also be found farther south throughout the Hawaiian Archipelago. In Japanese waters, the broad alfonsin has been captured from Sagami and Suruga Bays, the Sea of Japan from Wonsan to Pusan, and the Kyushu-Palau Ridge. In the South Pacific, the broad alfonsin is known from the Campbell (New Zealand) Plateau (Busakhin 1982; Okamura et al. 1982).

A third congener, *B. mollis*, was captured by hook-and-line fishermen in Sagami Bay. Known in Japan as fusenkinme, it is considered a rare species. At present, the distribution of *B. mollis* is apparently limited to the waters of Sagami Bay (Abe 1959; Busakhin 1982).

In addition to the alfonsin, other less valuable species caught in the bottom longline and handline fishery are *Hyperoglyphe japonica* (medai), *Paracaesio caeruleus* (aodai), *Erilepis zonifer* (aburaboozu), *Helicolenus hilgendorfi* (yumekasago), *Sebastes* sp. (akodai), and *Epinephelus* sp. (kue) (Masuzawa et al. 1975; Suisan Sekai 1976; Sasaki 1978).

THE FISHERY

The hook-and-line fishery for alfonsin, primarily in the area from Sagami Bay to the Izu Islands, has existed in Japan for many years. Although the history of the fishery is not well-known, it appears that around 1875, vessels from Misaki fished for alfonsin, medai, and mutsu, *Scombrops boops*, off Chiba Prefecture and Shimoda. Around 1915-16, the fishery expanded to the Izu Islands area as more of the vessels became powered by engines. By the 1970's, over 1,400 boats were participating to some degree in the groundfish fishery, although not all the vessels targeted alfonsin (Masuzawa et al. 1975). Annual landings of alfonsin alone exceeded 1,000 metric tons (MT) in Tokyo and neighboring prefectures (Abe 1969).

The size of vessels in the Japanese fishery varies from under 5 tons to over 100 tons. The small vessels fish mainly just offshore from their home ports whereas the large vessels fish near the Nansei Islands and the Zunan area. Some of the large, 20- to 100-ton vessels have operated in the Midway area of the SE-NHR, usually targeting alfonsin (Masuzawa et al. 1975).

Although the alfonsin resource on the central North Pacific seamounts had been discovered by Soviet trawlers in 1967 (Sakiura 1972), it was not until around 1973 that the Japanese initiated fishing for alfonsin with hook and line at Milwaukee Seamounts (Masuzawa et al. 1975). Since that time, vessels from Korea and Taiwan have joined the fishery (Suisan Sekai 1976; [Hawaii.] Department of Land and Natural Resources 1979). In 1975, the Japanese hook-and-line fishery in the SE-NHR took about 4,000 MT of groundfish, of which about 500 MT were caught within the 200-mile U.S. Fishery Conservation Zone (FCZ) and also harvested about 500-600 MT of alfonsin and other groundfishes off Guam and the Northern Mariana Islands (Federal Register 1977). Little else, however, is known about the activity of vessels in this "open fishery" which does not require permits or licenses (Sasaki 1978).

In 1977, the National Oceanic and Atmospheric Administration (NOAA), Department of Commerce, put into effect a Preliminary Fishery Management Plan to regulate foreign fishing for groundfishes at the seamounts, specifically the Hancock Seamounts within the FCZ. Since then, foreign fishing for seamount groundfishes has been exclusively conducted by trawling, and hook-and-line operations for alfonsin around Midway have ceased.

UNITED STATES RESEARCH

From 1976 to 1981, the Southwest Fisheries Center (SWFC) Honolulu Laboratory, National Marine Fisheries Service (NMFS), participated in a cooperative investigation of the marine resources of the Northwestern Hawaiian Islands (NWHI) (Fig. 2). Within the scope of the NWHI studies, limited surveys of the fishery resources of the seamounts within the Hawaiian Archipelago, particularly at Hancock Seamounts, were conducted. The SWFC has since initiated a program to further survey the seamount resources of the SE-NHR, including Koko, Kammu, Colahan, Hancock, and Seamount 11.

Methods

One of the principal fishing methods employed by the SWFC to assess the distribution and abundance of seamount species was the vertical handline which in general was similar to the Hawaiian deep-sea handline gear described by Uchida and Uchiyama (1986). Usually, hydraulic powered gurdies were employed to haul in the line, but in some early cruises hand retrieval or electric reels (gurdies) were used. The gurdies spooled approximately 1,100 m of 118-kg test, hard-braided nylon line attached to a terminal rig consisting of a drop line (about 1.5 m long, 113-kg test monofilament leader) separated by three-way swivels, hook lines (about 0.5 m long, 13.6-kg test monofilament leader), recurved "circle" hooks, and a 1.4- to 2.3-kg lead weight (Fig. 3). The size of hook varied depending on the target species. For alfonsin, we normally used No. 18 to 22 hooks, although some large fish were taken on No. 28 to 30 hooks. The number of hooks per line varied from 5 to 20 but was normally 10 to 12, each usually baited with stripped squid. Fishing was done day and night while the vessel drifted over banks 146-640 m (80-350 fathoms) deep.

Results and discussion

The major effort to sample groundfishes with handlines was concentrated at Southeast (SE) and Northwest (NW) Hancock Seamounts and Seamount 11. At SE and NW Hancock (total effort was 1,059.0 and 1,278.6 hook-h, respectively) pelagic armorhead dominated the catch, constituting 59.2% of the total fishes caught at SE Hancock and 75.4% taken at NW Hancock (Table 1). Alfonsin comprised 5.8 and 12.2% of the fishes taken at SE and NW Hancock, respectively. The greatest depth of capture was about 640 m for alfonsin and about 510 m for pelagic armorhead. Major incidental species of commercial value were *Hozukius guyotensis* and *Helicolenus avius*, which are fishes closely related to the akodai and the yumekasago, dogfish, *Squalus* sp., and medai.

At Seamount 11, 437.0 hook-h of handlining were conducted; dogfish (48.2%), alfonsin (21.1%), and pelagic armorhead (12.3%) comprised the majority of the catch. The grouper, *Epinephelus quernus*, was also taken here which reflects a transition of ichthyofauna from the armorhead-alfonsin complex characteristic of the SE-NHR seamounts to the tropical snapper-grouper complex that characterizes

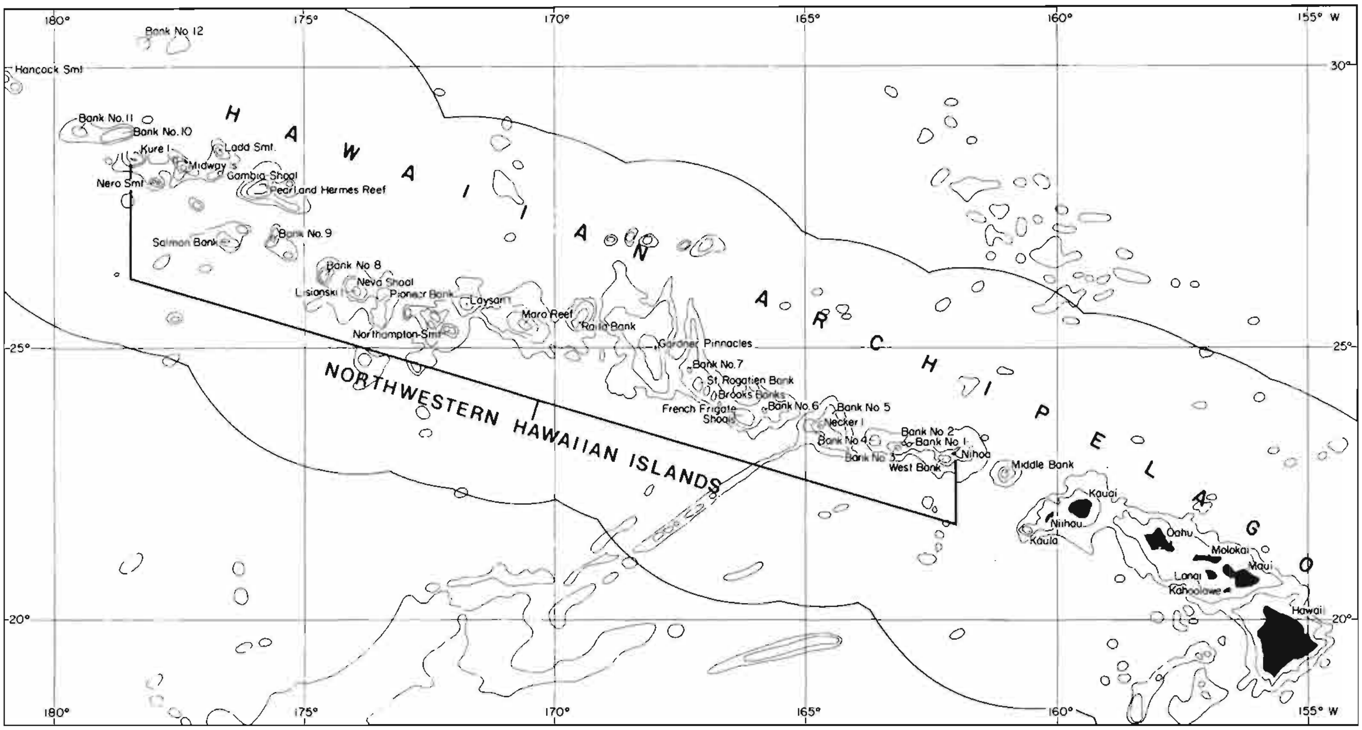


Figure 2.—The Hawaiian Archipelago, including the Northwestern Hawaiian Islands.

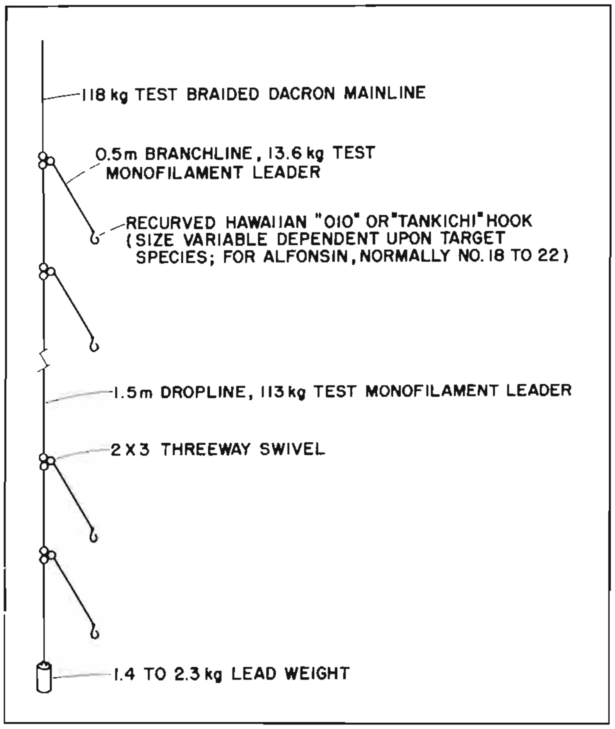


Figure 3.—Terminal rig of Hawaiian deep-sea handline gear when fishing for alfonsin, *Beryx splendens*.

Table 1.—Total number and catch per unit effort (CPUE × 10^{-1}) (by hook-h) of groundfish taken by handline at three seamounts along the northern Hawaiian Ridge.

	SE Hancock		NW Hancock		Seamount 11	
	No.	CPUE	No.	CPUE	No.	CPUE
Etmopterus sp.	2	0.02	1	0.01	1	0.02
Squalus sp.	51	0.48	11	0.09	55	1.26
Polymixia berndti	9	0.08	4	0.03		
Moridae	1	0.01	1	0.01		
Macrouridae					1	0.02
Beryx splendens	24	0.23	55	0.43	24	0.55
Hozukius guyotensis	11	0.10	10	0.08		
Helicolenus avius	2	0.02				
Scorpaenidae					1	0.02
Epinephelus quernus					4	0.09
Plectranthias kelloggi	2	0.02	2	0.02		
Cookeola boops					6	0.14
Decapterus tabl	12	0.11	5	0.04		
Pseudopentaceros wheeleri	247	2.33	341	2.67	14	0.32
Parapercis sp.	1	0.01				
Scomber japonicus	44	0.42	2	0.02		
Promethichthys prometheus	1	0.01			8	0.18
Ruvettus pretiosus	1	0.01				
Hyperoglyphe japonica	9	0.08	20	0.16		
Total fishes	417	3.94	452	3.53	114	2.61

the NWHI banks south of Kure Atoll. Humphreys et al. (1984) attributed the sharp demarcation of the ichthyofauna around the 180th meridian to differences in summit depth and temperature.

Little effort was expended at other seamounts in the SE-NHR. At Koko Seamount, 73.2 hook-h of fishing produced 11 *H. avius*, and at Kammu Seamount, 6 pelagic armorhead and 4 dogfish were taken in 140.0 hook-h. Twenty pelagic armorhead, 1 dogfish, 1 medai, and 1 broad alfonsin were caught at Colahan Seamount in 80.4 hook-h of fishing and at Yuryaku Seamount, there was no catch in 36.0 hook-h.

The SWFC surveys have shown that alfonsin caught on the slopes with handlines were significantly larger than those taken on the summit by trawling ($F = 4{,}644.6$; df = 1,562; $P < 0.0001$). Handline-caught alfonsin from the slope ranged from 24.3 to 41.3 cm standard length (SL) and averaged 33.0 cm SL but trawl-caught alfonsin from the summit ranged from 12.5 to 31.5 cm SL and averaged only 16.5 cm SL (Fig. 4). Since most of the trawl-caught alfonsin from the summit were juveniles and those caught on the slope were adults, this difference in size classes between the two habitats may be attributed to depth preference of the age classes. Our results corroborate the findings by Iguchi (1973) who reported that alfonsin taken from seamounts in the SE-NHR at depths >400 m averaged 37.7-38.4 cm, whereas those taken in depths <300 m were composed of two modal size classes at 16.8 and 21.9 cm. He postulated that alfonsin initially occupy relatively shallow waters as juveniles and progressively move into deeper water as they grow larger.

The size of handline- and trawl-caught pelagic armorhead was similar, although large specimens of *P. wheeleri* (49.5-54.7 cm total length, 2.0-3.4 kg) have been hooked in deep waters at French Frigate Shoals, Ladd Seamount, and Kure Atoll in the NWHI (Randall 1980; Tagami and Humphreys in prep). The occurrence of this species as far south as French Frigate Shoals has spurred speculation that the distributional range of pelagic armorhead through the Hawaiian Archipelago is much wider than previously believed.

To test consumer reaction, approximately 240 kg of four species of frozen groundfishes from the seamounts were placed on sale in July 1983 through the Honolulu fish auction. The akodai-like *H. guyotensis* received the highest prices ranging from $0.25 to $0.57/kg. Alfonsin also received $0.25/kg, whereas pelagic armorhead received $0.23/kg and medai received $0.11/kg. The pelagic armorhead were taken by trawl and handline, whereas the other three species were captured exclusively with hook and line. The limited market test suggested that product promotion would be necessary to develop a commercially feasible domestic fishery for seamount species. Similarly when pelagic armorhead was initially marketed in Japan, it met stiff consumer resistance. Extensive advertising and sales promotion there, however, boosted market demands ([U.S.] NMFS 1975).

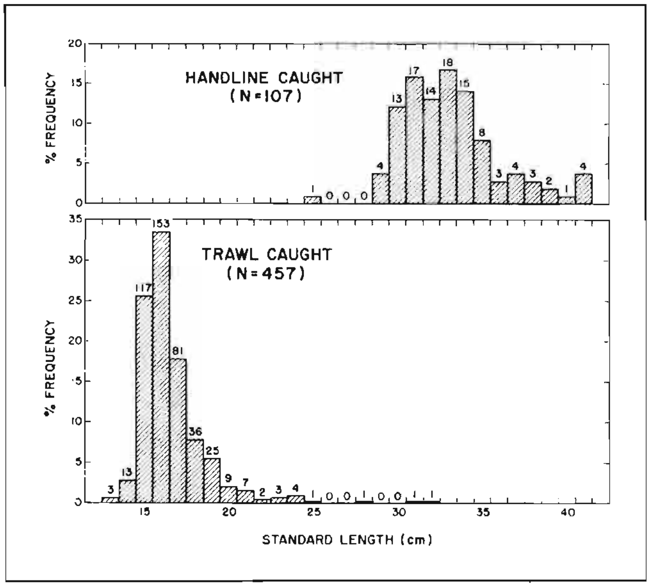


Figure 4.—Length-frequency comparison of handline versus trawl-caught alfonsin, *Beryx splendens*.

OTHER RESEARCH

Exploratory surveys for deep groundfish were initiated by the Pacific Tuna Development Foundation (PTDF) through the Government of Guam in 1980 and the State of Hawaii in 1981. In both surveys, the chartered fishing vessels used primarily vertical handlines, similar to the gear described earlier.

The PTDF-Guam surveys, conducted on the deep banks and seamounts of the South Honshu Ridge and around the Northern Mariana Islands, targeted depths from 40 to 640 m (22-350 fathoms); most of the effort was focused at depths <274 m (150 fathoms). As a result, the catch was composed primarily of fishes in the tropical snapper-grouper complex. Limited effort in waters deeper than 366 m (200 fathoms) yielded occasional catches of polymixiids, gempylids, and squalids (Hosmer and Kami 1981). Although the alfonsin was targeted during the surveys, none was taken. In 1977, however, two chartered Korean vessels with bottom longline gear caught 15 broad alfonsin in the Northern Marianas. Another Japanese vessel under charter to the Commonwealth of the Northern Mariana Islands caught about 227 kg (500 lb) of broad alfonsin near Saipan with a bottom gill net (Uchida 1983).

The broad alfonsin, the pomfret, *Eumegistus illustrus*, and other groundfishes that inhabit depths greater than those usual for commercially valuable snappers and groupers were sought during exploratory surveys conducted around the main Hawaiian Islands by the PTDF and the Hawaii State Department of Land and Natural Resources. Only a single broad alfonsin off Lanai and two off Oahu in depths of about 320 m (175 fathoms) were taken; however, the pomfret was moderately abundant (75 caught, 72.2% of the catch by weight) and appeared to hold the most potential as a new deep groundfish resource. In a consumer acceptance test at the Honolulu fish auction, fresh pomfret received prices ranging from $0.39 to $0.82/kg while fresh broad alfonsin received $0.45/kg (Okamoto 1982).

FUTURE RESEARCH AND CONCLUSIONS

A major problem of deep-sea multihook gear has been the tangling of hooks. A proposed solution involves the use of terminal rigs with dropper lines constructed of polyvinyl chloride pipes, which can be utilized on vertical handlines as well as on bottom longlines. This experimental gear, originally devised in the eastern Caribbean Sea for use over extremely rocky bottom and to alleviate the hauling effort, was found to be extremely successful and effectively caught all the species of snapper inhabiting waters down to 549 m (300 fathoms) (Crowley 1982). In depths of 183-366 m (100-200 fathoms), 3,000 or more hooks could be set and hauled by a three-man crew in one day compared with no more than 1,500 hooks set and hauled in a day with conventional nylon gear.

In conclusion, preliminary findings reveal the existence of a potentially exploitable groundfish resource in the SE-NHR seamounts; however, we need to determine the feasibility of a domestic hook-and-line fishery on these slopes and to decide how such a resource should be managed. The feasiblity of such a domestic fishery will ultimately depend on whether market prices will cover the inevitably high operational costs.

CITATIONS

ABE, T.
1959. New, rare or uncommon fishes from Japanese waters. VII. Description of a new species of *Beryx*. Jpn. J. Ichthyol. 7(5/6):157-163.
1969. Notes on some edible marine fishes collected between the Bonin Islands and the mouth of Sagami Bay—III. Bull. Tokai Reg. Fish. Res. Lab. 60:5-8.

BUSAKHIN, S. V.
1982. Systematics and distribution of the Family Berycidae (Osteichthyes) in the world ocean. J. Ichthyol. 22:1-21.

CHIKUNI, S.
1971. Groundfish on the seamount in the North Pacific. [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 19:1-14. (Engl. transl. by K. Tatara, 1972, 12 p., Transl. No. 2130; Fish. Res. Board Can.)

CROWLEY, M.
1982. PVC pipes mark new off-bottom longlining setup. Natl. Fisherm. 63:54-55.

FEDERAL REGISTER.
1977. Seamount groundfish fishery of the Pacific. Preliminary Management Plan. Federal Register 42(28):8568-8576.

[HAWAII.] DEPARTMENT OF LAND AND NATURAL RESOURCES.
1979. Hawaii Fisheries Development Plan. Department of Land and Natural Resources, State of Hawaii, 297 p.

HOSMER, A., and H. KAMI.
1981. PTDF seamount groundfish development project—Guam, May 1980-January 1981, FV *Typhoon*. Aquat. Wildl. Resour., Guam, 25 p.

HUMPHREYS, R. L., Jr., D. T. TAGAMI, and M. P. SEKI.
1984. Seamount fishery resources within the southern Emperor-northern Hawaiian Ridge area. *In* R. W. Grigg and K. Y. Tanoue (editors), Proceedings of the Second Symposium on Resource Investigations in the Northwestern Hawaiian Islands, Vol. 2, May 25-27, 1983, University of Hawaii, Honolulu, Hawaii, p. 226-236. UNIHI-SEAGRANT-MR-84-01.

IGUCHI, K.
1973. Research by trawl fishery for commercialization of the fishing grounds by the Japan Marine Fishery Resource Research Center. . .outline of trawl fishery investigation for commercialization in the central North Pacific Ocean—II. [In Jpn.] Bull. Jpn. Soc. Oceanogr. 23:47-56. (Engl. transl. by T. Otsu, 1984, 12 p., Transl. No. 96; available Southwest Fish. Cent. Honolulu Lab., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396.)

MASUZAWA, H., Y. KURATA, and K. ONISHI.
1975. Population ecology of Japanese alfonsin and other demersal fishes. [In Jpn.] Jpn. Fish. Resour. Conserv. Assoc., Fish. Res. Rep. 28:1-105.

OKAMOTO, H.
1982. Deep bottomfish surveys-Hawaii. Completion report prepared for Pacific Tuna Development Foundation under Project No. 35, Deep Bottom Fishing Surveys-Hawaii. Div. Aquat. Resour., Dep. Land Natur. Resour., Honolulu, 21 p.

OKAMURA, O., K. AMAOKA, and F. MITANI.
1982. Fishes of the Kyushu-Palau Ridge and Tosa Bay. The intensive research of unexploited fishery resources on continental slopes. Jpn. Fish. Resourc. Conserv. Assoc., Tokyo, Japan, 435 p.

ONISHI, K., and K. SATO.
1970. Study on berycoid fish resources. Shizuoka Fish. Exp. Stn., Project Rep. 1969:195-208.

RANDALL, J. E.
1980. New records of fishes from the Hawaiian Islands. Pac. Sci. 34:211-232.

SAKIURA, H. (translator).
1972. The pelagic armorhead, *Pentaceros richardsoni*, fishing grounds off the Hawaiian Islands, as viewed by the Soviets (So-Ren kara mita Hawaii oki kusakari tsubodai gyojyo). [In Jpn.] Suisan Shuho (The Fishing & Food Industry Weekly) 658:28-31, June 15, 1972. (Engl. transl. by T. Otsu, 1977, 7 p., Transl. No. 17; available Southwest Fish. Cent. Honolulu Lab., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396.)

SASAKI, T.
1978. The progress and present status of the seamount fishing ground development program (Kaizan gyojyo kaihatsu no keika to genjo). [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 33:51-53. (Engl. transl. by T. Otsu, 1979, 6 p., Transl. No. 35; available Southwest Fish. Cent. Honolulu Lab., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396.)

SUISAN SEKAI.
1976. The present status of the alfonsin, *Beryx splendens*, fishery in the Midway fishing grounds (Midway kai-iki no kin-me sogyo no genkyo). [In Jpn.] (Excerpt.) Suisan Sekai 25(8):28-32. (Engl. transl. by T. Otsu, 1977, 5 p., Transl. No. 18; available Southwest Fish. Cent. Honolulu Lab., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396.)

TAGAMI, D. T., and R. L. HUMPHREYS, Jr.
In prep. Occurrence of pelagic armorhead *Pseudopentaceros* sp. in the Northwestern Hawaiian Islands waters. Southwest Fish. Cent. Honolulu Lab., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396.

UCHIDA, R. N.
1983. Summary of environmental and fishing information on Guam and the Commonwealth of the Northern Mariana Islands: A review of the plankton communities and fishery resources. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-33, 159 p.

UCHIDA, R. N., and D. T. TAGAMI.
1984. Groundfish fisheries and research in the vicinity of seamounts in the North Pacific Ocean. Mar. Fish. Rev. 46(2):1-17.

UCHIDA, R. N., and J. H. UCHIYAMA.
1986. Fishery atlas of the Northwestern Hawaiian Islands. U.S. Dep. Commer., NOAA Tech. Rep. 38, 142 p.

[U.S.] NATIONAL MARINE FISHERIES SERVICE.
1975. Japanese trawl operations off Midway Islands. *In* J. H. Shohara and S. C. Sonu (compilers), Foreign Fish. Inf. Release 75-15, Suppl. Market News Rep., p. 4. Natl. Mar. Fish. Serv., Southwest Region, Terminal Island, CA 90731.

Albacore, *Thunnus Alalunga*, Pole-and-Line Fishery around the Emperor Seamounts

MINATO YASUI
Shizuoka Prefectural Fisheries Experimental Station
Izu Branch, Shizuoka, 425 Japan

ABSTRACT

Albacore, *Thunnus alalunga*, pole-and-line fishing has been carried out in the Emperor Seamounts area since 1973. When exploitation began, the operations were confined to summer; since 1976, however, fishing has extended into the fall. The present investigation covers the total catch, shifts in the fishing grounds, and size composition of fish taken in the vicinity of the Emperor Seamounts.

Catches of albacore by the pole-and-line fishery in the vicinity of the Emperor Seamounts have ranged from 4,000 to 15,000 metric tons, representing roughly 5 to 25% of the total catch of this species by this fishery in the North Pacific from 1973 to 1983. The seasonal fishing ground in the Emperor Seamounts area begins near Kimmei Seamount. As the fishery develops, the grounds shift northward along the seamount chain, then westward. Albacore caught in this area range from 2- to 5-year olds; however, not all age groups are represented in the annual catches. Recoveries of tagged fish disclosed that the albacore move away from the seamount area and migrate northeastward or westward but tend to stay in the Emperor Seamounts area fairly long. Past knowledge about feeding is rather sparse; recent studies, however, have indicated that the albacore in the Emperor Seamounts area feed heavily on sardine in the summer.

Because albacore is highly migratory, it is important to monitor stocks exploited elsewhere in the North Pacific to understand the variation in their availability and abundance in the Emperor Seamounts area.

INTRODUCTION

Albacore, *Thunnus alalunga*, fishing in Japan begins each year near and around the home islands in early spring, and as the season advances, shifts toward the east. In recent years, the eastward boundary of the fishing grounds has stretched well beyond the international dateline, resulting in prolongation of the fishing season (Fig. 1).

The catch of albacore by Japanese pole-and-line fishing between 1970 and 1983 amounted to about 20,000-70,000 metric tons (MT), of which 4,000 to 15,000 MT came from the Emperor Seamounts area. In this area, the formation of the fishing grounds appears to be related to bottom topography, and in particular, seamounts and sea rises.

CATCHES

The history of albacore pole-and-line fishing around the Emperor Seamounts area dates back to the 1940's. Landings from this area have varied considerably from year to year (Table 1). For example, available statistics show that in 1974, the catch amounted to well over 15,000 MT, whereas in 1980 it was only 2,400 MT. Viewed from a slightly different perspective, the catches of albacore from the Emperor Seamounts area contributed about 15% to the total landings for the species in 1975, whereas those in 1980 contributed only 5%.

The fall albacore pole-and-line fishery has been in operation in the Emperor Seamounts area since 1976 (Morita 1977; Shiohama 1977; Tanaka 1977a; Yasui and Mori 1984) when the catch amounted to 7,400 MT. Since then, catches have decreased each year, amounting to no more than 300 MT in 1980. Annual catches have fluctuated since the 1940's when pole-and-line and longline fishing first began (Japan Fishery Agency 1939, 1940, 1942). It cannot be concluded that the recent downward trend in catches from this area is a sign of a decrease in the albacore stock, however, due to high fluctuations throughout this period.

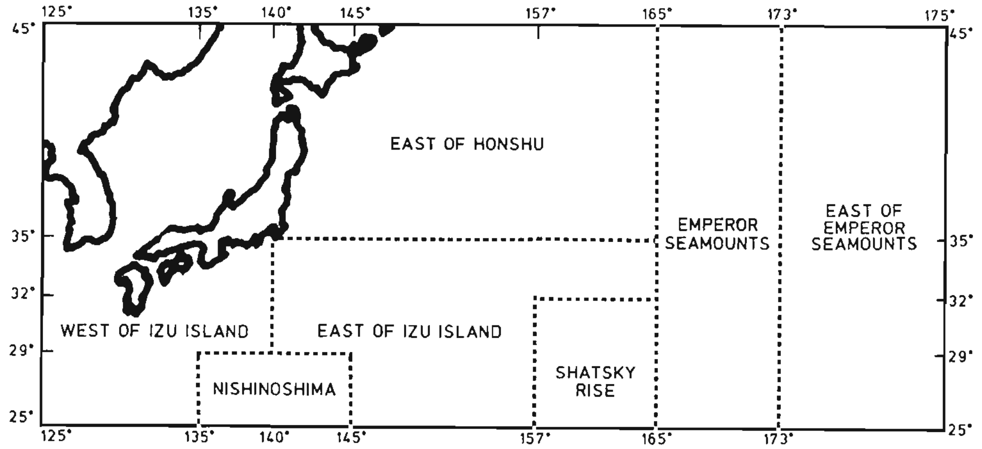


Figure 1.—Division of albacore fishing ground in the North Pacific by Japanese vessels.

Table 1.—Albacore landings of Japanese pole-and-line fishery around the Emperor Seamounts, 1970-84. (The sum total of fall and summer is not equal to annum since the data base is different between fall and summer.)

Year	Annum[1]	Fall season (September-December)	Summer season (April-August)
1970	0	0	No data
1971	0	0	No data
1972	226	0	No data
1973	10,623	0	No data
1974	15,618	0	No data
1975	13,100	0	No data
1976	19,269	7,359	2,361
1977	4,091	3,983	87
1978	4,436	3,750	595
1979	13,355	2,942	9,412
1980	2,416	277	1,967
1981			764
1982			2,341
1983			6,531

[1] [Japan.] Fishery Agency (1974-82).

[2] Association for Operation of Research Vessels (unpublished data).

FISHING SEASONS AND GROUNDS

Among the various factors that influence the formation of fishing grounds, topography is the one that has been most extensively investigated. In tuna fishing, for example, it was found that good fishing grounds occurred over banks and seamounts. This is demonstrated by the development of a longline fishery for albacore around the Emperor Seamounts area as early as 1938 (Japan Fishery Agency 1939, 1940, 1942). However, pole-and-line fishing for albacore in this area, proposed by Inoue (1966) in the 1960's, did not develop into a full-fledged fishery until the 1970's.

Summer season

Seasonal variation in the fishing grounds has been described in a number of reports including those by Asano (1976), Tanaka (1977b, 1978, 1979, 1980, 1981, 1982, 1983, 1984), Konagaya (1980, 1981, 1982), and Konagaya and Yasui (1983).

The fishing ground in the Emperor Seamounts area is usually formed after the middle of June when the fishing in the Kuroshio front deteriorates. Good fishing was experienced on these grounds every year from 1973 to 1976 (Konagaya 1978). During these years, it was not unusual for the average catch of each vessel to reach 30 MT per day. Generally speaking, the fishing ground in the Emperor Seamounts area begins to form near Kimmei Seamount near lat. 35°N, long. 171°E, then shifts northward to about lat. 30°-40°N, before moving westward (Konagaya 1978). Sometimes, however, good fishing for albacore continues in this area, generally when cold water moves from north to south along the western edge of the fishing ground (Yasui 1983b).

During years of poor fishing (1977, 1978, and 1981) temperature and current appear to be important factors. Yasui (1978) ascribed the poor fishing in 1977 to the existence of cold water (temperatures below 10°C) at 100 m and occasionally at 50 m. In other words, the optimum temperature belt of 17° to 20°C was available only in very thin layers in 1977. Poor catches in 1981 were ascribed to the rapid movement of albacore schools resulting from the absence of meandering of the Kuroshio and its extension current (Yasui 1983b).

The temperature indicative of the albacore fishing ground in this area is 16°C at 100 m (Yasui 1983b); similarly, Tsuruta and Maeda (1984) reported it to be 16°-17°C at that depth in 1983. Yasui (1983b) also noted that the temperature indicative of the fishing ground in this area is 15°-16°C at 200 m.

Fall season

The fall fishery for albacore developed as a result of accidental drift gill net catches of the species by vessels fishing squid. Variations in the fall catches of albacore from the Emperor Seamounts area have been reported by Yasui and Mori (1984). Early in the season, the fishing grounds are usually located either to the east or west of the Emperor Seamounts, then move westward (Fig. 1). In 1976, when good fishing conditions for albacore prevailed, the sea surface temperature was 1°-2°C higher than the average. It was believed that the complicated topographical features of the Emperor Seamounts were also responsible for the formation of favorable oceanographic conditions that contributed to good fishing (Tanaka 1977a).

In scouting the fishing grounds for favorable areas, Kobayashi (1981) mentioned that it was important to check the protrusion of warm water into the area, whereas Inoue (1983) reported that a good indicator may be the amount of mixing of southward migrating skipjack tuna, *Katsuwonus pelamis*, and albacore.

LENGTH COMPOSITION

Summer season

Albacore caught by pole-and-line fishing around the Emperor Seamounts usually consist of four age groups: (1) 2-year olds, 50-60 cm long and averaging 2-3 kg; (2) 3-year olds, 60-70 cm long and averaging 4-4.5 kg; (3) 4-year olds, 70-80 cm long and averaging 9-9.5 kg; and (4) 5-year olds, 80-90 cm long and averaging 13-14 kg. The age composition of the catch, however, is not fixed and varies from year to year. For example, Warashina (1980, 1981, 1982, 1983, 1984) found that four age groups were represented in the catch in 1979. However, in 1980 and 1983, 5-year olds were not present, whereas in 1981, 3-year olds were not present among the four age groups. The 1982 catch included only two age groups.

The albacore caught in the Emperor Seamounts area have been observed to exhibit some uncommon biological characteristics; some were relatively thin whereas others had blue-tainted flesh. Furthermore, the mode in the length-frequency distribution was different from that of albacore taken within the Kuroshio front (Tanaka 1977a; Shiohama 1980; Warashina 1980). It is possible that these different characteristics indicate that the fish in the Emperor Seamounts area come not only from the Kuroshio front, but also from grounds farther to the west or south.

Fall season

Yasui and Mori (1984) noted that albacore caught in 1976-82 in the Emperor Seamounts area ranged from 3- to 5-year olds and 3- and 4-year olds predominated. This coincides roughly with the results obtained by Shiohama (1977) for the 1976 season in the pole-and-line and longline fisheries.

TAG RELEASE AND RECOVERY

The following observations are based on the results of tagging studies published by the Far Seas Fisheries Research Laboratory (1974-82) and by the Tohoku Regional Fisheries Research Laboratory (1979-83). In 1971-82, of 5,139 albacore tagged and released by several Japanese institutions, about 1,600 were tagged in the vicinity of the Emperor Seamounts. During the same period, the American Fishermen's Research Foundation, through the cooperation of the National Marine Fisheries Service, Southwest Fisheries Center, tagged 21,000 albacore.

The results of these tagging studies show that albacore in the Emperor Seamounts area have a tendency to stay in the area for a relatively long period, i.e., a few months. The majority of the recoveries showed a westward movement except a few which showed an eastward movement to the U.S. Pacific coast ([Japan.] Fishery Agency, Far Seas Fisheries Research Laboratory 1980; Yasui 1980). Kume (1974) noted that two albacore released at lat. 35°44'N, long. 171°31'E in the Emperor Seamounts area on June 15, 1974 were recovered southwest of Vancouver on September 30 and October 3 of the same year. According to Kikawa et al. (1977), however, these two recoveries were exceptions. Most of the albacore released in the Emperor Seamounts area were recovered between long. 150° and 170°E, and some were recovered as far west as Japan.

Albacore released off the U.S. Pacific coast were recaptured by Japanese vessels, usually after a lapse of 1-2 years. These recaptures increased after Japanese vessels began to exploit the albacore stock in the Kuroshio front in 1971. Most of the recoveries centered around the Emperor Seamounts when good fishing grounds developed in this area. When fishing was poor in the Emperor Seamounts area in 1976, Tanaka (1977a) reported that most of the recaptures came from the grounds west of long. 160°E. Asano (1976), who classified albacore recaptures by bottom depth, observed that most were taken at 600-1,500 m, especially along the southern slope of the Emperor Seamounts. Compared with the observations by Ishii and Inoue (1956), who found albacore fishing grounds formed mainly at 420 m in the Coral Sea, Asano's findings showed that the albacore inhabited depths considerably greater. Tagging studies by Yasui and Mori (1984) also showed that albacore caught with pole-and-line in the fall were 2-year olds that came from the east, whereas the 3- and 4-year-old age groups came from not only the east, but also from western and southern regions.

FOOD HABITS AND FEEDING BEHAVIOR

Very little research has been carried out on food habits of albacore caught in the Emperor Seamounts area. The results of two studies on albacore from this area indicate that longline-caught fish had fed on small squids and euphausids (Japan Fishery Agency 1940), whereas gill net-caught fish had eaten squids and small unidentified fishes (Fujii et al. 1979).

More recent studies, conducted through concerted efforts of the Association for Operation of Research Vessels (Japan), showed that albacore caught by the pole-and-line vessels in the summers of 1982 and 1983 had fed extensively on sardine, cephalopods, and amphipods (Nihira and Yasui 1983; Yasui 1983a). Furthermore, Yasui reported that in 1982, when albacore fishing was quite poor, sardine was found in only 17.5% of the albacore sampled from the Emperor Seamounts area. In contrast, during the 1983 season when albacore fishing was comparatively good, the percentage of albacore with sardine in their stomachs was 46.5% and other food items also occurred rather frequently. From these observations, it can be concluded that poor albacore fishing can, to some degree, be associated with low availability of prey items in the Emperor Seamounts area. Particularly noteworthy is that sardine, which are usually thought to be distributed near or around land masses, play a very important role as prey for albacore in the distant fishing grounds of the Emperor Seamounts. This poses a new problem: that is, if sardine reproduce in waters close to land masses, then how did they appear in stomachs of albacore taken a considerable distance offshore? One can infer that the Kuroshio and its extension system may be responsible for sweeping eggs and larvae into the waters around the Emperor Seamounts.

Despite the importance of sardine in the diet of albacore, the availability of this particular prey apparently fluctuates throughout the year in the Emperor Seamounts area. Nihira (1982), who examined pole-and-line caught albacore taken in the fall found no sardines in their stomachs. Apparently, during this time of the year, albacore feed heavily on saury; but there also appears to be a difference in diet with fish size. Whereas albacore >60 cm fed extensively on saury, those smaller showed no particular preference for this prey. Nihira concluded that despite the very close association of saury and albacore with respect to their distribution over the Emperor Seamounts area, there apparently is an upper limit to the size of prey that small albacore can consume.

CITATIONS

ASANO, M.

1976. Recent pole and line fishery ground for albacore. [In Jpn.] Report of 1975 Year Season Tuna Fishery Research Conference, p. 235-244.

1979. Change of albacore baitboat fishing in the northwest Pacific Ocean. [In Jpn., Engl. summ.] Bull. Tohoku Reg. Fish. Res. Lab. 41:71-102.

FUJII, T., N. MASUDA, G. KOBAYASHI, G. ANMA, H. YAMAGUCHI, and N. KIJIMA.

1979. Oceanographical condition and distributions of fish species near the polar front. [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. Part 1, 35:44-51.

INOUE, M.

1966. Exploitation of albacore fishing ground in summer season in the northwestern Pacific. [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 9:54-61.

1983. Exploitation of fishing grounds of southward migrants of fall skipjacks in the northwestern Pacific Ocean. [In Jpn., Engl. summ.] J. Fac. Mar. Sci. Technol., Tokai Univ. 17:121-130.

ISHII, K., and M. INOUE.

1956. Some notes on the ovary of albacore, *Germo germo*, taken from the Coral Sea. [In Jpn., Engl. summ.] Bull. Jpn. Sci. Fish. 22(2):89-93.

[JAPAN.] FISHERY AGENCY.

1939. Record of promotion for albacore fishing ground survey on 1938 year season. [In Jpn.] Fish. Agency, 150 p.

1940. Record of promotion for albacore fishing ground survey on 1939 year season. [In Jpn.] Fish. Agency, 172 p.

1942. Record of promotion for albacore fishing ground survey on 1940 year season. [In Jpn.] Fish. Agency, 134 p.

[JAPAN.] FISHERY AGENCY, FAR SEAS FISHERIES RESEARCH LABORATORY.

1974. Report of tag release of tunas in 1973 year season. [In Jpn.] Fish. Agency, Far Seas Fish. Res. Lab., 25 p.

1975. Report of tag release of tunas in 1974 year season. [In Jpn.] Fish. Agency, Far Seas Fish. Res. Lab., 19 p.

1976. Report of tag release of tunas in 1975 year season. [In Jpn.] Fish. Agency, Far Seas Fish. Res. Lab., 12 p.

1977. Report of tag release of tunas in 1976 year season. [In Jpn.] Fish. Agency, Far Seas Fish. Res. Lab., 23 p.

1978. Report of tag release of tunas in 1977 year season. [In Jpn.] Fish. Agency, Far Seas Fish. Res. Lab., 15 p.

1979. Report of tag release of tunas in 1978 year season. [In Jpn.] Fish. Agency, Far Seas Fish. Res. Lab., 23 p.

1980. Report of tag release of tunas in 1979 year season. [In Jpn.] Fish. Agency, Far Seas Fish. Res. Lab., 17 p.

1981. Report of tag release of tunas in 1980 year season. [In Jpn.] Fish. Agency, Far Seas Fish. Res. Lab., 27 p.

1982. Report of tag release of tunas in 1981 year season. [In Jpn.] Fish. Agency, Far Seas Fish. Res. Lab., 20 p.

[JAPAN.] FISHERY AGENCY, RESEARCH DEPARTMENT.

1974. Statistical record of pole and line skipjack fishery in 1970 year season. [In Jpn.] Fish. Agency, Res. Dep., 216 p.

1975. Statistical record of pole and line skipjack fishery in 1971 year season. [In Jpn.] Fish. Agency, Res. Dep., 238 p.

1977a. Statistical record of pole and line skipjack fishery in 1972 year season. [In Jpn.] Fish. Agency, Res. Dep., 266 p.

1977b. Statistical record of pole and line skipjack fishery in 1973 year season. [In Jpn.] Fish. Agency, Res. Dep., 272 p.

1977c. Statistical record of pole and line skipjack fishery in 1974 year season. [In Jpn.] Fish. Agency, Res. Dep., 293 p.

1977d. Statistical record of pole and line skipjack fishery in 1975 year season. [In Jpn.] Fish. Agency, Res. Dep., 293 p.

1977e. Statistical record of pole and line skipjack fishery in 1976 year season. [In Jpn.] Fish. Agency, Res. Dep., 291 p.

1979. Statistical record of pole and line skipjack fishery in 1977 year season. [In Jpn.] Fish. Agency, Res. Dep., 333 p.

1980. Statistical record of pole and line skipjack fishery in 1978 year season. [In Jpn.] Fish. Agency, Res. Dep., 287 p.

1981. Statistical record of pole and line skipjack fishery in 1979 year season. [In Jpn.] Fish. Agency, Res. Dep., 322 p.

1982. Statistical record of pole and line skipjack fishery in 1980 year season. [In Jpn.] Fish. Agency, Res. Dep., 295 p.

[JAPAN.] FISHERY AGENCY, TOHOKU REGIONAL FISHERIES RESEARCH LABORATORY.

1979. Report of results on tag release survey for skipjack, 1978 year season. [In Jpn.] Fish. Agency, Tohoku Reg. Fish. Res. Lab., 59 p.

1980. Report of results on tag release survey for skipjack, 1979 year season. [In Jpn.] Fish. Agency, Tohoku Reg. Fish. Res. Lab., 43 p.

1981. Report of results on tag release survey for skipjack, 1980 year season. [In Jpn.] Fish. Agency, Tohoku Reg. Fish. Res. Lab., 63 p.

1982. Report of results on tag release survey for skipjack, 1981 year season. [In Jpn.] Fish. Agency, Tohoku Reg. Fish. Res. Lab., 47 p.

1983. Report of results on tag release survey for skipjack, 1982 year season. [In Jpn.] Fish. Agency, Tohoku Reg. Fish. Res. Lab., 34 p.

KIKAWA, S., T. SHIOHAMA, Y. MORITA, and S. KUME.

1977. Preliminary study on the movement of the North Pacific albacore based on the tagging. [In Jpn., Engl. summ.] Bull. Far Seas Fish. Res. Lab. (Shimizu) 15:101-113.

KOBAYASHI, M.

1981. Water temperature structure and albacore fishing ground. [In Jpn.] Memorial Bull. 80th Anniv. Foundation, Ibaragi Pref. Fish. Exp. Stn., p. 20-33.

KONAGAYA, T.

1978. Pelagic fisheries resources around the Emperor Seamounts. [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 33:67-69.

1980. Summary of pole and line fishery research in 1979 year season. [In Jpn.] Report of 1979 Year Season Tuna Fishery Research Conference, p. 95-98.

1981. Summary of pole and line fishery research in 1980 year season. [In Jpn.] Report of 1980 Year Season Tuna Fishery Research Conference, p. 112-116.

1982. Summary of pole and line fishery research in 1981 year season. [In Jpn.] Report of 1981 Year Season Tuna Fishery Research Conference, p. 91-95.

KONAGAYA, T., and M. YASUI.

1983. Summary of pole and line fishery research in 1982 year season. [In Jpn.] Report of 1982 Year Season Tuna Fishery Research Conference, p. 94-97.

KUME, S.

1974. Recapture record of tagged albacore from North American waters. [In Jpn.] Far Seas Fish. Res. Lab. News 20, p. 13.

MORITA, S.

1977. On the albacore fishery during the fall of 1976 by Japanese pole-and-line boats. Report of 2d North Pacific Albacore Workshop, p. 16.

NIHIRA, A.

1982. Saury from the stomach contents of fall albacore caught in the northwest Pacific. [In Jpn.] Report of 31st Saury Workshop, p. 178-184.

NIHIRA, A., and M. YASUI.

1983. Food organisms of albacore caught in the northwest Pacific. Results of co-operative research by Japanese tuna research cruises in 1982. [In Jpn.] Atlas of Albacore Pole and Line Fishing Ground in 1982 Year Season, p. 51-53.

SHIOHAMA, T.

1977. Fishing ground formation of pole and line albacore during fall and winter. [In Jpn.] Report of 1976 Year Season Tuna Fishery Research Conference, p. 112-119.

1980. Results of albacore tag release. [In Jpn.] Report of 1979 Year Season Tuna Fishery Research Conference, p. 105-115.

TANAKA, T.

1977a. Pole fishing ground of albacore in the North Pacific Ocean. [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 31:49-53.

1977b. Development of pole and line albacore fishing ground in 1976 year season. [In Jpn.] Atlas of Pole and Line Albacore Fishing Ground in 1976 Year Season, p. 5-8.

1978. Development of pole and line albacore fishing ground in 1977 year season. [In Jpn.] Atlas of Pole and Line Albacore Fishing Ground in 1977 Year Season, p. 3-7.

1979. Development of pole and line albacore fishing ground in 1978 year season. [In Jpn.] Atlas of Pole and Line Albacore Fishing Ground in 1978 Year Season, p. 3-6.

1980. Development of pole and line albacore fishing ground in 1979 year season. [In Jpn.] Atlas of Pole and Line Albacore Fishing Ground in 1979 Year Season, p. 3-8.

1981. Development of pole and line albacore fishing ground in 1980 year season. [In Jpn.] Atlas of Pole and Line Albacore Fishing Ground in 1980 Year Season, p. 3-7.

1982. Development of pole and line albacore fishing ground in 1981 year season. [In Jpn.] Atlas of Pole and Line Albacore Fishing Ground in 1981 Year Season, p. 3-5.

1983. Development of pole and line albacore fishing ground in 1982 year season. [In Jpn.] Atlas of Pole and Line Albacore Fishing Ground in 1982 Year Season, p. 3-5.

1984. Development of pole and line albacore fishing ground in 1983 year season. [In Jpn.] Atlas of Pole and Line Albacore Fishing Ground in 1983 Year Season, p. 3-6.

TSURUTA, K., and K. MAEDA.

1984. Pole and line albacore fishing ground and ocean conditions in the northwest Pacific, 1983. [In Jpn.] Atlas of Pole and Line Albacore Fishing Ground in 1983 Year Season, p. 48-53.

WARASHINA, I.

1980. Size composition of pole and line albacore during summer of 1979 year season. [In Jpn.] Atlas of Pole and Line Albacore Fishing Ground in 1979 Year Season, p. 8-9.

1981. Size composition of pole and line albacore during summer of 1980 year season. [In Jpn.] Atlas of Pole and Line Albacore Fishing Ground in 1980 Year Season, p. 7-8.

1982. Size composition of pole and line albacore during summer of 1981 year season. [In Jpn.] Atlas of Pole and Line Albacore Fishing Ground in 1981 Year Season, p. 5-7.

1983. Size composition of pole and line albacore during summer of 1982 year season. [In Jpn.] Atlas of Pole and Line Albacore Fishing Ground in 1982 Year Season, p. 5-7.

1984. Size composition of pole and line albacore during summer of 1983 year season. [In Jpn.] Atlas of Pole and Line Albacore Fishing Ground in 1983 Year Season, p. 6-8.

YASUI, M.

1978. Comparative study on recent albacore fishing ground formation in ocean front. [In Jpn.] Atlas of Pole and Line Albacore Fishing Ground in 1977 Year Season, p. 45-49.

1980. Movement and migration of albacore. Shizuoka Pref. Fish. Exp. Stn. *Hekisui* 3:1-2.

1983a. Food habits of albacore in the northwest Pacific. Results of co-operative research cruises in 1982 and 1983. Eight North Pacific Albacore Workshop, NPA-13.

1983b. Relationship between deep water temperature and albacore fishing conditions caught by pole and line in the east off Honshu, 1982. [In Jpn.] Atlas of Pole and Line Albacore Fishing Ground in 1982 Year Season, p. 54-57.

YASUI, M., and N. MORI.

1984. Fluctuations in fishing conditions in pole and line fishing of albacore during the fall seasons in the North Pacific. [In Jpn., Engl. summ.] Bull. Shizuoka Pref. Fish. Exp. Stn. 19:1-19.

Session 2. Review of Seamount Fisheries

RICHARD N. UCHIDA and SIGEITI HAYASI

This session was devoted to a review and discussion of the present status of seamount fisheries.

Sasaki traced the historical development and described the present status of the Japanese trawl fishery for pelagic armorhead and alfonsin over the seamounts of the southern Emperor-northern Hawaiian Ridge. Of particular significance was the drastic decline in catches of pelagic armorhead beginning in 1976. Whereas pelagic armorhead represented more than 90% of the total trawl catch in 1969-75, they constituted only 80% in 1976, 59% in 1977, 26% in 1978, and between 5 and 13% since then. The alfonsin catch, however, has risen, reaching 87% of the trawl catch in 1982.

Sasaki concluded that the rapid decline in relative abundance of pelagic armorhead in 1973 and subsequent years was a reflection of reduced stock size and recruitment resulting from overexploitation in 1967-75. He reported that for alfonsin, relative abundance remained high at Kimmei and Milwaukee Seamounts, declined at Colahan Seamount, and was generally low at Hancock Seamounts.

Sasaki emphasized that open-ocean seamounts are not highly productive and resources associated with them cannot support large trawl fisheries. The exceptions were the seamounts in the southern Emperor-northern Hawaiian Ridge; however, highly efficient trawling operations can easily deplete the resources because of the limited habitat.

Seki and Tagami traced the historical development of the handline and bottom longline fisheries for alfonsin. Since the fishery began in 1875, it has expanded and now includes the grounds off Chiba Prefecture and Shimoda to those in distant waters near Nansei Islands and Zunan. Fishing grounds developed as far away as Midway, however, have been abandoned in recent years.

Current NMFS research on alfonsin has been concentrated in the southern Emperor-northern Hawaiian Ridge seamounts and has emphasized the Hancock Seamounts. Handline and vertical longline catches from untrawlable and sloping areas of the seamounts, indicated that although the size of pelagic armorhead taken by handline and by trawls were nearly identical, alfonsin taken by handline were significantly larger than trawl-caught ones.

Yasui's presentation brought out that the albacore, although highly migratory, apparently were associated with seamounts in the Emperor Seamount chain during one phase of their transpacific migration. Catches in the region of the seamounts ranged from 4,000 to 15,000 MT, comprising 5 to 25% of the total albacore landings by Japanese vessels. By following fleet movement, Yasui determined that albacore first appeared near the seamount chain at Kimmei, then moved northward along the chain and finally westward. The albacore taken here were usually 2- to 5-year olds, although certain age groups were absent in some years. The albacore apparently remained relatively long in the seamount region, feeding mainly on sardines and squids.

In the discussion that followed, it was brought out that because catches of pelagic armorhead over the central North Pacific seamounts fluctuate considerably, it may be appropriate to consider the species pelagic rather than demersal. Studies of other species indicated that, in general, pelagic stocks undergo wider fluctuations in abundance than demersal ones. It was noted that at times, it is difficult to differentiate pelagic from demersal stocks and that pelagic armorhead should really be considered a demersal species because over the past 3-4 years, there has been no improvement in the catch.

An example of reduction in CPUE in two contrasting fisheries involved a local groundfish stock in which reduction in CPUE was fishery-dependent and in a highly migratory pelagic stock in which the reduction was fishery-independent and brought about by changes in oceanic conditions. It was noted that even groundfish can sometimes exhibit large natural fluctuations during their early pelagic stages.

The following explanations appear to be reasonable for two of the papers presented in this session. For albacore, it does not appear that the CPUE around the seamounts is representative of the entire stock, because the species is widely distributed and migrates extensively over a wide range and only some portion of the stock visits the Emperor Seamounts. For pelagic armorhead, however, the continuous reduction of CPUE can be considered a decrease in stock size, because the species only inhabits waters around certain seamounts.

For alfonsin, it was pointed out that the reduction of CPUE could be only a temporary phenomenon because of its migratory habits. The possibility that the reduction in alfonsin CPUE could reflect the practice of discarding small fish was also raised, but it was brought out that there is no evidence that this was occurring.

A question of whether the increase in total catch of alfonsin was directly related to a decrease in the stock of pelagic armorhead brought out that the trawlers began targeting alfonsin when pelagic armorhead fishing was no longer profitable. On this same line of questioning, Sasaki was asked if any significant adjustments were made to trawling operations in targeting the alfonsin. He replied that none was required except in fishing depth. He added, however, that in trawling for pelagic armorhead, the net was towed directly off the bottom except where large populations of pelagic armorhead were detected. When this occurred, the trawl was fished higher in the water column. Similarly, trawling for alfonsin required only a depth adjustment to fish higher off the bottom.

Pelagic armorhead and alfonsin occurred in good quantities over the seamounts but early commercial trawling operations only targeted the former because of economic reasons. Their abundance over the seamounts was so high that large trawlers could easily make profitable catches. In addition, because alfonsin was sold fresh in Japanese fish markets, frozen ones were not considered highly desirable. It was brought out that freezing clouded the eye lenses of alfonsin making them lower in value. It was noted that alfonsin occurred in good numbers only on two seamounts in the southern Emperor-northern Hawaiian Ridge whereas pelagic armorhead were abundant at four of the seamounts.

Before the session concluded, participants expressed concern on whether increased catches of alfonsin truly reflected an increase in abundance of the species, in view of the decrease in the stock of pelagic armorhead. It was brought out that more studies were needed on ecological factors that influence the stock, on depth distribution of the two major seamount-associated species, and on composition of the seamount community.

Precious Corals: An Important Seamount Fisheries Resource

RICHARD W. GRIGG
Hawaii Institute of Marine Biology
University of Hawaii
Kaneohe, Hawaii 96744

INTRODUCTION

Precious corals are important deepwater resources frequently found on seamounts. They consist of a variety of deepwater anthozoan corals including species of red and pink coral, *Corallium* spp., gold coral, *Primnoa* and *Parazoanthus* spp., black coral, *Anthipathes* spp., and bamboo coral, *Lepidisis olapa*. The fishery extends worldwide but the richest beds exist on seamounts in the western North Pacific Ocean and the western Mediterranean Sea. During the past 5 years more than half of the world's harvest of *Corallium* has come from the Emperor Seamounts. The history of the fishery and ecology of various species have been recently reviewed by Grigg (1984a). Worldwide, the fishery is worth about $50 million ex-vessel. Most species require a rocky substratum and occur most abundantly in areas swept by strong bottom currents (e.g., seamounts). Most are slow growing and have low rates of recruitment and mortality. For these reasons, precious corals are quite vulnerable to overexploitation and fishing must be carefully managed to avoid overexploitation.

Unfortunately, the fishery in most parts of the world is unregulated. One reason is that many beds of precious coral are found outside of territorial limits in international waters. Another is the difficulty of enforcement. In most countries, records of catch and effort are difficult to obtain. Limited records of imports and exports can be obtained from custom agencies but these are often incomplete. For this reason, during the last decade it has been necessary to compile statistics gathered directly from private sources (fishermen and coral jewelry wholesalers) (Grigg 1970, 1972, 1975, 1982, 1984a, 1984b; Grigg and Eldredge 1975; Western Pacific Regional Fishery Management Council 1979; Food and Agriculture Organization of the United Nations (FAO) 1984). These data must be treated as estimates rather than firm records of catch and fishing effort (Table 1). Work is underway to establish reporting requirements within producing countries and at the international level through the International Union for the Conservation of Nature (IUCN). Until these efforts succeed, it will be necessary to continue reporting estimates provided by the private sector. In this paper, the status of the fishery in 1983 is reviewed and recommendations for future research and conservation are given.

STATUS OF THE FISHERY, 1983

Estimates of catch, fishing effort and value of coral species belonging to the genus *Corallium* harvested in 1983 are given in Table 1. For the past 5 years >50% of the world's landings have come from the region of the Emperor-Hawaiian Ridge Seamounts. In 1983, the actual catch from this region was about 140,000 kg, approximately 70% of the world's production. The other major source area in 1983 was the Mediterranean Sea (Table 1), where approximately 50,000 kg of *Corallium rubrum* (the famous red coral of commerce) is harvested by draggers and divers. Most of the red coral from the Mediterranean Sea for the past 2 years has been found in the Alboran Sea on shallow banks off the coast of Spain (FAO 1984). Mediterranean red coral is often referred to collectively as "Sardenia coral" and is of excellent quality, particularly for the manufacture of beads.

Lack of regulation of the fishery in the Mediterranean has caused depletion of the vast majority of known beds. This history in combination with the discovery off Albora Island provided impetus for the FAO to convene a workshop in 1983 in Majorca on management needs for precious coral in the Mediterranean. The Majorca

Table 1.—World landings of precious coral, 1983.

Area	No. of boats/divers	Average catch (kg)	Value (US$/kg)
Mediterranean[1]			
Sardenia	146 boats 20 divers	50,000	$320
Torre del Greco	20 boats		
Spain	?		
Taiwan[1]			
Far Seas (Midway)	20 boats	90,000	69
Domestic (traditional area)	50 boats	6,500	490
Japan[2]			
Ogasawara area	8 boats	1,746	543
South China Sea	1 boat	35	754
Far Seas (Midway)	14 boats	49,313	62
Total		197,594	$149

[1] Data from Mediterranean based on interviews with Italian and Taiwan coral merchants (values represent averages of estimates given by individuals).

[2] Data from Japan provided by All Japan Coral Fishing Association.

meeting focused on the need to conserve red coral resources in the Mediterranean and on enforcement strategies. Italian and Spanish fishermen, for example, have attempted to manage beds by rotating effort (5 years in Italy and 25 years in Spain). The latter approach obviously results in a more complete recovery, but it also creates a condition where protected beds are more valuable and correspondingly more attractive to poaching activity. Given the complex history and condition of the fishery, one recommendation of the Majorca meeting was for FAO to establish a 5-year working group on precious coral resources in the Mediterranean to work out details of improved management and help solve problems of jurisdiction and enforcement.

The conservation of precious corals is also receiving attention at the international level through the efforts of IUCN. In 1981, black corals were added to Appendix II of CITES, which requires that international customs agencies monitor all imports and exports of black coral or black coral products. Efforts are presently underway to add species of *Corallium* to Appendix II also. Pressure from international organizations such as IUCN on the governments of producing countries (Japan, Taiwan, Italy, etc.) may help to create the infrastructure necessary to require catch and effort reports from the fishermen.

RECOMMENDATIONS FOR CONSERVATION AND FUTURE RESEARCH

1. Government agencies responsible for fishery resource management of major producing countries should begin to collect records of catch and effort for precious corals.
2. Research programs are needed in the Mediterranean and the Pacific, particularly with regard to documenting the impacts of past fishing and the recovery of harvested coral beds. Important parameters to measure are recruitment, growth, and mortality.
3. Support for research should be sought from governments of producing countries including resource-related organizations within the United Nations.
4. Species of *Corallium* and species of commercially valuable gold coral, i.e., *Parazoanthus* and *Primnoa* spp., should be added to Appendix II of CITES.

CITATIONS

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS.
1984. Status of precious coral fishery, 1982. Food Agric. Organ., Fish. Rep. 306, 142 p.

GRIGG, R. W.
1970. Status of the precious coral industry in Japan, Taiwan, and Okinawa. University of Hawaii Sea Grant Adv. Rep. 1:1-15. [Also in Final Rep. of the Sino-American Colloq. on Oceanogr. Res. 1971.]

GRIGG, R. W. (editor).
1972. Economics and market potential of the precious coral industry in Hawaii. UNIHI-SEAGRANT-AR-71-03. 2d printing, 22 p.

GRIGG, R. W.
1975. The commercial potential of precious corals in the Western Caroline Islands. Sea Grant Advisory Rep., Univ. Hawaii, UNIHI-SEAGRANT-AR-75-03, 14 p.
1982. Precious coral in the Pacific; economics and development potential. Infofish marketing Dig. 2:8-11.
1984a. Resource management of precious corals: A review and application to shallow water reef-building corals. Mar. Ecol. 5(1):57-74.
1984b. Economics and future development of the precious coral fishery in the Pacific. *In* C. Gopalakrishnan (editor), The emerging marine economy of the Pacific, p. 77-85. Butterworth Publ., Ann Arbor Sci., Stoneham, Mass.

GRIGG, R. W., and L. ELDREDGE.
1975. The commercial potential of precious corals in the northern Mariana Islands. Sea Grant Tech. Rep., Univ. Guam, UGSG-75-01, 16 p.

WESTERN PACIFIC REGIONAL FISHERY MANAGEMENT COUNCIL.
1979. Final environmental impact statement and fishery management plan for the precious coral fisheries of the western Pacific region. Western Pac. Reg. Fish. Management Council, Honolulu, 116 p.

Fish and Crab Populations of Gulf of Alaska Seamounts

MILES S. ALTON
Northwest and Alaska Fisheries Center
National Marine Fisheries Service, NOAA
Seattle, Washington 98115-0070

ABSTRACT

In 1979 researchers of the National Marine Fisheries Service (NMFS) investigated the fish and crab populations associated with the summits of Gulf of Alaska seamounts. Commercial type trawls and traps were used to sample the populations. The seamount populations were composed mainly of species that are also important in the community of animals found on the lower slope region of the continental shelf of the northeast Pacific. These seamount species are sablefish, *Anoplopoma fimbria*; the macrourids (*Coryphaenoides acrolepis* and *C. pectoralis*); the thornyhead rockfish, *Sebastolobus altivelis*; and crabs (*Lithodes couesi* and *Chionoecetes tanneri*).

Trap catch rates of sablefish were higher from the seamounts than from (NMFS) trap survey sites off southeastern Alaska. However, the seamount sablefish appeared to be composed of only large, mature fish that arrived on the seamounts from other regions. There was no indication of young fish being recruited to these seamount populations. The rate of emigration from these populations is judged to be low from results of tag recoveries.

Trap catches of crab were unexpectedly high. The reproductive condition of the crabs suggests that breeding occurs on the seamounts, but the fate of the offspring is left to conjecture. There was some evidence that growth of *C. tanneri* may be less in the seamount environment than in the region of the lower slope of the continental shelf off Oregon.

INTRODUCTION

In 1979 the U.S. National Marine Fisheries Service (NMFS) investigated the fish and shellfish population associated with Gulf of Alaska seamounts (Hughes 1981). The investigation was stimulated by the discovery and eventual exploitation of sizable fish populations of pelagic armorhead, *Pseudopentaceros wheeleri*, and alfonsin, *Beryx splendens*, on seamounts in other parts of the North Pacific (Sakiura 1972; Takahashi and Sasaki 1977). The NMFS explorations were confined to nine seamounts (Fig. 1) of which five (Dickins, Welker, Quinn, Giacomini, and Patton) are located in the fishery conservation zone of the United States and the remainder (Durgin, Pratt, Applequist, and Surveyor), in international waters.

Three reports resulted from NMFS explorations: one on the fish and shellfish resources (Hughes 1981), another on a photographic survey of the seamounts (Raymore 1982), and a third by Somerton (1981) on the life history of the crab, *Lithodes couesi*, which was frequently encountered on the seamounts.

The purpose of this paper is to review the findings of the above authors as to the nature of seamount populations.

DESCRIPTION OF SAMPLING

Hughes (1981) provides a detailed description of the methods employed in sampling the fauna associated with the seamounts, and hence only a brief treatment will be given in this paper. Commercial type trawls and traps were used from a chartered commercial fishing vessel. A midwater trawl was fished above the summit of the seamounts to sample near surface (10-30 m) as well as midwater depths (150-450 m). The procedure was to lower the net to a specified depth and then tow the net at that depth for periods of 45 min to 1-1/2 h. The trawl was opened at all times, so sampling

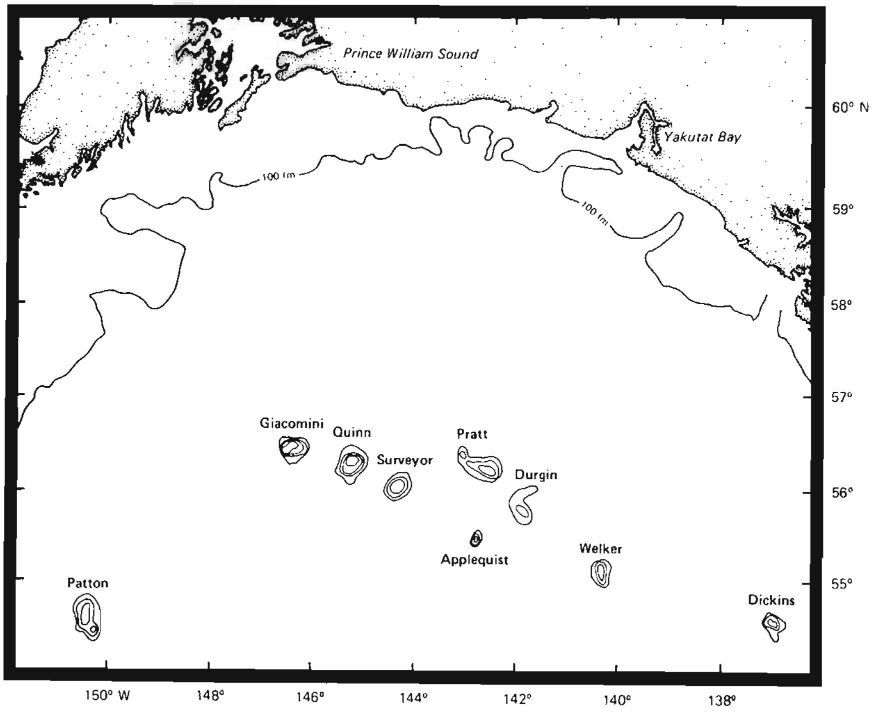


Figure 1.—Location of Gulf of Alaska seamounts surveyed by the National Marine Fisheries Service in 1979.

was occurring during the lowering and raising of the net. Sampling of the summit fauna was by bottom trawling and setting of baited traps. The duration of the bottom trawling was approximately one-half hour for most tows. A small mesh liner (1-1/4 in. (3.2 cm)) was used on the inside of the cod end of the midwater and bottom trawl so that small animals could be retained. A string of 7-10 sablefish traps were attached along a common groundline at intervals of 92 m and left to soak for periods of 10 to 36 h. Two king crab traps were added to the string at a later time when the catch of crabs in the sablefish traps began to increase.

Expendable bathythermograph (XBT) casts were made to obtain a temperature-depth profile above the summits of the seamounts and adjacent to the seamounts.

PHYSICAL FEATURES OF GULF OF ALASKA SEAMOUNTS

The seamounts investigated lie some 85 to 230 nmi from the nearest edge (200 m isobath) of the continental shelf of the Gulf of Alaska and rise some 3,300 to 3,700 m from the surrounding sea floor. The summits of these seamounts are the shallowest (182-915 m) of all the Gulf of Alaska seamounts and range in area from 3 km^2 for Applequist Seamount to 240 km^2 for Surveyor Seamount (Table 1). Pinnacles and rock outcrops are common features of the seamount summits, although Giacomini and Quinn Seamounts have no prominent pinnacles. The extent of soft bottom on the summit varies considerably from seamount to seamount. For those seamounts photographically surveyed, the sediment appeared to be finely grained and thinly layered, and a moderate to strong current was evident in some summit areas.

Water temperature profiles from the sea surface to the seamount summits were typical of the oceanic region of the northeast Pacific showing a surface layer at 0-30 m of isothermal conditions, a thermocline from about 30-50 m, and a gradual decrease in temperature with increasing depth from 200 m to the summit. The development of a thermocline was evident during the period of the investigations from early June to mid-July. Although no salinity measurements were made, there is a permanent halocline at approximately 100-200 m that characterizes northeast Pacific waters (Dodimead et al. 1963). Below the halocline, water temperature decreases from about 6°C at 200 m to 3°-4.5°C at the surface of the summits.

DESCRIPTION OF FAUNA

Three groups of animals can be distinguished from the sampling above and on the summit of the seamounts: an epipelagic group within 30 m of the surface, a bathypelagic group from about 150 m downward to near the surface of the summits, and a third group closely associated with the surface of the summits.

In the epipelagic zone, salmon (*Oncorhynchus*) was the most frequently captured animal. Four of the eight near surface tows contained salmon including 17 chum salmon, *O. keta*, 6 sockeye salmon, *O. nerka*, and 4 pink salmon, *O. gorbuscha*. Prowfish (*Zaprora*) were caught twice, and a small number of small fish (myctophids, cyclopterids, and oneirodids), and squid were captured in this zone.

The bathypelagic fish fauna was the most diversified of the groups encountered in the investigations with 21 species representing 15 families. This group at times was numerous in the midwater catches but by weight was insignificant compared to the bottom trawl catches on the summit. Hughes (1981) provides a list of bathypelagic fish taken in the Gulf of Alaska seamount investigations.

Table 1.—Physical features of Gulf of Alaska seamounts investigated by the National Marine Fisheries Service in 1979.

Seamount	Depth of summit (m)	Area of summit (km^2)	Topography of summit
Applequist	746	3	Steep peak of hard substrate.
Dickins	417-750	26	Patchy areas of hard and soft bottom; scattered pinnacles.
Durgin	650-714	72	Pinnacles and hard bottom are prominent features of the eastern half of the summit; soft sediment and occasional pinnacles are prominent of the western half.
Giacomini	676-732	69	Flat-topped with a thin layer of soft sediment predominating.
Patton	182-900	82	Series of pinnacles and canyons; evidence of current scour from scarcity of fine sediment and presence of exposed cobbles and pebbles.
Pratt	700-824	52	Mixture of soft and hard bottom with occasional pinnacles.
Quinn	682-823	42	Considerable area of soft sediment with absence of pinnacles.
Surveyor	366-824	240	Extensive areas of soft sediment; pinnacles present.
Welker	705-915	72	Pinnacles common over surface of summit.

The animals taken at the surface of the seamounts were species that are typical of the lower slope region (about 500-1,200 m) of the continental shelf of western North America from California to Alaska. (For a description of the various components of the lower slope fauna off the west coast of North America, see Day and Pearcy 1968, Alton 1972, Pereyra and Alton 1972, and Pearcy et al. 1982.) They were sablefish, *Anoplopoma fimbria*, macrourids (*Coryphaenoides acrolepis* and *C. pectoralis*), rockfish, *Sebastolobus altivelis*, and crabs (*Chionoecetes tanneri* and *Lithodes couesi*)—all relatively numerous and occurring frequently in the trap and trawl catches. Other less frequently encountered representatives of the lower slope fauna were the deep-sea sole (*Embassichthys*), the longfin cod (*Antimora*), and the eelpout (*Bothrocara*). The fish and crab faunas of the Gulf of Alaska seamounts summits are, therefore, extensions of the lower slope fish and crab faunas but separated by abyssal depths that exceed 3,000 m.

AVAILABILITY OF ANIMALS ON THE SEAMOUNT SUMMITS

Trap fishing

The most numerous animals taken in the traps were sablefish and crabs (*L. couesi* and *C. tanneri*). The only large catch of the crab, *L. aequispina*, was from the Patton Seamount. The macrourids were also frequently captured by traps.

Sablefish is an important commercially sought fish of the northeastern Pacific and Bering Sea where it is principally fished at the edge and slope of the continental shelf and inside waters of southeastern Alaska and British Columbia. Chikuni (1971) was the first to report its presence on Gulf of Alaska seamounts.

During NMFS investigation of the seamounts, the catch rates of sablefish in the traps were higher than those in NMFS surveys off southeastern Alaska where traps and fishing procedures were similar to those used on the seamounts (Table 2).

Table 2.—Comparisons of trap catch rates of marketable sablefish (≥57 m in fork length) between the seamount and southeastern Alaska surveys at similar bottom depths. Catch rate is the number of fish caught per trap standardized to a 24-h soak time.

	Catch rate	
Survey location and sampling depth	Range	Overall average
Gulf of Alaska seamounts (350-900 m)	[1]1.9-19.3	6.9
Southeastern Alaska (400-850 m)	[2]1.5-3.2	2.5

[1] By seamount.

[2] By year for the period 1978-81.

The king crab traps were much more efficient in catching crabs than were the sablefish traps. This was consistent on all the seamounts where both trap types were fished. The average catch per trap of crabs in the king crab traps was 47, and for the sablefish traps, 18.

The trap catch of crabs on the seamounts was much higher than anticipated and suggested a higher density than indicated for the slope region off southeastern Alaska from trap surveys (Table 3). *Lithodes couesi* was the most numerous crab found on the seamounts followed by *C. tanneri* and *L. aequispina*.

Table 3.—Comparison of crab catches by sablefish traps between seamount surveys and surveys of slope region off southeastern Alaska (data from Hughes 1981).

	Seamounts (effort = 216 traps)		Southeast Alaska (effort = 1,500 traps)	
Species	No. caught	No. per trap	No. caught	No. per trap
Lithodes couesi	1,019	4.7	62	<0.1
Chionoecetes tanneri	673	3.1	143	0.1
Lithodes aequispini	130	0.6	0	0
Total	1,822	8.4	205	0.1

Bottom trawling

Only 10 tows on the seamount summits were considered successful since the bottom was often too irregular for trawling. Catch rates ranged from 60 to 100 kg per 30 min trawl and averaged about 50 kg per 30 min. These rates are low in comparison to those obtained during NMFS trawl surveys of the continental slope off Oregon using a similar type trawl and at similar depths (Table 4).

The principal fishes in the summit trawl catches were macrourids (*C. acrolepis*, *C. cinereus*, and *C. pectoralis*), sablefish, and the thornyhead rockfish, *S. altivelis*. Crabs (lithodid species and *C. tanneri*) were frequently caught but never in any great number. In NMFS trawl surveys of the continental slope off Oregon, these species were also encountered except the macrourid (*C. cinereus*). The only flounder caught on the seamounts was the deep-sea sole (*Embassichthys*), but its occurrence was rare.

DISCUSSION

The nature of Gulf of Alaska seamount populations

I will confine my discussion to those species, sablefish and crabs (*L. couesi* and *C. tanneri*), that were frequently encountered on the summit of the seamounts in relatively large numbers.

Sablefish—It would be useful at this point to briefly review the life history of sablefish as it relates to the recruitment of young fish into the adult population. Mason et al. (1983) confirmed from ichthyoplankton surveys and studies of sablefish maturity that major spawning of sablefish occurs along the slope of the continental shelf during winter months. The eggs hatch in deep water, and the larvae ascend to near surface waters where transformation to the juvenile stage occurs. Juveniles are found widely distributed in offshore as well as inshore waters. The inshore waters such as those of Puget Sound, British Columbia, and southeastern Alaska appear to be major nursery areas for the young. As maturity approaches (about ages 3 and 4), the young fish begin to move offshore and enter the adult population in the slope region.

This movement of the young from shelf to slope waters has been demonstrated by Umeda et al. (1983) for Bering Sea sablefish, by Sasaki (1983) for Aleutians and Gulf of Alaska fish, and by McFarlane and Beamish (1983b) for sablefish off British Columbia. The increase in modal size of sablefish with increasing depth on the slope reflects the movement of young fish into the predominantly adult population of the lower continental slope (Fig. 2).

Whereas the sablefish populations occupying the continental slope region are maintained by recruitment of young fish (3- and 4-year-olds) from shallower bottom depths, recruitment into the seamount populations appears to come from older and larger fish. Sablefish caught on the seamounts were consistently large (Fig. 3), mostly age 5 and older (Fig. 4). No fish <52 cm were found either from trawling or trap fishing. Chikuni (1971) also shows from Japanese research trawling on Patton Seamount in the Gulf of Alaska that only large fish (≥54 cm) were caught.

This occurrence of only large fish was not due to gear selection since similar traps have caught smaller sablefish along the continental slope off southeastern Alaska and the west coast of the U.S. These NMFS surveys in the slope region showed that sablefish were recruited to the traps at about 40 cm, a consistent finding by year and survey site (Fig. 5). A high proportion of small fish has also been obtained during NMFS trawl surveys of the continental slope (Fig. 2). Thus, sampling gear selectivity cannot explain the presence of only large fish on the seamounts. Hughes (1981) reported finding no extensive off bottom signs of fish on the ship's echo sounder, and no sablefish were caught by midwater trawling above the seamounts. This suggests that sablefish, whether small or large, may

Table 4.—Comparison of bottom trawling catch rates of fish between the seamount surveys and the surveys of the lower slope region off northern Oregon.

Area	Depth (m)	Catch rates (kg/30 min)	Principal fish species by order of abundance by weight
Seamount summits	531-810	50	Rattails, sablefish, and *Sebastolobus*
Lower slope off Oregon[1]	457-869	100-200	Sablefish, *Sebastolobus*, and dover sole (*Microstomus*)

[1] From Alton (1972).

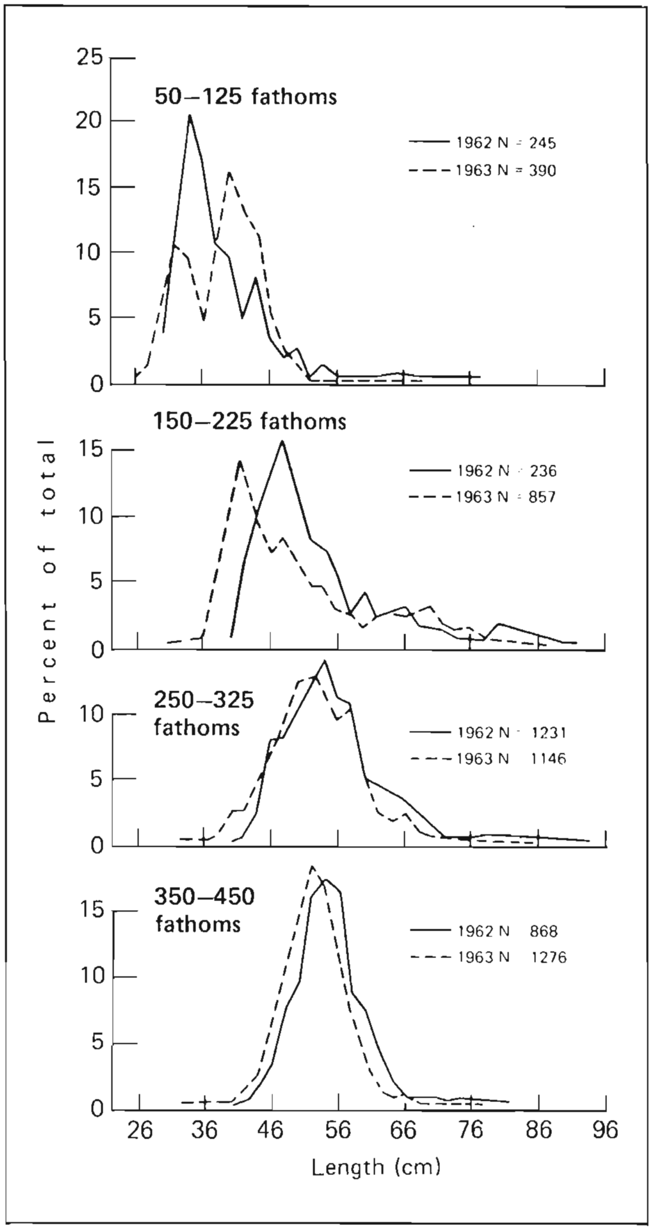


Figure 2.—Size composition of sablefish, *Anoplopoma fimbria*, sampled by research trawl catches from the edge and slope of the continental shelf off Oregon in 1962 and 1963 (figure from Alton 1972).

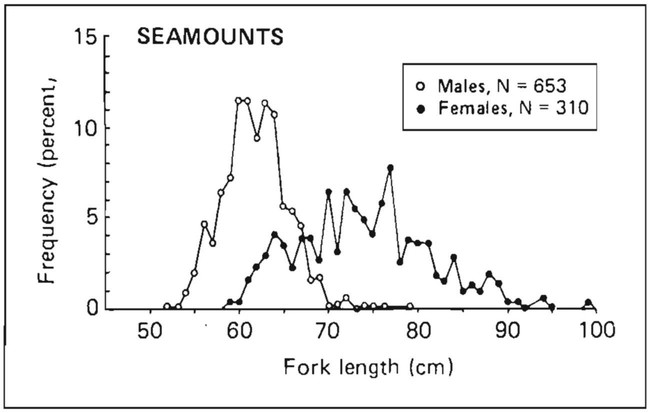


Figure 3.—Length-frequency distribution of sablefish obtained from Gulf of Alaska seamounts (figure from Hughes 1981).

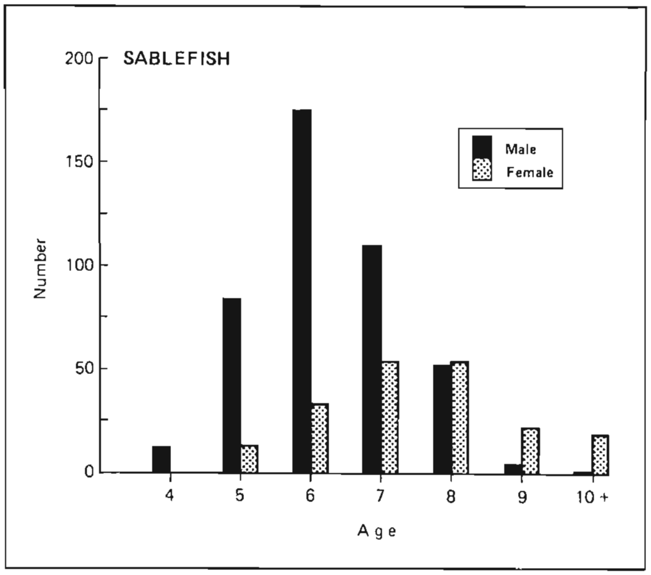


Figure 4.—Age composition of sablefish captured by trap gear on Gulf of Alaska seamounts.

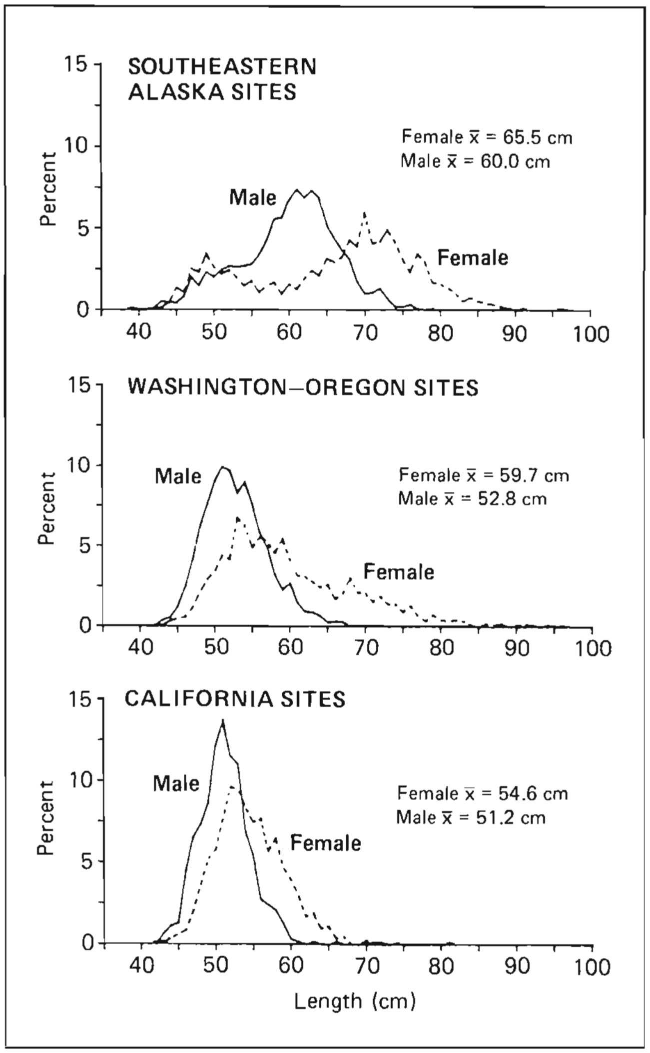


Figure 5.—Length-frequency distribution of sablefish collected at various sites off Alaska and the west coast of the U.S. during National Marine Fisheries Service trap surveys at depths of the continental slope of 550 m and greater.

not have been in midwater. The conclusion is that only large sablefish are associated with Gulf of Alaska seamounts.

Hughes (1981) shows that the smallest female sablefish taken on the seamounts was 58 cm, and the smallest male was 52 cm (Fig. 3). Such a nonoverlap by size of the sexes does not occur in fish caught on the continental slope (Fig. 5). Since Hughes (1981) used a composite of size information from all seamount sampling, I examined the length data from individual trap sets and confirmed that this nonoverlap was a consistent feature. My explanation for this nonoverlap in sizes is that only mature fish enter the seamount population from elsewhere, and that since males mature at a smaller size than females, the males are recruited to the population at a smaller size than the females. Mason et al. (1983) gave 52 cm as the size at 50% maturity for males and 58 cm for females.

That only mature fish, regardless of sex, are recruited to the seamount populations may also explain the predominance of males over females found by Hughes (1981) in seamount catches. Males recruit to the population at age 4 but mainly at age 5; for females recruitment starts mainly at age 6 (Fig. 4). Since younger ages are usually more numerous than older ages, the recruitment of the males at an earlier age may explain the uneven sex ratio.

If we assume that only mature fish occupy the seamounts, then what circumstances would bring this about? It is unlikely that the seamount populations are a continuation along the sea bottom of the adjacent slope populations since abyssal depths of 3,000 m or more separate the seamount and continental slope populations, and because sablefish abundance in the slope region declines rapidly beyond 1,000-1,500 m (Alton 1972). However, Canadian researchers (Beamish et al. 1979) have caught moderate numbers of sablefish off British Columbia at a depth of 2,740 m using fish traps, but their effort in deeper water (3,600 m) was unsuccessful in capturing sablefish.

Another explanation would be that the seamount population consists of fish that came from the populations of the slope region through migration at middepths. That sablefish migrate great distances has been shown by several studies (Sasaki 1980; Bracken 1982; Beamish and McFarlane 1983; Dark 1983; Wespestad et al. 1983). Sasaki (1980) has recorded the recovery of one sablefish on the Pratt Seamount that was tagged a year earlier at a set line station in the vicinity of the slope region south of Unimak Pass. The straight line distance between the release site and the Pratt Seamount is some 850 nmi.

Immature fish migrate great distances also, but they were absent from the seamount populations. No males younger than 4 and no females younger than 5 were captured during the seamount sampling. There remains the possibility that they may have been at depths above the summits and avoided capture by midwater trawling.

I tentatively conclude that the sablefish inhabiting the summits of Gulf of Alaska seamounts are mature fish whose populations are maintained by fish migrating from the slope region of the continental shelf. These migrants are assumed to travel at intermediate depths and for unknown reasons (perhaps bottom habitat, other sablefish) are attracted to the seamounts. The rate of emigration from seamount populations is believed to be low as suggested from the results of tagging. During NMFS investigations, 99 sablefish captured on the seamounts were tagged and released. Thirty of these were obtained from the Durgin Seamount, where three were recovered. This is an exceptionally high recovery rate (10%). Two of the recoveries were at large for 31-32 days, the third fish was captured 425 days after being released. All three fish were caught by Japanese commercial longline vessels. There is no information on possible fishing effort on other seamounts where fish were tagged and released. The high rate of tag recoveries from the same seamount and the presumed limited fishing effort in recovering these fish may suggest a small and localized population on this seamount.

Deep-sea king crab—*Lithodes couesi* was the most abundant crab found on the seamounts and was captured almost entirely with traps. The trap-caught crabs were all large and females predominated. The incidence of three small crabs in the trawl catches indicates that the traps were probably selective towards the larger individuals (Somerton 1981).

Somerton (1981) noted the shallower depth distribution of the seamount crabs compared to populations of the lower slope and suggests that this may be due to the absence of predators or competitors on the seamounts, thus allowing the seamount crabs to expand their bathymetric range.

Most Tanner crabs were obtained by trap fishing on the seamounts. These crabs were mainly adults although there may have been some juveniles at the lower end of the size range (Fig. 6). The size selectivity of the traps, similar to that for *L. couesi*, may have been operative for Tanner crab, but as Pereyra (1972) shows for the continental slope population, the young may be in deeper water. The depths where Tanner crab were caught on the summits (350-800 m) fall within the range of the adults given by Pereyra (1972).

Trophic considerations

Raymore's (1982) photographic survey of some of the Gulf of Alaska seamounts gives the impression of a current-swept surface of gravel and boulders; sediment when present is thinly layered. The thick sediment of the lower continental slope region with its highly developed bottom community of benthophagic soles and detrital feeding invertebrates is absent. Crabs may be one of the more numerous of the inhabitants of the seamount surface. Food would appear to be very limiting for these crabs, and growth in such environs may be much less than that in the habitat of the lower slope region of the continental shelf. Some evidence of this slower growth comes from a comparison of the length-frequency distribution between seamount and continental slope Tanner crabs. The size of adult crabs sampled from the continental slope region off Oregon was much greater than the size of adult crabs collected from the seamounts (Fig. 6). Selectivity could be a factor in this difference since the seamount crabs were collected by trap fishing and the maximum size of the crab was limited by the size of the trap opening; for trawling there would be no upper limit for the size of the crab taken. Such selectivity, if it exists, would affect the much larger males and not the smaller females. Yet, the reduced size of the seamount crabs was exhibited by both sexes. Therefore, there may exist a real growth difference between Tanner crab of the seamounts and those occupying the continental slope region.

The apparent paucity of available food on the surface of the seamounts would mean that the sablefish and other numerous fish near the surface would have to obtain most of their sustenance from the bathypelagic zone or from each other. Sablefish is a generalist in its feeding and can prey upon bottom as well as nektonic animals. McFarlane and Beamish (1983a) provide a list of the prey of adult sablefish which includes bathypelagic fish, macrourids, and rockfish (*Sebastolobus*). Sablefish collected from the seamounts were examined for food contents and all but one (which contained a shrimp) had empty stomachs. This occurrence of empty stomachs is common in trap-caught sablefish and may result from regurgitation as the fish is rapidly raised from deep water to the surface.

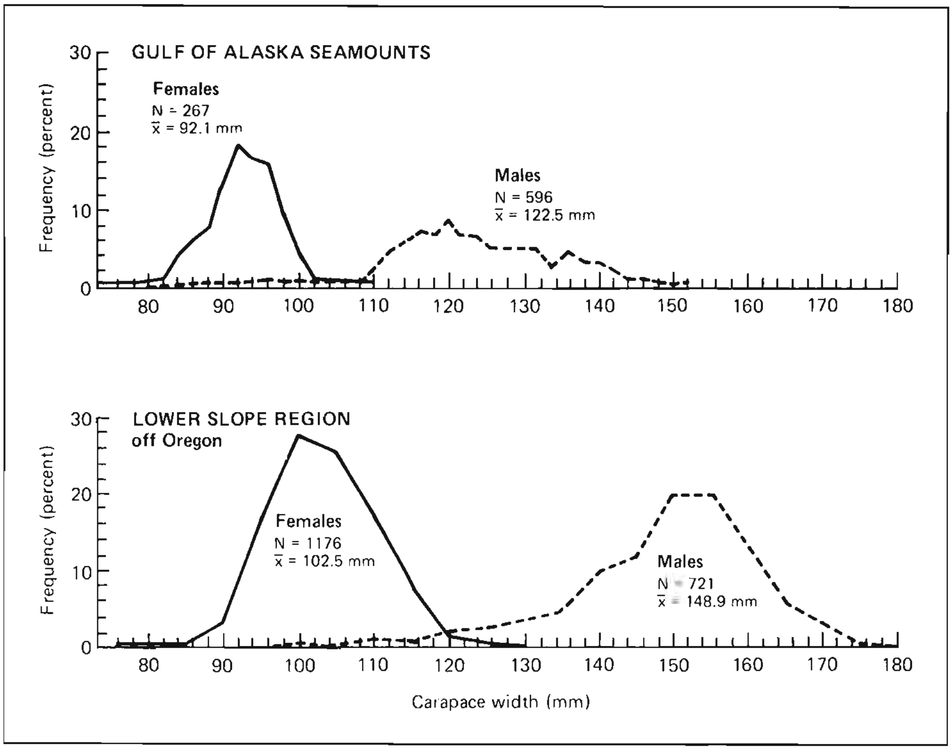


Figure 6.—Length-frequency distribution of Tanner crab captured by trap gear on the Gulf of Alaska seamounts and by bottom trawling on the continental slope off Oregon. The lower figure is from Pereyra (1972).

Macrourids are opportunistic in their feeding and can feed on both benthic as well as nektonic animals (Novikov 1970; Pearcy and Ambler 1974).

The bathypelagic fauna comprised of fish, squid, shrimp, and other forms may be the only food source sufficient to maintain the populations of nectobenthic fish, such as sablefish and macrourids, on the Gulf of Alaska seamounts.

CITATIONS

ALTON, M. S.
1972. Characteristics of the demersal fish fauna inhabiting the Outer Continental Shelf and slope off the northern Oregon coast. *In* A. T. Pruter and D. L. Alverson (editors), The Columbia River estuary and adjacent ocean waters, p. 583-634. Univ. Washington Press, Seattle.

BEAMISH, R. J., C. HOULE, C. WOOD, and R. SCARSBROOK.
1979. A summary of sablefish tagging and exploratory trapping studies conducted during 1978 by the Pacific Biological Station. Can. Data Rep. Fish. Aquat. Sci. 162, 163 p.

BEAMISH, R. J., and G. A. MCFARLANE.
1983. Summary of results of the Canadian sablefish tagging program. Proc. Int. Sablefish Symp., Alaska Sea Grant Rep. 83-8:147-183.

BRACKEN, B. E.
1982. Sablefish (*Anoplopoma fimbria*) migration in the Gulf of Alaska based on gulf-wide tag recoveries, 1973-81. Alaska Dep. Fish Game Inf. Leafl. 199, 24 p.

CHIKUNI, S.
1971. Groundfish on the seamounts in the North Pacific. Bull. Jpn. Soc. Fish. Oceanogr. 19:1-14. [In Jpn.] (Engl. transl. by K. Tatara, 1972; available Fish Res. Board Can. Transl. Ser. 2130.)

DARK, T. A.
1983. Movement of tagged sablefish released at abundance index sites of southeastern Alaska, Washington, Oregon, and California during 1978-81. Proc. Int. Sablefish Symp., Alaska Sea Grant Rep. 83-8:191-207.

DAY, D. S., and W. G. PEARCY.
1968. Species associations of benthic fishes on the continental shelf and slope off Oregon. J. Fish. Res. Board Can. 25:2665-2675.

DODIMEAD, A. J., F. FAVORITE, and T. HIRANO.
1963. Salmon of the North Pacific Ocean. Part II. Review of oceanography of the subarctic Pacific region. Int. N. Pac. Fish. Comm., Bull. 13, 195 p.

HUGHES, S. E.
1981. Initial U.S. exploration of nine Gulf of Alaska seamounts and their associated fish and shellfish resources. Mar. Fish. Rev. 42(1):26-33.

MASON, J. C., R. J. BEAMISH, and G. A. McFARLANE.

1983. Sexual maturity, fecundity, spawning, and early life history of sablefish (*Anoplopoma fimbria*) off the Pacific coast of Canada. Can. J. Fish. Aquat. Sci. 40:2126-2134.

McFARLANE, G. A., and R. J. BEAMISH.

1983a. Biology of adult sablefish (*Anoplopoma fimbria*) in waters off western Canada. Proc. Int. Sablefish Symp., Alaska Sea Grant Rep. 83-8:59-80.

1983b. Preliminary observations on the juvenile biology of sablefish (*Anoplopoma fimbria*) in waters off the west coast of Canada. Proc. Int. Sablefish Symp., Alaska Sea Grant Rep. 83-8:119-135.

NOVIKOV, N. P.

1970. Preliminary observations on the juvenile biology of sablefish (*Anoplopoma fimbria*) in waters off the west coast of Canada. Proc. Int. Sablefish Symp., Alaska Sea Grant Rep. 83-8:119-135.

PEARCY, W. G., and J. W. AMBLER.

1974. Food habits of deep-sea macrourid fishes off the Oregon coast. Deep-Sea Res. 21:745-749.

PEARCY, W. G., D. L. STEIN, and R. S. CARNEY.

1982. The deep-sea benthic fish fauna of the northeastern Pacific Ocean on Cascadia and Tufts Abyssal Plains and adjoining continental slopes. Biol. Oceanogr. 1:375-428.

PEREYRA, W. T.

1972. Bathymetric and seasonal abundance and general ecology of the Tanner crab, *Chionoecetes tanneri* Rathbun (Brachyura: Majaidae), off the northern Oregon coast. *In* A. T. Pruter and D. L. Alverson (editors), The Columbia River estuary and adjacent ocean waters, p. 538-582. Univ. Washington Press, Seattle.

PEREYRA, W. T., and M. S. ALTON.

1972. Distribution and relative abundance of invertebrates off the northern Oregon coast. *In* A. T. Pruter and D. L. Alverson (editors), The Columbia River estuary and adjacent ocean waters, p. 444-474. Univ. Washington Press, Seattle.

RAYMORE, P. A., Jr.

1982. Photographic investigations on three seamounts in the Gulf of Alaska. Pac. Sci. 36:15-34.

SAKIURA, H. (translator).

1972. The pelagic armorhead, *Pentaceros richardsoni*, fishing grounds off the Hawaiian Islands, as viewed by the Soviets (So-Ren kara mita Hawaii oki kusakari tsubodai gyojyo). [In Jpn.] Suisan Shuho (The Fishing & Food Industry Weekly) 658:28-31, June 15, 1972. (Engl. transl. by T. Otsu, 1977, 7 p., Transl. No. 17; available Southwest Fish. Cent. Honolulu Lab., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396.)

SASAKI, T.

1980. An interim report on U.S.-Japan black cod tagging experiments conducted in the Aleutian region and Gulf of Alaska in 1978 and 1979. [In Jpn.] Far Seas Fish. Res. Lab., Jpn. Fish. Agency, Shimizu, Jpn., 6 p.

1983. Relative abundance and size structure of sablefish in the eastern Bering Sea, Aleutian region and Gulf of Alaska based on the results of Japan-U.S. joint longline surveys from 1979 to 1982. Proc. Int. Sablefish Symp., Alaska Sea Grant Rep. 83-8:239-253.

SOMERTON, D. A.

1981. Contribution to the life history of the deep-sea king crab, *Lithodes couesi*, in the Gulf of Alaska. Fish. Bull., U.S. 79:259-269.

TAKAHASHI, Y., and T. SASAKI.

1977. Trawl fishery in the central North Pacific seamounts. Northern waters groundfish fishery—data 3 (Hokuyo soko-uo gyogyo—Shiryo (3) (Northern waters groundfish fishery—Data (3)). [In Jpn.] Division of Northern Waters Groundfish Resources, Far Seas Fish. Res. Lab., 45 p. (Engl. transl. by T. Otsu, 1977, 49 p., Transl. No. 22; available Southwest Fish. Cent. Honolulu Lab., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396.)

UMEDA, Y., T. M. SAMPLE, and R. R. BAKKALA.

1983. Recruitment processes of sablefish in the eastern Bering Sea. Proc. Int. Sablefish Symp., Alaska Sea Grant Rep. 83-8:291-303.

WESPESTAD, V. G., K. THORSEN, and S. A. MIZROCH.

1983. Movement of sablefish, *Anoplopoma fimbria*, in the northeastern Pacific Ocean as determined by tagging experiments (1971-80). Fish. Bull., U.S. 81:415-420.

Session 3. Summary

RICHARD N. UCHIDA and SIGEITI HAYASI

The two papers presented in the session demonstrated that other important and potentially important resources are associated with seamounts. In the first paper, Grigg reported that precious corals may be found in the vicinity of seamounts and that the precious coral fishery can be considered in part a seamount fishery.

Commercial grades of precious coral are red and pink (*Corallium* spp.). Less valuable corals include gold, black, and bamboo. In the last 5 years, more than half of the world's supply of *Corallium* sp. has been harvested from grounds in the Emperor Seamounts at depths between 400 and 1,500 m. Recent discoveries of new precious coral grounds in the Mediterranean and off Hokkaido are also associated with seamounts or shallow banks.

In the second paper Alton dealt with fish and crab populations associated with Gulf of Alaska seamounts. These seamount populations were composed mainly of commercially valuable species that are part of the lower slope community of the continental shelves in the northeastern Pacific. Alton, however, found no evidence of recruitment of young fish to the seamount populations, that seamount-associated sablefish were large, mature fish that arrived from other regions, and that there was a low rate of emigration from the seamount populations.

Alton concluded from the surveys that despite high catches of crabs and sablefish from seamounts, the nature of the population and the limited habitat suggest that seamount populations can support only a limited fishery.

Discussion on the presentations brought out that coral tangle nets are about 40% efficient. Repeated passes of this type of gear break up coral and cause extensive damage to the grounds, which may require many years to recover.

In response to a question of aging coral, Grigg replied that growth rings can be used to determine age of mature coral. He noted that gonadal development may slow coral growth and thus ring formation. Immature coral, however, also shows evidence of growth rings, but it is not known why they occur. Grigg stated that for some species, male coral matures at age 2 and females at age 4.

Coral harvesting can also be done by the use of submersibles, but whether it is efficient to do so depends on economic considerations.

On a question of how mature sablefish find their way from their lower-slope habitat to the offshore seamounts, Alton speculated that sablefish migrate in midwater to reach them. The rationale for such speculation is that the seamount-associated sablefish are firm-fleshed, unlike some continental slope sablefish which inhabit deep water and have softer flesh. Furthermore, sablefish have been reported in catches of midwater trawls.

For hake caught by trawling over Alaskan seamounts, it was noted that they differed in size and age from those taken by trap fishermen off Oregon, indicating differential growth rates by area. Sablefish from the eastern Bering Sea as well as over the seamounts showed extensive horizontal and vertical distributions; therefore, even if the seamount stock of this species were harvested intensively, the effect of fishing would not be as severe as that for pelagic armorhead, which is closely associated with and dependent on the seamount habitat.

Further discussion pointed out that the sablefish resource in the North Pacific is not limiting, and the present fishing intensity is not likely to affect it. Any fishery developed for the seamount-associated sablefish, however, would need to be properly managed.

Review and Current Status of Research on the Biology and Ecology of the Genus *Pseudopentaceros*

ROBERT L. HUMPHREYS, Jr.
DARRYL T. TAGAMI
Southwest Fisheries Center Honolulu Laboratory
National Marine Fisheries Service, NOAA
Honolulu, Hawaii 96822-2396

ABSTRACT

The genus *Pseudopentaceros* has two species, the pelagic armorhead, *P. wheeleri*, confined to the North Pacific, and *P. richardsoni*, confined to the Southern Hemisphere. Center of abundance and spawning grounds for pelagic armorhead is the southern Emperor-northern Hawaiian Ridge (SE-NHR) seamounts and for *P. richardsoni* the Walvis Ridge. Adult pelagic armorhead typically inhabit the summits and upper slopes of the SE-NHR seamounts and open ocean adults and juveniles occur in waters of the northern and northeastern Pacific.

Pelagic armorhead on the SE-NHR summits aggregate at night and typically remain dispersed during daylight hours. Surface and near surface aggregations have been reported from the northern and northeastern Pacific. Within the SE-NHR, diet consists mainly of mesopelagic organisms associated with the deep scattering layer. The peak spawning period within this region extends from late December through January. Among pelagic armorhead collected from the Hancock Seamounts (located within the SE-NHR), females were significantly larger than males. Results of various age and growth studies on pelagic armorhead indicate either 2-3 years or 7-9 years for the age composition at the SE-NHR seamounts.

Morphological variation of pelagic armorhead has led to taxonomic difficulties. Three body types—lean, intermediate, and fat—occur among SE-NHR pelagic armorhead. The lean and intermediate types were described as *P. wheeleri* and the fat type as *P. pectoralis*. Preliminary results of a morphological investigation demonstrate intergradation of characters between fat and intermediate and intermediate and lean. These results cast doubt on the existence of two separate species in the North Pacific. A hypothetical life history, which assumes the existence of only one North Pacific species is presented; we suggest that fat types undergo a morphological change to intermediate and lean types after settlement on the seamounts.

INTRODUCTION

A recent revision of the Family Pentacerotidae by Hardy (1983) placed the pelagic armorhead[1] into the genus *Pseudopentaceros* and recognized three separate species. Previously, only a single species, *Pentaceros richardsoni*, was recognized. Hardy's revision includes a single species, *Pseudopentaceros richardsoni*, in the Southern Hemisphere and two species, *P. wheeleri* and *P. pectoralis*, in the North Pacific. *Pseudopentaceros richardsoni* differs from *P. wheeleri* and *P. pectoralis* in meristic characters (26 total vertebrae and $\geqslant 32$ midline throat scales from isthmus to pelvic fin insertions) and morphometric characters (least bony interorbital width $\geqslant 3.0$ in head length and body depth at first anal spine >3.0 in standard length) distinguish *P. wheeleri* from *P. pectoralis*. Since virtually all of the biological information on pelagic armorhead predates Hardy's revision, however, considerable uncertainty exists concerning the identity of the species in past literature. Hereafter, we refer to *P. wheeleri* and *P. pectoralis* as "pelagic armorhead" unless species identification is discernible from a reference. All *Pseudopentaceros* recorded from southern latitudes will be referred to as *P. richardsoni* since its distribution is known only from the Southern Hemisphere and the other two species are unrecorded from this region.

The Soviet discovery in 1967 of vast concentrations of pelagic armorhead near the seamounts of the southern Emperor-northern Hawaiian Ridge (SE-NHR) and later discovery of concentrations of *P. richardsoni* from seamounts of the Walvis Ridge focused attention on a genus previously considered rare and whose biology and ecology were virtually unknown. Subsequently, biological investigations (primarily on pelagic armorhead) were initiated by Soviet and Japanese researchers. Although these studies have contributed much new information, our current understanding of various life history aspects of *Pseudopentaceros* remains incomplete.

A compilation of the current biological and ecological information on *Pseudopentaceros* will initially be presented in this review. Subsequently, we will focus on preliminary results from our study of morphological variation in pelagic armorhead and suggest a hypothetical life history.

LIFE HISTORY INFORMATION

Distribution

The distribution of *Pseudopentaceros* appears in Figure 1. Hardy (1983) reports the general distribution of *P. wheeleri* from Japan to Hawaii in the northern Pacific Ocean. Collection sites of specimens examined were Kimmei (actually Koko) Seamount in the southern Emperor Seamount Chain, from Hancock Seamounts in the northern Hawaiian Ridge, and off Hachijo Island, Japan. Hardy reported the distribution of *P. pectoralis* extending from Hawaii to the northern and northeastern Pacific across to the west coast of North America and south to California. The distribution of the two species overlap in the central North Pacific. Collection sites of *P. pectoralis* material examined by Hardy (1983) include Ladd Seamount in the northern Hawaiian Ridge, oceanic waters of the northern Pacific Ocean, and off the coasts of Oregon and California. Morphological information in Sasaki (1974), Takahashi and Sasaki (1977), and from our observations supports this distribution.

---

[1] Pelagic armorhead was proposed as a common name for *Pentaceros richardsoni* by Follett and Dempster (1963); it is not meant to indicate habitat preference.

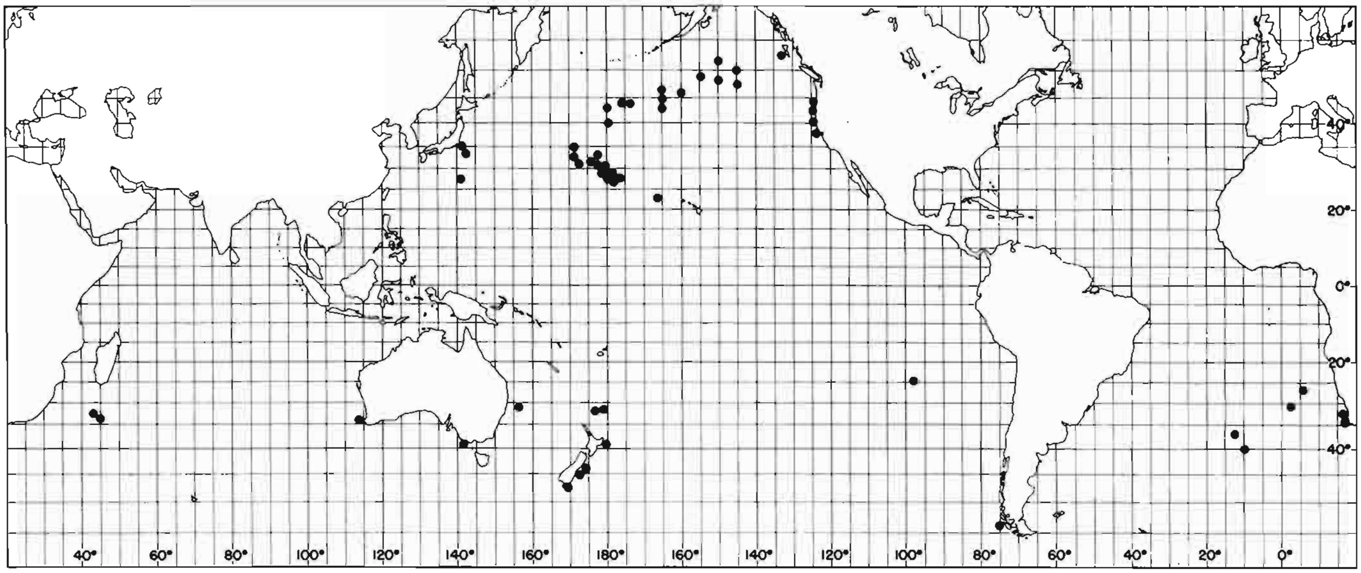


Figure 1.—Worldwide distribution of *Pseudopentaceros*. Solid dots in the Southern Hemisphere represent *P. richardsoni* and in the North Pacific Ocean, *P. wheeleri* and *P. pectoralis* combined.

Previous to Hardy's revision, captures of pelagic armorhead were from California (Follett and Dempster 1963; Smith 1965), Oregon (Wagner and Bond 1961), British Columbia (Clemens and Wilby 1961; Hart 1973), around Japan near the Boso Peninsula (Abe 1957), off Hachijo Island (Abe 1969), the Ogasawara Islands (Zama et al. 1977), in northern oceanic waters south of the Aleutian Islands and around the Gulf of Alaska (Welander et al. 1957; Larkins 1964; Honma and Mizusawa 1969; Chikuni 1970; Hokkaido University, Faculty of Fisheries 1976, 1979, 1981, 1982, 1983; Randall 1980). Among the central North Pacific seamounts, pelagic armorhead have been reported from Mellish Bank (Takahashi and Sasaki 1977), from Koko, Yuryaku, and Kammu of the southern Emperor Seamount Chain and from Colahan, C-H, Northwest (NW) and Southeast (SE) Hancock, unnamed Seamounts 10 and 11 (Sakiura 1972) and from Kure Atoll and Ladd Seamount (Randall 1980), all located along the northern Hawaiian Ridge. Two specimens have been captured in the central region of the Hawaiian Ridge at Laysan Island and French Frigate Shoals (Tagami, manuscr. in prep.). Surveys conducted elsewhere in the North Pacific have generally not found pelagic armorhead. From distribution records of pelagic armorhead and known oceanographic conditions in the northeast Pacific and SE-NHR seamounts, Chikuni (1971) proposed that pelagic armorhead are capable of inhabiting waters of 5°-20°C (8°-15°C optimum). The SE-NHR seamounts include Koko, Yuryaku, Kammu, Colahan, C-H, NW and SE Hancock, and unnamed Seamounts 10 and 11.

Borets (1980) reported that pelagic armorhead "fry" from 8 to 40 mm long were collected in ring trawl tows conducted near the SE-NHR seamounts. Highest catches of these transformed juveniles were made near the Milwaukee Seamounts (Yuryaku and Kammu) but these juveniles were not found near Koko Seamount. Numerous hauls for young pelagic armorhead conducted near the northern Hawaiian Ridge during winter collected only a small number of eggs and larvae. No reports were found on the capture of eggs and larvae of pelagic armorhead outside of the SE-NHR region. The existence of eddies and meandering surface circulation over the SE-NHR and their intensification during the winter is thought to retain early life stages of pelagic armorhead in the seamounts region (Borets 1980).

Pseudopentaceros richardsoni in the South Pacific is known from Derwent Hunter Seamount (Sasaki 1978), off New Zealand and the south coast of Australia (Hardy 1983), and the Sala y Gomez Ridge (Borets 1980). In the South Atlantic, *P. richardsoni* is known from Cape Point, South Africa (Smith 1964), from Valdivia Seamount and other seamounts along the Walvis Ridge (Pakhorukov 1980; Sasaki 1986), in the South Indian Ocean from the Madagascar Ridge (Kotlyar 1982), and off western Australia (Hardy 1983). Juvenile *P. richardsoni* have been collected from the South Pacific off Cape Horn (Smith 1964), off Kermadec Island and over the South Fiji Basin (Hardy 1983), and in the South Atlantic from near Gough Island and Tristan da Cunha (Penrith 1967; Borets 1980; Pakhorukov 1980). No reports were found on the distribution of earlier life stages of *P. richardsoni*. The center of abundance for *P. richardsoni* is the seamounts of the Walvis Ridge.

Data for 1969-81 show that virtually all of the pelagic armorhead caught in the trawl fishery at the SE-NHR seamounts ranged from 26 to 33 cm fork length (FL) in an overall size range of 15-40 cm FL (Takahashi and Sasaki 1977; Sasaki 1982). The mean annual length has increased somewhat from a low of 27.4 cm in 1972 to 32.1 cm FL in 1981 (Table 1). Takahashi and Sasaki (1977) and

Table 1.—Length data of pelagic armorhead taken by Japanese trawlers, all seamounts combined (Takahashi and Sasaki 1977; Sasaki 1982).

Year	Sample size	Mean fork length (cm)	Range of fork lengths (cm)
1969	375	29.2	24-36
1970	166	29.2	26-34
1971	4,400	28.9	24-40
1972	6,410	27.4	20-34
1973	3,138	29.0	25-35
1974	20,724	28.8	21-37
1975	11,736	28.9	23-35
1976	8,517	29.5	15-35
1978	5,508	31.3	23-44
1979	2,412	30.9	21-39
1981	2,664	32.1	27-40

Borets (1980) report little variation in size composition among the seamounts of the SE-NHR. Takahashi and Sasaki (1977) reported the tendency of the largest pelagic armorhead to occur in the trawl catches at 300-390 m depths and smaller fish at 200-290 and 400-490 m. Size distribution data for pelagic armorhead from other areas are scant; fish from these areas generally fall within the size range noted above. The largest recorded size for pelagic armorhead is a 54.7 cm FL specimen from French Frigate Shoals (Tagami, manuscr. in prep.). Analysis of sex-length data on pelagic armorhead taken from the Hancock Seamounts during 1978-82 indicated that the greater mean fork length of females and the annual pattern of this difference were highly significant (see Table 2). *Pseudopentaceros richardsoni* taken in the trawl fishery on the Walvis Ridge (Pakhorukov 1980) ranged from 35 to 48 cm long (mean length, 41 cm). The largest recorded *P. richardsoni* is a 55.5 cm total length (TL) specimen from South Africa (Smith 1964).

Adult and juvenile *P. pectoralis* have been collected from surface and near surface waters in the open ocean (Sasaki 1974), and in the SE-NHR, adult pelagic armorhead occur over summit depths of 160 to 400 m and to acoustically recorded depths of 800 m (Borets 1980). Eggs, larvae, and small juveniles of pelagic armorhead appear restricted to the surface layer (Borets 1975, 1979; Fedosova and Komrakov 1975). Adult and juvenile *P. richardsoni* have been collected from the surface; adults have also been collected at 1,000 m (Kotlyar 1982; Hardy 1983).

Table 2.—The ANOVA of length data, by sex, for pelagic armorhead taken at Hancock Seamounts by Japanese trawlers (NS = $P > 0.05$; *** $P \leq 0.001$).

Year	Number of males	Mean fork length of males (cm)	Number of females	Mean fork length of females (cm)	ANOVA		
					Source	df	PR>F
1978	222	29.1	325	29.7	Sex	1	***
1979	461	29.0	577	29.7	Year	4	***
1980	2,302	29.7	1,759	30.5	Sex and year	4	NS
1981	620	29.7	817	30.7			
1982	578	29.9	790	30.7			

Behavior

Reports from Japanese whaling ships working the northeast Pacific during the summer months of 1967-69 noted the handline capture of numerous pelagic armorhead at night under the ships' lights. Pelagic armorhead were also found in the stomachs of sei whales; the whales appeared satiated in the early morning and near evening. Chikuni (1970) concluded that pelagic armorhead in this area are capable of forming large near-surface aggregations during daylight and night hours. Aggregations of pelagic armorhead are also present over the summits of the SE-NHR seamounts at night but are typically absent during the day. Early Soviet surveys over these summits acoustically detected aggregations ranging in average thickness from 15 to 35 m (Sakiura 1972). Variation in nocturnal catches reported by Nasu and Sasaki (1973) suggests these aggregations exhibit a patchy distribution over the summits.

Sakiura (1972) reported that acoustically detected nocturnal aggregations of pelagic armorhead near the summits ascended to the level of the thermocline and dispersed after dawn. This position was maintained throughout the day until dusk when schools began descending over the summits. Kitani and Iguchi (1974) proposed that this nocturnal descent actually extends to a depth below the summit level whereas Sasaki (1974) reported that vertical movements were ambiguous over some of the seamounts but clearly evident at SE Hancock Seamount. An alternate explanation is that pelagic armorhead inhabit the slope areas during daylight and ascend to the summit upon nightfall. These observations and interpretations based on acoustical observations may be misleading, however, due to the movements of high densities of micronekton over some seamounts (Boehlert and Seki 1984). Further studies are needed to clarify the periodicity, predictability, and range of these movements.

Feeding habits

Borets (1975) reported that the feeding period of SE-NHR pelagic armorhead extends from March to September. During this period, 40% of the stomachs examined were empty while another 40% had only remnants of food; full stomachs were rarely encountered. Borets also noted that during the feeding period, the condition factor of fish was higher compared with fish during the winter.

Sakiura (1972) reported that during a 24-h period, pelagic armorhead of the SE-NHR feed during daylight, and that feeding peaked from 0800 to 1000. Field observations by T. K. Kazama and W. B. Barnett (both of Southwest Fish. Cent. Honolulu Lab.) on the condition and volume of stomach contents indicated feeding occurred during daylight, primarily in the morning and late afternoon. However, Kitani and Iguchi (1974) found a higher proportion of stomachs with food during 0000-0800. Fedosova and Komrakov (1975) reported that over a 24-h period, juvenile pelagic armorhead (8.5-23.0 mm long) collected within the SE-NHR region showed evidence of round-the-clock feeding which peaked in the morning and evening hours. No data on time of feeding and feeding periods of *P. richardsoni* are available.

The important prey items in the diet of SE-NHR pelagic armorhead, as reported in Sakiura (1972), were surface dwelling crustaceans. However, information on the feeding habits of these fish in Nasu and Sasaki (1973), Japan Fisheries Agency (1974), Sasaki (1974), Borets (1979), and Kazama and Barnett (field observations) indicates that a major portion of the diet consists of deep-scattering-layer (DSL) organisms. Specifically, these include amphipods, copepods, euphausiids, macrura, pteropods, sergestids, tunicates, myctophids, and mesopelagic fishes. Borets (1975) reported that 73 species of zooplankton (mainly copepods and amphipods) have been identified from stomachs of SE-NHR pelagic armorhead, including six species of Radiolaria.

Feeding periodicity data suggest that pelagic armorhead preferentially feed on that portion of the DSL whose vertical descent is blocked by the expanse of the seamount summit. Although this explanation accounts for the presence of pelagic armorhead aggregations near the summits around dawn, it does not explain their presence over the summits in the evening when stomachs are typically empty. Fedosova (1980) linked times of favorable feeding conditions for young pelagic armorhead to increases in the winter-spring plankton biomass during warm years. Fedosova and Komrakov (1975) reported that the major prey items of 8.5-23.0 mm long pelagic armorhead from the SE-NHR were copepods, chaetognaths, and larval bivalve mollusks. Copepods had the highest frequency of occurrence (93.8%); the dominant species was *Clausocalanus arcuicornis* followed by *Oithona similis* and *Mecynocera clausi*. Size of food items ranged from 0.35 to 9.0 mm. No reports on the feeding habits of *P. richardsoni* are available.

Reproduction

Information on the spawning period of pelagic armorhead is available only for the SE-NHR seamounts; reproductive adults have not been recorded from oceanic waters of the northern and northeastern Pacific. Bilim et al. (1978) reported prespawning conditions in mid-November; the spawning period began in early December and peaked during late December through January. In February, spawning had largely been completed and by March all mature females were spent. Chen (1980) reported that some individuals at Kammu Seamount had well-developed gonads during May. Borets (1975) commented on the absence during the spawning period of nearly ripe and running ripe females from bottom trawl catches over the SE-NHR seamounts and suggested that pelagic armorhead spawn in midwater. Reproductive adults of *P. richardsoni* have been reported from the Walvis Ridge (Borets 1980), but no information was available on time of spawning.

A histological study of oocyte development in pelagic armorhead from the SE-NHR seamounts was conducted by Bilim et al. (1978). Results indicated that during the spawning season, only one group of oocytes undergo synchronous development up to the time of hydration. The hydration process and release of eggs are asynchronous. During spawning, eggs are released in four to six batches and average 20,000 per batch. Borets (1979) reported that fecundity estimates of 30 cm long females from three SE-NHR seamounts ranged from 99,000 to 110,000 eggs. No information was available on fecundity of *P. richardsoni*.

Age and growth

An analysis of scales from two specimens of pelagic armorhead, 22 and 32 cm FL, indicated that these fish were 3 and 6 years old, respectively (Chikuni 1970). From these results and data indicating that trawl caught pelagic armorhead from the SE-NHR seamounts averaged 30 cm FL, Chikuni surmised that such fish were 5-7 years old. Results of an age and growth study reported in Borets (1979) indicate that a 30 cm FL fish is 7-9 years old. The data also indicate that growth rate of pelagic armorhead at various seamounts within the SE-NHR is similar up until an age of 5-6 years and the majority of the trawl catch is composed of 6-8 year olds. Preliminary results from an analysis of growth increments on the sagitta, however, indicate an age of 2-3 years for a 30 cm FL individual and a large proportion of 2-year olds in the SE-NHR trawl catches (J. H. Uchiyama and J. D. Sampaga, Southwest Fish. Cent. Honolulu Lab., pers. commun. March 1985). Hart (1973) reported that a specimen held in captivity at Vancouver Aquarium for 3 years grew from 25.4 to 32.9 cm. According to the data presented in Borets (1979), such a growth increase in the wild from a similar initial size would require 4-5 years.

Parasitism

Kazatchenko and Kurochkin (1974) reported that the copepod *Pennella hawaiiensis* infested 59% of pelagic armorhead (range 44-80%) examined from trawl catches in the SE-NHR seamounts. Kurochkin (1985) stated that the early marketing of Soviet catches of pelagic armorhead (some 133,000 tons) was temporarily prohibited until the origin of the dark formations in the musculature were attributed to this parasite and found nonhazardous for human consumption. The frequent presence of another ectoparasite was noted among pelagic armorhead at SE Hancock Seamount (Japan Fisheries Agency 1974); we have rarely seen this unidentified parasite which resembles a cooked grain of rice. A preliminary survey of the parasitofauna of *P. wheeleri* and *P. pectoralis* taken from the Hancock Seamounts revealed the presence of monogenetic and diagenetic trematodes, larval nematodes, and crustaceans; all are currently being identified. All four types of parasites were present in a sample of 20 *P. wheeleri* whereas only the monogenetic trematodes and larval nematodes occurred in eight *P. pectoralis*. Larval nematodes were the only parasites present in three *P. pectoralis* which were collected from oceanic waters of the northeastern Pacific. The only record of parasites in *P. richardsoni* is that of larval cestodes (*Gymnorhynchus gigas*) found in the musculature of specimens collected from the Whale (Walvis) Ridge (Alioshkina et al. 1985).

MORPHOLOGICAL VARIATION

Description and available biological data

Before Hardy's recognition of two species of *Pseudopentaceros* in the North Pacific, the existence of morphological variation in pelagic armorhead and its characterization into two to three body types was reported in Kuroiwa (1973), Japan Fisheries Agency (1974), Sasaki (1974), Takahashi and Sasaki (1977), Zama et al. (1977), and Chen (1980). These types were subjectively classified by body depth and appearance as the fat, lean, and intermediate types (Fig. 2).

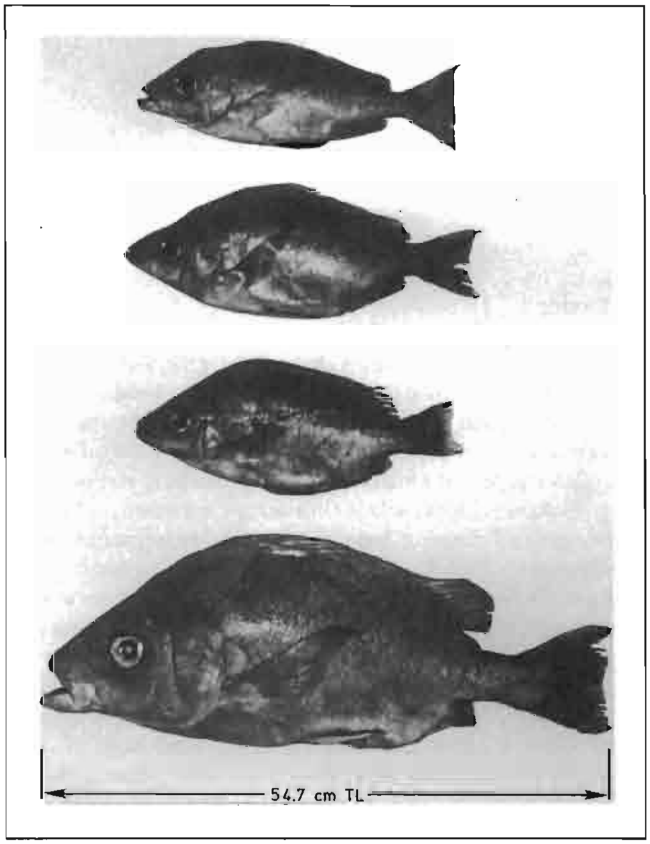


Figure 2.—Specimens representing the various body types of pelagic armorhead. Types starting from the top: lean, intermediate, fat, and a large adult.

The fat type is deeper bodied and that portion of the body below the dorsal fin appears somewhat "square-shaped" in profile. Body coloration is dark blue dorsally and whitish ventrally; dorsal spots occur on some individuals. Juvenile pelagic armorhead resemble the fat type in body profile and according to Honma and Mizusawa (1969), the coloration is basically blue dorsally and white ventrally. Coloration along the dorsal and lateral regions is highly mottled. Small juveniles (8-15 mm FL) collected by the National Marine Fisheries Service (NMFS), Honolulu Laboratory (HL) personnel from surface waters above the Hancock Seamounts resemble the juvenile fat type in body profile and coloration. Adult and juvenile fat type collected from oceanic waters of the northern and northeastern Pacific and examined by the senior author are invariably *P. pectoralis*. Some of the adult fat type taken from the SE-NHR seamounts, however, are less vivid in coloration and have standard length/body depth at first anal spine (SL/BDFAS) ratios which are intermediate between *P. pectoralis* and *P. wheeleri*. Identity of the small juveniles from the Hancock Seamounts has not been determined.

The lean type is characterized by a relatively shallow body, particularly in the posterior portion. Body coloration is uniformly light brown, and spots are absent. We have seen some very emaciated lean individuals at the Hancock Seamounts as have Takahashi and Sasaki (1977). These fish possess an even shallower body with skin which is easily ruptured and exhibit a discoloration of the viscera, suggesting a poor physiological condition. The intermediate type has a body depth in between the other two types but the coloration coincides with the lean type. Large deposits of fat are commonly found in the visceral cavity of the intermediate and fat types whereas these fat deposits are usually reduced in the lean type and absent among very lean individuals. The intermediates and leans are the predominant morphotypes found at the SE-NHR seamounts and have not been recorded from oceanic waters of the northern and northeastern Pacific. Preadult stages of intermediates and leans have not been reported. Numerous lean and intermediate types examined by the senior author (taken from the SE-NHR seamounts) were virtually all identified to *P. wheeleri*.

Trawl specimens collected at the Hancock Seamounts during research cruises of the NMFS, HL yielded approximate male to female ratios as follows: 2:1, 1:2, and 1:1 for the lean, intermediate, and fat type, respectively. In commercial catches, however, a ratio of 1.2:1 occurs in the SE-NHR seamounts (Nasu and Sasaki 1973; Japan Fisheries Agency 1974).

Four large adult specimens >42 cm FL have been collected outside of the SE-NHR seamounts along the Hawaiian Ridge. One of the specimens served as the holotype for *P. pectoralis* in Hardy's revision of *Pseudopentaceros* and two identified to *P. wheeleri*. The fourth specimen had a head length-least interorbital width (HL/LIW) ratio of *P. wheeleri* and a SL/BDFAS ratio of *P. pectoralis*. Thus these large specimens show variation as do smaller fish (Fig. 2).

Before the publication of Hardy's revision, a morphometric and meristic study was initiated to elucidate the nature and significance of the body type variation in pelagic armorhead. A total of 342 specimens were examined; the sample consisted of 86 lean, 110 intermediate, and 146 fat types collected from NW and SE Hancock Seamounts. Each specimen was examined for 12 meristic and 11 morphometric characters. Results of an analysis of variance (ANOVA) on the meristic characters show no significant differences between means compared by body type, sex, and seamount. No meristic differences were presented in Hardy (1983) to distinguish between *P. wheeleri* and *P. pectoralis*. The ANOVA results on the morphometric characters showed highly significant differences within sex and body type for each morphometric character. To ascertain whether these differences could be used in distinguishing between body types, morphometric values were converted into ratios relative to SL (SL/body measurement). Results with SL/greatest orbit length, SL/least interorbital width, and SL/snout length show that ratio values overlap all body types for each of these body proportions (Fig. 3). All three body types show a range of ratio values which overlap in SL/head length and SL/predorsal length (Fig. 4). No such overlap occurred between fats and leans in SL/predorsal to prepelvic length and SL/maximum body depth although each of these types overlapped with the intermediate range. One of two characters presented by Hardy (1983) to distinguish *P. wheeleri* from *P. pectoralis* and examined in this study was HL/LIW. The ranges of both HL/LIW values in each type show a large overlap (Fig. 5). Furthermore, the range of HL/LIW values for each body type includes the ratios 2.9 and 3.0, which represent the maximum HL/LIW value for *P. pectoralis* and minimum HL/LIW value for *P. wheeleri*, respectively (Hardy 1983). Although the above results are from a preliminary study, results of a more comprehensive morphometric and electrophoretic examination of body types will be forthcoming (R. L. Humphreys and G. Winans, Southwest Fish. Center Honolulu Lab., report in prep.).

In Hardy's study, the type material for *P. wheeleri* included 12 specimens from 23.7 to 30.2 cm SL, and for *P. pectoralis*, 9 specimens from 6.6 to 42.5 cm SL. Only four specimens of *P. pectoralis*, however, were of similar size to the *P. wheeleri* material; the rest of the *P. pectoralis* were juveniles and a large adult specimen. Furthermore, it appears that no fat type specimens from the SE-NHR seamounts were available to Hardy. At this point, the existence of two separate species within the North Pacific seems doubtful. No information is available which would dispute the validity of *P. richardsoni* as a separate species constituting all pelagic armorhead in the Southern Hemisphere (Fujii 1986).

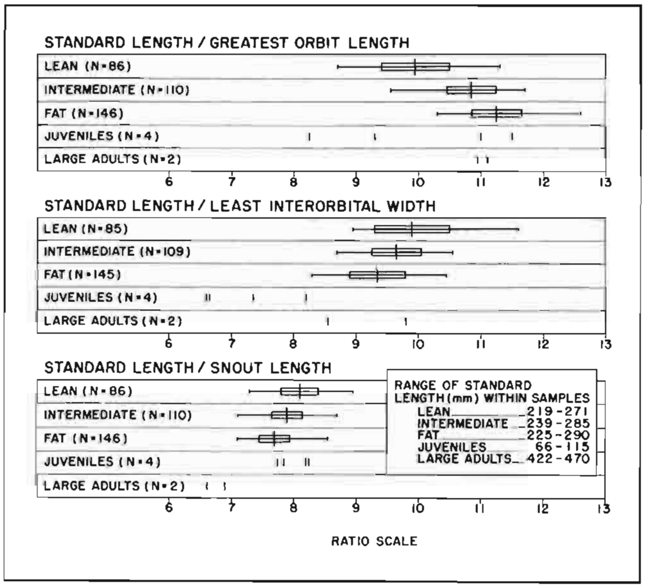


Figure 3.—Ratios of various morphological characters separated by body type, juvenile, and large adult stages. For body type, arithmetic mean is indicated by vertical lines, ±1 standard deviation (boxes), and range (horizontal lines). For juveniles and large adults, vertical lines indicate actual values.

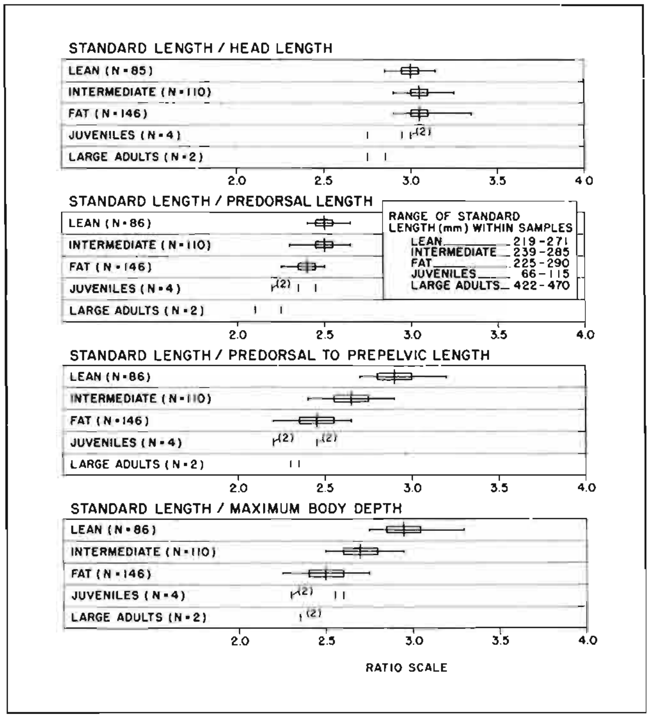


Figure 4.—Ratios of various morphological characters separated by body type, juvenile, and large adult stages. For body type, arithmetic mean is indicated by vertical lines, ±1 standard deviation (boxes), and range (horizontal lines). For juveniles and large adults, vertical lines indicate actual values.

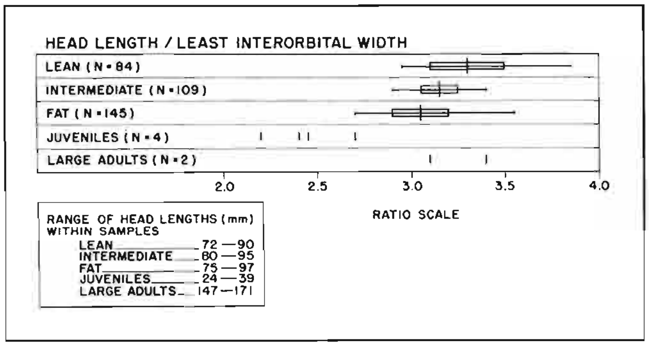


Figure 5.—Ratios of least interorbital width into head length, separated by body type, juvenile and large adult stages. For body type, arithmetic mean is indicated by vertical lines, ±1 standard deviation (boxes), and range (horizontal lines). For juveniles and large adults, vertical lines indicate actual values.

A hypothetical life history of pelagic armorhead

Life histories of pelagic armorhead have been proposed by Chikuni (1970) and Borets (1979, 1980). Chikuni suggested that larvae are dispersed by surface currents away from the seamounts into an area bounded by lat. 15° and 55°N. Early development was thought to be pelagic in surface or midlayer waters with a shift to a demersal existence over seamounts when the fish are 4-5 years old. Borets reported that pelagic armorhead remain pelagic up to age 7 whereupon a change to a demersal habitat occurs and the fish form aggregations over seamounts. Furthermore, the new array of environmental conditions encountered by this habitat change affects the growth and metabolic activity of the fish. Once settled, the fish do not leave the proximity of a given seamount.

The following life history we propose is based, in part, on these previous life history proposals and represents an attempt at incorporating data on morphological variation and current biological and ecological information into a general description of the life history of pelagic armorhead. The crucial assumption in this life history is that there is only one species of pelagic armorhead. The center of reproduction is the SE-NHR seamounts. In the early planktonic stage, they are initially contained by surface currents over the SE-NHR seamounts; individuals rapidly develop into a nektonic stage and actively move away from the seamounts before reaching 5 cm FL. The juveniles are epipelagic and are confined to a temperature regime of 5°-15°C. All juveniles are actually young fat types; juveniles resembling the lean or intermediate types do not exist. The juvenile and adult fat type represent the prereproductive, dispersal phase of the life history; during this phase, energy is stored through an accumulation of body fat. The majority of the fat type change to a demersal existence over the seamounts upon reaching 26-33 cm FL. This shift in habitat involves a change of body coloration, reproductive development, and a gradual loss in body depth and fat content. All fat type fish undergo a transition to the intermediate type upon settlement over the seamounts. The lean type represents a further transition from the intermediate type. The factors which determine the time of transition from the fat type to the intermediate and lean type are probably time of year relative to the reproductive season, size at settlement, and availability of food during settlement. The very lean type represents individuals which have previously spawned and had originally settled at a less than optimum size; the energy demands incurred eventually depleted these fish of virtually all energy reserves. These fish are subsequently susceptible to high mortality. It should be emphasized, however, that upon settlement, the onset of reproductive activity may be energetically the most costly physiological process. The very lean type represents the minimum fork length of settled individuals at the seamounts and would explain the apparently smaller fork lengths among these fish and why pelagic armorhead <26 cm FL are rarely found in trawl catches. On the other hand, an upper limit of about 33 cm FL occurs among the majority of transitional individuals at the seamounts. This phenomenon is attributed to a drastic reduction in growth upon settlement; hence, increases in length and weight are largely confined to the open ocean fat type. The infrequently captured large adults which resemble the fat and intermediate types represent "strays" which undergo a protracted fat type phase and eventually undergo settlement at a much larger size compared to the rest of the population. Additionally, a drastic reduction in growth and the onset of reproductive activity would also occur in these individuals upon settlement.

We also propose that recruitment of fat type to the SE-NHR seamounts is probably continuous but at a low level. This pattern of recruitment, coupled with a rapid transition to the intermediate phase, would explain the low percentage of fat types in trawl catches from this region. No theory is advanced to explain the mechanism responsible for the return of open ocean fat type to the seamounts. Finally, if all pelagic armorhead undergo an initial fat type phase, this would imply the existence of a pelagic population removed from the seamounts which is considerably larger than realized; based on the low catches in salmon gill nets and other gear, however, the population is either highly dispersed or inhabits an environment poorly sampled in most studies.

Specific findings which would invalidate this proposed life history of pelagic armorhead include genetic evidence of more than one species in the North Pacific, evidence of spawning in the fat type population, the occurrence of lean and intermediate type preadult stages, or evidence that fat type individuals are physiologically incapable of changing into the intermediate type.

CITATIONS

ABE, T.

1957. New rare or uncommon fishes from Japanese waters. VI. Notes on the rare fishes of the Family Histiopteridae. Jpn. J. Ichthyol. 6(1/2):35-39 and continued in 6(3):71-74.

1969. Notes on some edible marine fishes collected between the Bonin Islands and the mouth of Sagami Bay—III. Bull. Tokai Reg. Fish. Res. Lab. 60:5-8.

ALIOSHKINA, L. D., A. V. GAEVSKAYA, and A. A. KOVALIOVA.

1985. Parasitofauna of fishes of the Whale Ridge. *In* W. J. Hargis, Jr., (editor), Parasitology and pathology of marine organisms of the world ocean, p. 29. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 25.

BILIM, L. A., L. A. BORETS, and L. K. PLATOSHINA.

1978. Characteristics of ovogenesis and spawning of the boarfish in the region of the Hawaiian Islands. [In Russ., Engl. abstr.] Izv. Pac. Sci. Res. Inst. Fish. Oceanogr. (TINRO) 102:51-57.

BOEHLERT, G. W., and M. P. SEKI.

1984. Enhanced micronekton abundance over mid-Pacific seamounts. [Abstr.] EOS 65(45):928.

BORETS, L. A.

1975. Some results of studies on the boarfish (*Pentaceros richardsoni* Smith). [In Russ.] Invest. Biol. Fish. Fish. Oceanogr. TINRO, Vladivostok 6:82-90. (Engl. transl. by W. G. Van Campen, 1984, 9 p., Transl. No. 97; available Southwest Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396.)

1979. The population structure of the boarfish, *Pentaceros richardsoni*, from the Emperor Seamounts and the Hawaiian Ridge. J. Ichthyol. 19(3):15-20.

1980. The distribution and structure of the range of the boarfish *Pentaceros richardsoni*. J. Ichthyol. 20(3):141-143.

CHEN, C.-H.

1980. Primary studies of demersal fish resources investigations on trawl grounds at Kanmu Seamount. [In Chin.] Bull. Taiwan Fish. Res. Inst. 32:317-337. (Engl. transl. by W. G. Van Campen, 1983, 33 p., Transl. No. 79; available Southwest Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396.)

CHIKUNI, S.

1970. The "phantom fish," "kusakari tsubodai"—an outline. [In Jpn.] Enyo (Far Seas) Fish. Res. Lab. News 3:1-4. (Engl. transl. by J. H. Shohara, 7 p. (n.d.); available Natl. Mar. Fish. Serv., Terminal Island, CA 90731.)

1971. Groundfish on the seamounts in the North Pacific. [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 19:1-14. (Engl. transl. by K. Tatara, 1972, 12 p. Fish. Res. Board Can. Transl. Ser. No. 2130.)

CLEMENS, W. A., and G. V. WILBY.

1961. Fishes of the Pacific coast of Canada. 2d ed. Bull. Fish. Res. Board Can., 68, 443 p.

FEDOSOVA, R. A.

1980. Inter-year changes in the mesoplankton of the waters of the submarine banks of the Hawaiian Ridge (Northwestern Pacific Ocean). [In Russ.] Izv. Pac. Ocean Sci. Res. Inst. Fish. Oceanogr. TINRO 104:84-87.

FEDOSOVA, R. A., and O. E. KOMRAKOV.

1975. Feeding of *Pentaceros richardsoni* frys in the Hawaiian region. [In Russ.] Invest. Biol. Fish. Fish. Oceanogr. TINRO, Vladivostok 6:52-55. (Engl. transl. by W. G. Van Campen, 1985, 4 p., Transl. No. 100; available Southwest Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396.)

FOLLETT, W. I., and L. J. DEMPSTER.

1963. Relationships of the percoid fish *Pentaceros richardsoni* Smith, with description of a specimen from the coast of California. Proc. Calif. Acad. Sci., Fourth Ser. 32:315-338.

FUJII, E.

1986. The zoogeographical features of fishes in the vicininty of seamounts. *In* R. N. Uchida, S. Hayasi, and G. W. Boehlert (editors), Environment and resources of seamounts in the North Pacific, p. 67-69. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 43.

HARDY, G. S.

1983. A revision of the fishes of the Family Pentacerotidae (Perciformes). N.Z. J. Zool. 10:177-220.

HART, J. L.

1973. Pacific fishes of Canada. Bull. Fish. Res. Board Can. 180, 740 p.

HOKKAIDO UNIVERSITY, FACULTY OF FISHERIES.

1976. Data Record of Oceanographic Observations and Exploratory Fishing 19:145.

1979. Data Record of Oceanographic Observations and Exploratory Fishing 22:32,36.

1981. Data Record of Oceanographic Observations and Exploratory Fishing 24:33,39.

1982. Data Record of Oceanographic Observations and Exploratory Fishing 25:35,43.

1983.Data Record of Oceanographic Observations and Exploratory Fishing 26:79,87.

HONMA, Y., and R. MIZUSAWA.

1969. A record of the young of boarfish, *Pseudopentaceros richardsoni*, from the North Pacific. [In Jpn.] Jpn. J. Ichthyol. 15(3):134-136.

JAPAN FISHERIES AGENCY

1974. Survey of the North Pacific seamounts (Kita Taiheiyo kaizan chosa). Report of *Kaiyo Maru* survey cruises, 1972 season. [In Jpn.] Jpn. Fish. Agency, 136 p. (Engl. transl. by T. Otsu, 1981, 55 p., Transl. No. 54; available Southwest Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396.)

KAZATCHENKO, V. N., and YU. V. KUROCHKIN.

1974. On a new parasitic copepod species, *Pennella hawaiiensis* sp. nov., from the boarfish, *Pentaceros richardsoni*. [In Russ.] Trans. Pac. Res. Inst. Fish. Oceanogr. TINRO, Vladivostok 88:42-53.

KITANI, K., and K. IGUCHI.

1974. Some observations on the feature of fishing grounds on the seamounts in the central North Pacific Ocean as surveyed through the trawl operation. [In Jpn., Engl. abstr.] Bull. Far Seas Fish. Res. Lab. (Shimizu) 11:33-36.

KOTLYAR, A. N.

1982. First finding of *Parazen pacificus* Kamohara (Zeidae) and *Pentaceros richardsoni* (Pentacerotidae) in the Indian Ocean. [In Russ.] Bull. Mosk. O-Va. Ispyt. Prir. Otd. Biol. 87(3):34-36.

KUROCHKIN, YU. V.

1985. Applied and scientific aspects of marine parasitology. *In* W. J. Hargis, Jr., (editor), Parasitology and pathology of marine organisms of the world ocean, p. 15-18. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 25.

KUROIWA, M.

1973. Research by trawl fishery for commercialization of the fishing grounds by Japan Marine Fishery Resource Research Center. . . Outline of trawl fishery investigation for commercialization in the central North Pacific—I. [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 23:42-47. (Engl. transl. by W. G. Van Campen, 1984, 7 p., Transl. No. 95; Southwest Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396.)

LARKINS, H. A.

1964. Some epipelagic fishes of the North Pacific Ocean, Bering Sea, and Gulf of Alaska. Trans. Am. Fish. Soc. 93:286-290.

NASU, K., and T. SASAKI.

1973. Surveys of the mid-Pacific Seamounts by the research vessel *Kaiyo Maru*. [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 23:56-70. (Engl. transl. by T. Otsu, 1984, 17 p., Transl. No. 93; available Southwest Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396.)

PAKHORUKOV, N. P.

1980. Deep-sea bottom fishes of the Whale Ridge and adjacent areas. [In Russ.] *In* P. P. Shirshov (editor), Fishes of the open ocean, p. 19-31. Academy of Sciences of the USSR, Moscow.

PENRITH, M. J.

1967. The fishes of Tristan da Cunha, Gough Island, and the Vema Seamount. Ann. S. Afr. Mus. 48(22):523-548.

RANDALL, J. E.

1980. New records of fishes from the Hawaiian Islands. Pac. Sci. 34:211-232.

SAKIURA, H. (translator).

1972. The pelagic armorhead, *Pentaceros richardsoni*, fishing grounds off the Hawaiian Islands, as viewed by the Soviets (So-Ren kara mita Hawaii oki kusakari tsubodai gyojyo). [In Jpn.] Suisan Shuho (The Fishing & Food Industry Weekly) 658:28-31, June 15, 1972. (Engl. transl. by T. Otsu, 1977, 7 p., Transl. No. 17; available Southwest Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396.)

SASAKI, T.

1974. The pelagic armorhead, *Pentaceros richardsoni* Smith, in the North Pacific (Kita Taiheiyo no kusakari tsubodai. [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 24:156-165. (Engl. transl. by T. Otsu, 1977, 13 p., Transl. No. 16; available Southwest Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396.)

1978. The progress and present status of the seamount fishing ground development program (Kaizan gyojyo kaihatsu no keika to genjo. [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 33:51-53. (Engl. transl. by T. Otsu, 1979, 6 p., Transl. No. 35; available Southwest Fish. Cent., Natl. Mar. Fish. Serv., Honolulu, HI 96822-2396.)

1982. Unpublished data on length-frequency of pelagic armorhead from the SE-NHR seamounts for 1978-79, and 1981. Far Seas Fisheries Research Laboratory, Shimizu, Japan.

1986. Development and present status of Japanese trawl fisheries in the vicinity of seamounts. *In* R. N. Uchida, S. Hayasi, and G. W. Boehlert (editors), Environment and resources of seamounts in the North Pacific, p. 21-30. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 43.

SMITH, J. G.

1965. A second record of the pelagic armorhead, *Pentaceros richardsoni* Smith 1849, in California waters. Calif. Fish Game 51:213-214.

SMITH, J. L. B.

1964. Fishes of the Family Pentacerotidae. Rhodes Univ., Ichthyol. Bull. 29:567-578.

TAKAHASHI, Y., and T. SASAKI.

1977. Trawl fishery in the central North Pacific seamounts (Kita Taiheiyo chubu kaizan ni okeru tororu gyogyo). [In Jpn.] Hokuyo soko-uo gyogyo-Shiryo (3) (Northern waters groundfish fishery—Data (3)). Division of Northern Waters Groundfish Resources, Far Seas Fish. Res. Lab., 45 p. (Engl. transl. by T. Otsu, 1977, 49 p., Transl. No. 22; available Southwest Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396.)

WAGNER, E. J., and C. E. BOND.

1961. The percoid fish *Pseudopentaceros richardsoni* from Oregon waters. Fish Comm. Oregon, Res. Briefs 8(1):71-73.

WELANDER, A. D., R. C. JOHNSON, and R. A. HAJNY.

1957. Occurrence of the boar fish, *Pseudopentaceros richardsoni*, and the zeid, *Allocyttus verrucosus*, in the North Pacific. Copeia 1957:244-246.

ZAMA, A., M. ASAI, and F. YASUDA.

1977. Records of the pelagic armorhead, *Pentaceros richardsoni*, from Hachijo Island and the Ogasawara Islands. Jpn. J. Ichthyol. 24:57-60.

A Seamount Survey Around Izu Islands[1]

HIROYO KOAMI
Sea Sphere Research Institute
Yaizu, Japan

INTRODUCTION

The natural factors that affect the productivity of fishing grounds include weather, sea conditions, and resource trends. In addition, submarine topography is of basic importance since bottom topography influences currents and provides reliable clues to good fishing grounds for particular species. It is particularly important to have a thorough knowledge of the submarine topography for fishing grounds that are associated with seamounts and banks; although the "Basic Chart of the Ocean" (Umi no Kihon-zu) issued by the Hydrographic Department of the Maritime Safety Agency is consulted by the fishermen, detailed data of the submarine topography of the fishing grounds would be far more useful. Such data, if available, would enable the fishermen (jointly with use of the fish-finder) to estimate the movements of the various fish groups (pelagic species at the surface, the groundfish species at middepths, and the benthic species on the bottom) as they respond to changes in the direction and speed of currents that come into contact with the seamounts and banks. With such information, it may be possible for the fishermen to greatly increase their productivity through the establishment of a multispecies fishery.

MATERIALS AND METHODS

The Sea Sphere Research Institute carried out a survey of Suruga Bay in Shizuoka Prefecture from 1971 to 1976. Through the cooperation of the Yaizu Fisheries Cooperative Association, the Institute used the Association's fisheries training vessel *Wakadori* (19.7 gross tons) to survey the submarine topography of Senoumi Bank, situated near the middle of Suruga Bay. Senoumi Bank consists of Mae-se (literally "front bank") at the northern end with a minimum depth of 32 m, and the Aino-se (literally "adjoining bank") to the south with a minimum depth of 69 m. A survey of the banks in the vicinity of Niijima Islands was also conducted. In October 1982 the submarine topography of Takase Bank was studied to a depth of 250 m, and in October 1983, we conducted a similar survey of the Hyotan-no-se Bank (literally "gourd shoals") to a depth of 500 m. Recognized as a highly productive fishing ground, Senoumi Bank was surveyed with the aid of a new, highly accurate navigation system, which provided accurate fixes for particularly good fishing spots. For the survey of Takase, which parallels Niijima and Kozu Islands in the Izu group, however, swift currents prevented the use of this system and traditional navigation methods were used.

The entrance to Suruga Bay measures 56 km in the east-west direction, and the bay extends a distance of 58 km to the northernmost end. At the center of the bay, there is a long submarine ridge running from the foot of Mount Kuno (located on the northwest coast of the bay) to Omaezaki (western tip of the bay entrance). A 900-m deep basin is situated to the west of the ridge and a steep canyon called the Suruga Trough runs between the ridge and Izu Islands. Near the bay entrance between Iro-zaki and Omaezaki, the depth is approximately 2,400 m, and farther inside the bay between Ose-zaki and the Miho Peninsula, the bay is approximately 1,200 m deep.

Our surveys have resulted in topographical charts of the bottom made up of a combination of cross-sectional charts in several directions, isobath contours at depths <200 m, and cross-sectional charts of Suruga Bay at depths down to 2,500 m. The submarine topography of Senoumi Bank shows that the two constituent banks, both with flattened tops, are arranged like a caldera encircled by

---

[1] Translated from the Japanese by Tamio Otsu, September 1984.

concentric vertical cliffs (the inner cliff of Mae-se is 5-10 m high, and the outer cliff is 10-20 m high) (Figs. 1 and 2). There is topographic evidence of a large-scale landslide on the northwestern sides of both banks.

A counterclockwise current flows in Suruga Bay most of the year (80.6%) and influences the occurrence of upwelling along the slopes of the two banks on the southeastern side. The current and the resulting upwelling play a major role, along with the aforementioned calderalike topography, in the formation of a good fishing ground at Senoumi Bank.

Examples of fishing ground formation at Senoumi Bank

Schools of meji (young bluefin tuna, *Thunnus thynnus*), occur in Suruga Bay from September to November and are fished actively by small surface trolling and pole-and-line vessels. The best fishing grounds develop near the southeastern side of Mae-se (Fig. 1). A good fishing ground for migratory schooling fish such as mackerel, *Scomber japonicus*, and sardine, *Sardinops melanosticta*, forms near the northeastern section of Mae-se where the bottom topography is quite complex.

Senoumi Bank is also a good fishing ground for the demersal amadai (Branchiostegidae). Fish-finder records, underwater television, and direct observations from a submersible have revealed that the base on the inner sides of the calderalike cliffs of Mae-se is formed of mud-covered tiers with a steplike appearance and that the amadai are found on the bottommost step. The irregular surfaces on the slopes of Mae-se and Aino-se, the two banks that comprise Senoumi Bank, are good habitats for several species of netsuki-uo (groundfish). Depending on the flow of the current, however, the fish schools may shift around even though they continue to inhabit these irregular slope bottoms. Our isobath contour charts of

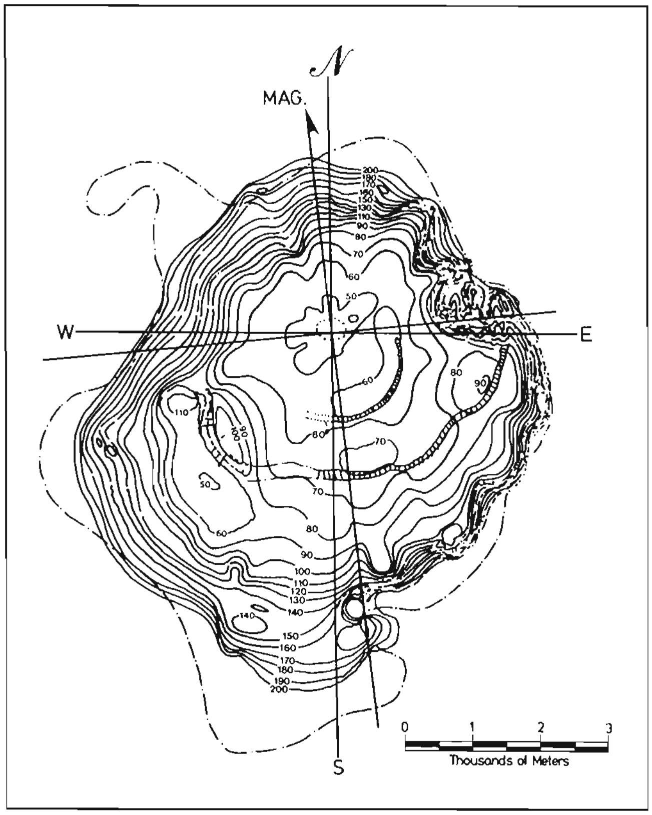


Figure 1.—Submarine topography (estimated isobaths) of Mae-se, Senoumi Bank, in Suruga Bay (for depths <200 m).

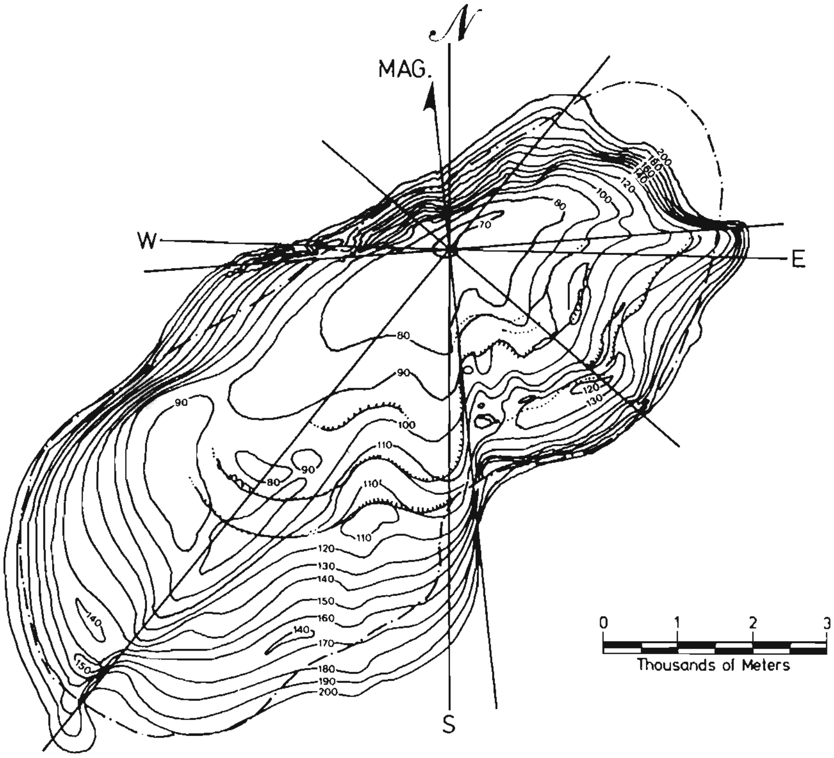


Figure 2.—Submarine topography (estimated isobaths) of Aino-se, Senoumi Bank, in Suruga Bay (for depths <200 m).

Senoumi Bank were distributed to the fishermen. With the chart and with supplementary information provided by us, the fishermen were able to catch about 30 amadai per day per vessel.

Survey of seamounts and banks in the vicinity of Izu Islands

Takase and Hyotan-no-se (Fig. 3) are part of a chain of seamounts and banks which run parallel and to the northwest of the Izu Islands (Toshima, Udonejima, Niijima, Shikinejima, Kozushima, and Zenisu). As compared to the Mae-se and Aino-se Banks that make up Senoumi Bank, the bottom topography of Takase and Hyotan-no-se Banks was considerably more complex. The latter banks are also thought to be volcanic.

Takase Bank is in the shape of a mountain. Similar to the two banks at Senoumi, there is a clear trace of a large landslide on its western side. The northwestern half of the crater near the shallowest part of Takase Bank seems to have crumbled. A good fishing ground has developed in this area. The second shallowest place is located farther to the northeast where fish tend to congregate to form a good fishing ground.

Hyotan-no-se Bank is composed of two flat-topped mountains aligned north to south, but the tip of the northern island is not as flat as hitherto believed. On its western side, there is an inclined portion and a V-shaped valley reaches a depth of 150 m. Local fishermen claim that fishing on Hyotan-no-se Bank is very good when the prevailing current moves south-north, but poor when the current shifts to east-west.

Management of seamount resources to achieve long-term stability

The fishery resources of seamounts and banks (excluding pelagic species in surface layers) typically have slow growth rates and are thus vulnerable to depletion from overfishing. The fishing grounds can thus be ruined within a very short time. As seen in Figure 4, there are numerous islands, seamounts, and banks situated over the Izu Rise; knowledge of this area, however, is still inadequate. The area near Izu Rise is regarded as an excellent fishing ground, and vessels from Chiba, Kanagawa, and Shizuoka Prefectures also fish here. More recently, purse seiners from various Tohoku prefectures have been fishing this area. As a result, a conflict has been brewing among these "outside" vessels and the local vessels of the Izu Islands.

The resources in the Izu fishing grounds may rapidly become exhausted from excessive fishing unless preventive measures are taken now. Before anything serious happens to this fishing ground, the research agencies of the various prefectures now fishing this area should cooperatively survey the submarine topography of the Izu Rise and carry out a long-term study of the fishery resources. Following a detailed study of the topography and resources of as many of the seamounts and banks as possible, the Izu Rise area should then be subdivided into several blocks from north to south.

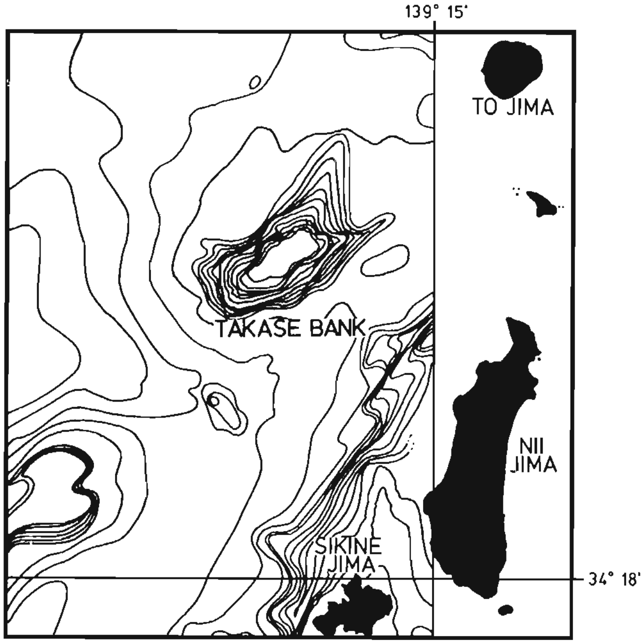


Figure 3.—The submarine topography of the waters in the vicinity of Takase Bank.

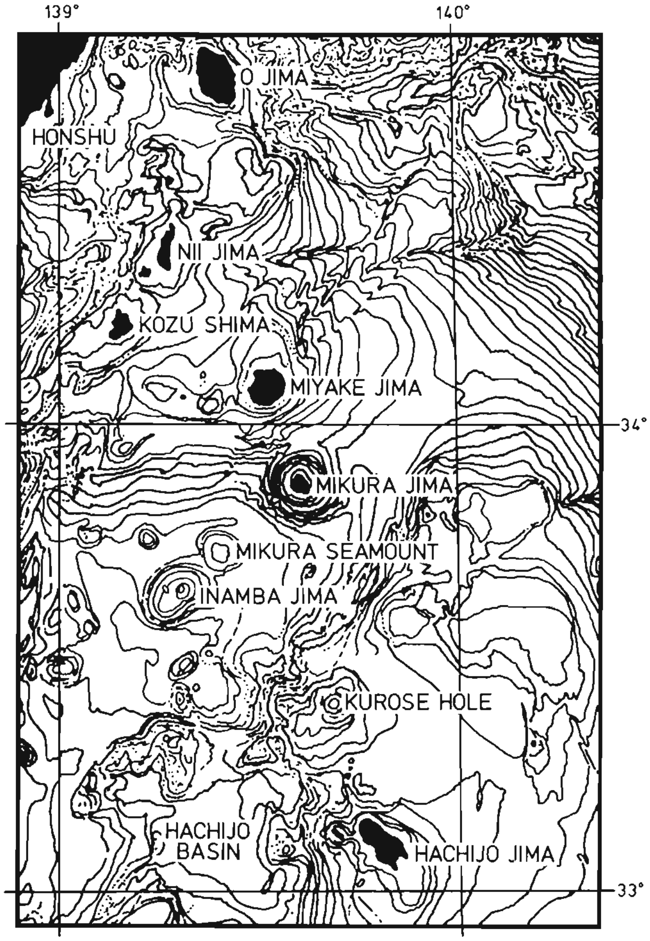


Figure 4.—The submarine topography of the Izu Rise.

One block may then be selected for harvesting for a set period of the time (e.g., 3 years) after which it would be closed to fishing for another set period (e.g., 3 years) as another block is opened. In this way, the blocks are opened for fishing on a rotational basis, similar to the ''rotation deforestation method.'' By adopting such a system, it may then be possible to operate a seamount fishery on a stable, long-term basis.

The execution of the above plan may also serve as a ''model'' for international cooperation in the management of the fishery resources of the Emperor Seamounts in the North Pacific Ocean. The international cooperation in the study of the Emperor Seamounts by Japan, the United States, Canada, etc., and the implementation of the ''rotational harvesting system'' described above, may even result in the recovery of those resources that have already been reduced to very low levels.

Zoogeographical Features of Fishes in the Vicinity of Seamounts

EIICHI FUJII
Tokai Regional Fisheries Research Laboratory
Tokyo, 104 Japan

INTRODUCTION

During the latter half of the 1960's, large resources of kusakari tsubodai, *Pseudopentaceros wheeleri*,[1] and kinmedai, *Beryx splendens*, were discovered on several seamounts in the southern portion of the Emperor Seamounts and the northwestern portion of the Hawaiian Ridge. Because of these discoveries, the various seamounts were suddenly regarded as potentially important fishing grounds for bottom fishes.

A wide variety of Japanese research vessels from governmental agencies and universities have studied the fish faunas of seamounts, typically using bottom hook-and-line gear, bottom trawls, and midwater trawls. Seamounts studied have included nine in the eastern Pacific between lat. 10° and 35°N, seamounts of the Kyushu-Palau Ridge, central North Pacific seamounts, and 11 areas in the central South Pacific. From these studies, a number of generalities have been developed. From a biogeographical standpoint, the seamounts appear to serve the function as a ''stepping stone'' in the distribution of inshore as well as of bottom-dwelling fishes. The occurrence of some endemic or undescribed species (observed only among bottom fishes) at several of the seamounts may be an indication that the fish communities on these seamounts are to a degree isolated (Fujii and Uyeno 1979; Katayama and Fujii 1982).

The composition of the fish fauna at each seamount appeared to be highly dependent on water depth from the sea surface to the seamount summit and on the oxygen content of the water at the summit. Species diversity was higher on seamounts with a large, flat surface area at the top (tablemount) as compared to seamounts with a small surface area; species diversity on tablemounts was typically similar to that on adjacent continental slope regions. For example, kusakari tsubodai is clearly dominant on the Kammu Seamount, the Southeast Hancock Seamount, and the Northwest Hancock Seamount (Japan Fisheries Agency 1974); *Caprodon longimanus* and *Allomycterus pilatus* on Wanganella Bank (Norfolk Ridge) (Japan Fisheries Agency 1976, 1977); and *Ariomma lurida* and *Emmelichthys struhsakeri* on the Kyushu-Palau Ridge (Fujii and Nakamura 1980). These species accounted for more than 80% of the total catches, in weight and in numbers, on these respective seamounts.

Results of our studies of several seamount groups suggest that the surface area of the seamount top, the depth of the seamount, and the distance between the continental slope and the seamount must all be considered in further biogeographical studies.

Our research on seamounts suggests that the distributional patterns of bottom fishes, when analyzed in relation to the bottom topography, can be separated into the following five types:

(Type I) Continental shelf. These species occur only on the continental shelf and continental slope areas.

(Type II) Continental shelf-seamount-insular shelf. These species are distributed on the continental shelf, continental slope, seamounts, insular shelf, and insular slope areas.

(Type IIIa) Seamount. These species occur only in the vicinity of seamounts.

(Type IIIb) Insular shelf. These species occur only in the insular shelf and insular slope areas.

---

[1] Hardy (1983) proposed two new names, *Pseudopentaceros wheeleri* and *Pseudopentaceros pectoralis*, for the North Pacific form which had been identified as *Pentaceros richardsoni* by many authors. In the present paper, both are treated as a single species by tentatively using the name *Pseudopentaceros wheeleri*, which is probably distinct from *Pseudopentaceros richardsoni* distributed in the Southern Hemisphere.

(Type IIIc) Seamount-insular shelf. These species are distributed on seamounts as well as insular shelf and insular slope areas and occasionally are found also in submarine canyons.

Following the above classification, the seamount fish fauna would have derived from the inshore-offshore type (II) and the offshore type (IIIa and IIIc) (Table 1).

In light of the objectives of this workshop to address the resources of seamounts, it is relevant to discuss the distribution and biogeography of the tsubodai, *Pentaceros japonicus*, and the kusakari tsubodai. Considerable differences are apparent in their life history patterns and in their patterns of distribution relative to seamounts. The juveniles of tsubodai are distributed in surface waters off southern Japan at lat. 25°-34°N, long. 130°-140°E. The young bottom fish as well as most of the adults are distributed in waters extending from the inshore waters of Japan to the East China Sea continental slope area (Fig. 1). According to Zama et al. (1977a), tsubodai enter the bottom-dwelling phase at a standard length (SL) between 76.6 and 94.0 mm. On the other hand, a 136.5 mm SL pelagic young specimen has been recorded from the vicinity of Shiriya (lat. 41°30′N, long. 142°00′E), and bottom-dwelling young (individuals near 100 mm SL with cloudlike patches on body) were observed from the Kimmei Seamount (lat. 35°27.6′N, long. 171°49.6′E) (Zama et al. 1977a; Hardy 1983).

The juveniles of kusakari tsubodai are distributed in surface waters extending from the southern portion of the Emperor Seamounts and the northwestern portion of the Hawaiian Ridge to the Aleutian Islands. The pelagic young occur in the offshore waters of the southwestern Gulf of Alaska, whereas the adults occur mainly on the seamounts of the central North Pacific Ocean (Fig. 2). Adults have also been recorded on the insular slopes in Japanese coastal waters, near submarine canyons and seamounts (Zama et al. 1977b; Okamura et al. 1982) and waters off Oregon. Borets (1979) reported that individuals of kusakari tsubodai have a pelagic existence until they are 7 years old (270-284 mm) and then settle down to a bottom-dwelling life. Spawning takes place in the central North Pacific seamount region. No spawning fish have been reported from Japanese coastal waters or from waters off Oregon (Borets 1979, 1980).

Tsubodai belongs to the inshore-offshore type of distribution (Type II) whereas kusakari tsubodai is of the offshore type (IIIc). Furthermore, the entire life histories of both species, with the

Table 1.—Principal bottom fishes on the Pacific seamounts and distributional patterns.

Species	Family	Japanese common name	Distributional pattern[1]	Distribution area[2]
Diaphus knappi	Myctophidae	Namida-hadaka	III-c	KPR, SSC, Madagascar, Zanzibar
Idiolychnus urolampus	Myctophid	Ojiro-hadaka	III-c	KPR, ESC, HI, Madagascar
Coelorinchus longicephalus	Macrouridae	Zunaga-sokodara	III-a	KPR
Coryphaenoides acrolepis	Macrouridae	Ibarahige	II	North Pacific, ESC
Nezumia propinquus	Macrouridae	Kiheri-nezumidara	I-c	KPR, HI
Lophiodes miacanthus	Lophiidae	Shimofuri-hana-anko	III-c	KPR, ESC, HI
Beryx splendens	Berycidae	Kinmedai	III-c	Pacific, Atlantic
Polymixia berndti	Polymixiidae	Arame-ginme	II	S. Japan, KPR, HI
Zenopsis nebulosus	Zeidae	Kagamidai	II	Pacific Ocean
Helicolenus avius	Scorpaenidae		III-a	ESC
Pontinus tentacularis	Scorpaenidae	Hiodoshi	III-c	South Pacific, Indian Ocean
Caprodon longimanus	Serranidae		III-c	New South Wales, NR, New Zealand
C. unicolor	Serranidae	Okiaka-isaki	III-a	HR
Lepidoperca magna	Serranidae	Okiaka-isaki	III-c	DHG, GS, NR, KR
Grammatonotus laysans	Serranidae		III-c	ESC, HI
G. macrophthalmus	Serranidae		III-c	ESC, HI
G. macrophthalmus	Serranidae	Oome-hanadai	III-a	KPR
Priacanthus boops	Priacanthidae	Chikame-kintoki	II	Pacific, Indian, Atlantic Oceans
Epigonus atherinoides	Apogonidae	Hirayase-mutsu	III-c	KPR, ESC, HR, HI
Emmelichthys struhsakeri	Emmelichthyidae	Rosoku-chibiki	III-c	S. Japan, KPR, HI, HR, E. Australia
Pentaceros japonicus	Pentacerotidae	Tsubodai	II	S. Japan, KPR, ESC
Pseudopentaceros wheeleri	Pentacerotidae	Kusakari-tsubodai	III-c	S. Japan, KPR, ESC, HR, HI, N. Pacific
Parapercis roseoviridis	Mugiloididae	Akaeri-toragisu	III-c	KPR, HI
Promethichthys prometheus	Gempylidae	Kuroshibi-kamasu	II	Pacific, Indian, Atlantic Oceans
Ariomma lurida	Ariommidae	Oome-medai	III-c	S. Japan, KPR, ESC, HR, HI, S. Pacific Ocean
Centrodraco otohime	Draconettidae	Otohime-numeri	III-A	KPR
Parabothus coarctatus	Bothidae	Sumire garei	III-c	S. Japan, KPR, ESC, HI
Polyplacapros tayleri	Ostraciidae		III-a	NR

[1] The distributional pattern is explained in text.

[2] DHG, Derwent Hunter Guyot; ESC = Emperor Seamount Chain; GS = Gifford Seamount; KPR = Kyushu Palu Ridge; KR = Kermadec Ridge, HI = Hawaiian Islands; HR = Hawaiian Ridge; NR = Norfolk Ridge; SSC = Savannah Seamount Chain.

exception of those bottom-dwelling young and adults that occur in places outside of the main distributional areas, are clearly separated. There is a very good possibility that tsubodai in the seamount region are migrants from coastal areas. Thus, similar to kusakari tsubodai that occur outside of the main distributional area, these fish too may not be spawning fish.

CITATIONS

BORETS, L. A.

1979. The population structure of the boarfish, *Pentaceros richardsoni*, from the Emperor Seamounts and the Hawaiian Ridge. J. Ichthyol. 19(3):15-20.

1980. The distribution and structure of the range of the boarfish, *Pentaceros richardsoni*. J. Ichthyol. 20(3):141-143.

FUJII, E., and I. NAKAMURA.

1980. Report of the intensive survey of the unexploited resources on the continental slope, FY 1979. [In Jpn.] (The 2d through 6th cruises of the *No. 2 Gyoyo Maru* in the Kyushu-Palau Ridge area.) Fish. Lab. Kyoto Univ. Faculty Agric., 83 p.

FUJII, E., and T. UYENO.

1979. *Polyplacapros tyleri*, a new genus and species of ostraciid trunkfish from off eastern Australia and Norfolk Ridge. J. Ichthyol. 26(1):1-10.

HARDY, G. D.

1983. A revision of the fishes of the Family Pentacerotidae (Perciformes). N.Z. J. Zool. 10:177-220.

[JAPAN.] FISHERIES AGENCY.

1974. Report of the survey by the research vessel *Kaiyo Maru*, FY 1972. [In Jpn.] North Pacific Seamount Survey, 136 p. (Engl. transl. of selected portions by T. Otsu, 1981, 55 p., Transl. No. 54; available Southwest Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396.)

1976. Report of the survey by the research vessel *Kaiyo Maru*, FY 1975. [In Jpn.] Survey of Australian waters as well as of the Norfolk Ridge. Jpn. Fish. Agency, 239 p.

1977. Report of the survey by the research vessel *Kaiyo Maru*, FY 1976. [In Jpn.] Survey of the central South Pacific seamounts. Jpn. Fish. Agency, 259 p.

KATAYAMA, M., and E. FUJII.

1982. Two new species of the anthiine Genus *Lepidoperca* from Australia and New Zealand. Jpn. J. Ichthyol. 29(3):241-252.

OKAMURA, I., K. AMAOKA, and F. MITANI (editors).

1982. Fishes of the Kyushu-Palau Ridge and Tosa Bay. Jpn. Fish. Res. Conserv. Assoc., Tokyo, 435 p.

ZAMA, A., M. ASAI, and F. YASUDA.

1977a. Changes with growth in bony cranial projections and color patterns in the Japanese boarfish, *Pentaceros japonicus*. Jpn. J. Ichthyol. 24(1):26-34.

1977b. Records of the pelagic armorhead patterns *Pentaceros japonicus*, from Hachijo Island and the Ogasawara Islands. Jpn. J. Ichthyol. 24(1):57-60.

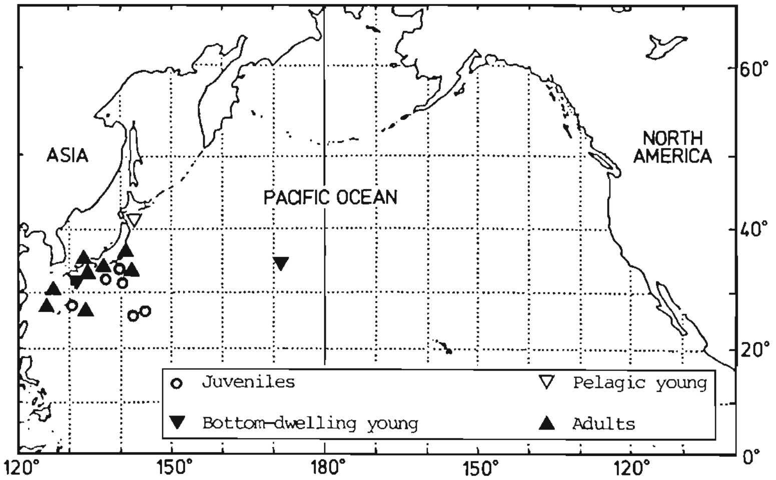


Figure 1.—The distribution of tsubodai, *Pentaceros japonicus*.

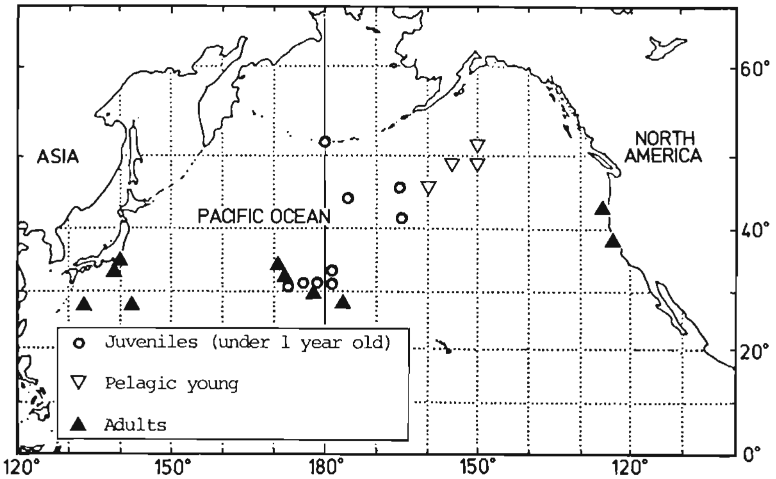


Figure 2.—The distribution of kusakari-tsubodai, *Pseudopentaceros wheeleri*.

Session 4. Summary

RICHARD N. UCHIDA and SIGEITI HAYASI

Three papers were presented in this session. The first, by Humphreys on pelagic armorhead, reviewed geographic and depth distributions, diurnal migration, food and feeding habits, and spawning, and discussed existing controversy surrounding age and growth, morphological variation, and systematics. The paper also provided a life history to account for the existence of different body types and reproductive conditions.

The second paper by Koami discussed the necessity of obtaining detailed topographic information on submerged banks and seamounts for efficient and long-term utilization of the marine resources associated with them. Detailed topographic information provides clues to finding productive fishing grounds for particular species. To prevent overfishing and eventual collapse of a fishery, Koami advocated establishment of a rotational system much like that used to reforest deforested areas. On a local scale, prefectural governments should cooperate to establish a system whereby species are harvested on a rotational system. The system, according to Koami, can also be applied to fishery resources of the North Pacific, but agreement will have to be reached amongst all nations harvesting the resource.

The third paper was presented by Fujii, who examined species composition of fish fauna over seamounts, seamount chain, ridges, banks, tablemounts, and continental slope. Classifying the fish fauna as "shelf," "oceanic," and "deep-sea," Fujii reported that seamount-associated fish fauna is influenced by characteristics of the surrounding water mass. For example, tropical and temperate water species are not mixed except at watermass boundaries, and a seamount with an overlying layer of low-oxygenated water has a fish fauna low in species diversity as well as biomass.

The ichthyofauna of seamounts is not as limited as believed. Fujii said that seamount shape influences community composition and density. Seamounts with narrow summits have fish communities of low species diversity and density compared to those found over continental slopes. The number of species, however, increases with the area of the summit. Tablemounts, for example, have communities with species diversity about equal to, and density higher, than those found over some continental shelves.

Because endemism is found only among bottom dwellers, Fujii pointed out that many endemic species are known from various seamounts, thus indicating isolation; therefore, seamounts may have important roles in speciation of fishes. He discussed speciation in the Pentacerotidae in some detail.

The discussion during the session brought out that studies on seabird diet and feeding behavior show no seamount-associated species among the prey items. A question was raised on the pelagic armorhead's life history, whether "fat" fish, which eventually mature and change morphologically to "lean" fish, will recover sufficiently to become "fat" once again. Humphreys replied that no concrete evidence of this type of change is available; however, in his opinion, "lean" fish will probably never recover and perish after spawning.

On distribution, it was brought out that pelagic armorhead exhibit an antitropical distribution; therefore, they are not likely to occur in tropical waters. In the Southern Hemisphere, the species of pelagic armorhead that occurs nearest to tropical waters in the Pacific are found near Australia at about lat. 30°S, and in the South Atlantic, the Soviets recorded pelagic armorhead from the southwest coast of Africa near lat. 20°S.

Problems in Assessing the Pelagic Armorhead Stock on the Central North Pacific Seamounts

JERRY A. WETHERALL
MARIAN Y. Y. YONG
Southwest Fisheries Center Honolulu Laboratory
National Marine Fisheries Service, NOAA
Honolulu, Hawaii 96822-2396

ABSTRACT

In this paper we examine catch and effort statistics from Japanese stern trawlers harvesting pelagic armorhead, *Pseudopentaceros wheeleri*, on the central North Pacific seamounts, and consider problems in using them to assess the armorhead stock. We begin by reviewing trends in the fishery. Next, we adopt a set of tentative assumptions about armorhead life history and population biology, and describe a nonlinear autoregressive model of armorhead stock changes based on the catch and effort data.

Trial applications of the model are then discussed. These were hampered by the unavailability of crucial data on Soviet armorhead catches, by technical difficulties in parameter estimation arising from statistical properties of the model, and by model misspecification. Despite these setbacks in applying the model, a cursory visual analysis of the Japanese trawl fishery statistics was ventured. This suggested that high variability in recruitment was probably the chief cause of fluctuations in fishing success through the mid-1970's. Further, it indicated that the collapse of the Japanese fishery in 1978 and subsequent years could not easily be ascribed to excessive trawling effort by Japanese vessels. Although the steady decline in armorhead catch per unit of effort (CPUE) reported by Japanese trawlers after 1972 was inversely correlated with their trawling effort, the behavior of the fishery in earlier years suggested that stock-independent factors may have played a more prominent role in armorhead recruitment.

Soviet catch summaries just recently made available (after the analysis of Japanese data was completed, and this manuscript first drafted) support some conclusions based on Japanese data alone. In particular, they indicate that recruitment fluctuations were largely independent of stock size during the early 1970's. However, they also show that Soviet catches were roughly five times larger than Japanese harvests during this period, suggesting that in later years, for which Soviet data are still unavailable, excessive fishing effort may indeed have played a role in the stock decline. Without a more complete and detailed Soviet record, especially during the period of stock collapse, the effects of exploitation cannot be estimated reliably.

Regardless of the causative factor, the present armorhead spawning stock is apparently at a very low level, and average recruitment may now be stock-limited. Therefore a sharp reduction in fishing mortality may be worth considering as a means to accelerate the stock's recovery.

TRENDS IN THE ARMORHEAD FISHERY

The history of armorhead fishing on the seamounts of the Emperor-Hawaiian Ridge was summarized by Takahashi and Sasaki (1977). According to their account, the resource was discovered by the Soviets in late 1967, and harvested by Russian trawlers for at least a few years. Sakiura (1972) reported that the Russian fleet took 133,400 metric tons (MT) in 1969 alone.

Unfortunately, when our analysis was done, and this paper initially drafted, there was no available record of the extent of Soviet fishing on the seamounts after 1969. However, Soviet research vessels were known to have visited the seamounts in 1976 and Japanese vessels had reported sighting Soviet trawlers operating on the seamounts. Very recently a report by the Soviet scientist Borets has become available which shows that the Soviet trawlers actually made very large catches of armorhead on the seamounts during the mid-1970's (see Boehlert 1986). Between 1968 and 1975, they caught roughly 730,000 MT, about five times the Japanese catch during the same period.

Japanese stern trawling began in August 1969 on the Kimmei Seamounts and the following month on Milwaukee Seamounts, and by the end of 1970 had spread to more southerly seamounts, including Colahan, C-H, and Hancock.[1] Nominal effort, measured in hours of trawling, has fluctuated greatly, particularly on Kimmei and Milwaukee, which have received the heaviest fishing pressure (Table 1; Fig. 1).

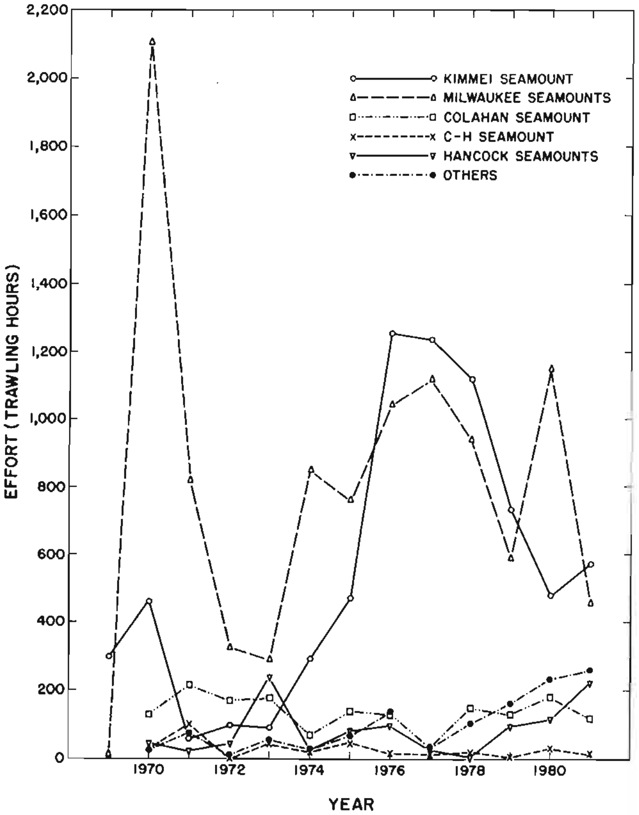


Figure 1.—Annual effort of Japanese trawlers on central North Pacific seamounts (by calendar year).

---

[1] Statistics on the Japanese trawl fishery were kindly provided by Takashi Sasaki of the Far Seas Fisheries Research Laboratory, Shimizu.

Likewise, the Japanese armorhead catch has been extremely variable, with about a 10-fold range on most seamounts during the early and mid-1970's (Table 1; Fig. 2). The peak aggregate catches of armorhead by Japanese trawlers were 34,825 MT in calendar year 1972 and 28,356 MT in 1973. (By comparison, the recent summary of Soviet catch statistics shows that Soviet vessels took about 98,000 MT in 1972 and 170,000 MT in 1973.) Despite relatively steady or increasing nominal effort, the Japanese armorhead catch on all seamounts declined sharply after 1976.

The catch per unit of effort (CPUE, in metric tons per hour of trawling) for Japanese vessels decreased on all seamounts during 1969-71, then increased everywhere in 1972, in some cases by a factor of 10 or 20. Beginning in 1973 or 1974 the general trend of CPUE turned downward, and catch rates for armorhead have been severely depressed at all seamounts since 1978 (Fig. 3). This is particularly so at Milwaukee and Kimmei. However, we note that since 1978 the dominant species in the trawl catches has been the alfonsin, *Beryx splendens*, previously only a minor constituent. The CPUE for this species has greatly increased during this period, suggesting either an upsurge in abundance of alfonsin or a switching of target species. If the latter is true, then the Japanese armorhead CPUE's during recent years may exaggerate the decline in the armorhead stock.

Although the Soviet statistics were not included in the modeling and analysis reported here, it is instructive to compare them with the Japanese data *post facto*, particularly to see if CPUE data show the same trends. If we look at annual statistics, the only discrepancy between the Japanese and Soviet CPUE trends is during the period 1969-71, when it appears the fishing power of Japanese trawlers was relatively low compared with later years, or Soviet fishing power relatively high. Both sets of statistics indicate an overall decline in armorhead abundance or availability from 1969 to 1971, a substantial increase in 1972, and a steady decline through 1975 (see data in Boehlert 1986).

Length-frequency statistics from the Japanese trawl catches show that the fishery harvests only a narrow size range of armorhead, generally from about 25 to 35 cm fork length (FL). Individuals of this size are thought to be 2 to 3 years old and sexually mature (see below). Apparently the fishable stock consists almost entirely of recruits, there being few survivors from earlier year classes. The length distributions are remarkably similar on the various seamounts, and vary little from year to year. However, two noticeable changes in the length distributions have occurred. In 1972, when CPUE rose dramatically on all seamounts, the length distribution shifted downwards by about 2 cm. This was especially clear at Milwaukee and Colahan, where the largest samples of armorhead were measured (length-frequency distributions for Milwaukee are given in Fig. 4). More typical distributions were seen the following several years. Then beginning in 1978, when CPUE dropped sharply, the distributions shifted upwards on most seamounts, and broadened. If one assumes no alteration in maturation schedules, the length-frequency shifts could be taken as evidence of density-dependent growth in the pre-recruit stage. Alternatively, if growth rates have been constant, the inverse relationship between mean length of the recruits

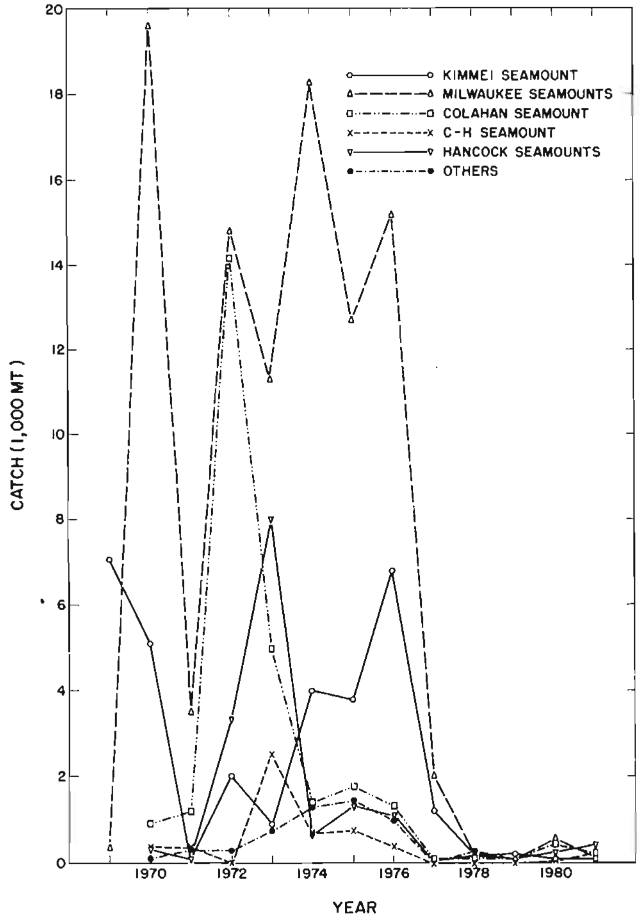


Figure 2.—Annual pelagic armorhead catch by Japanese trawlers on central North Pacific seamounts (by calendar year).

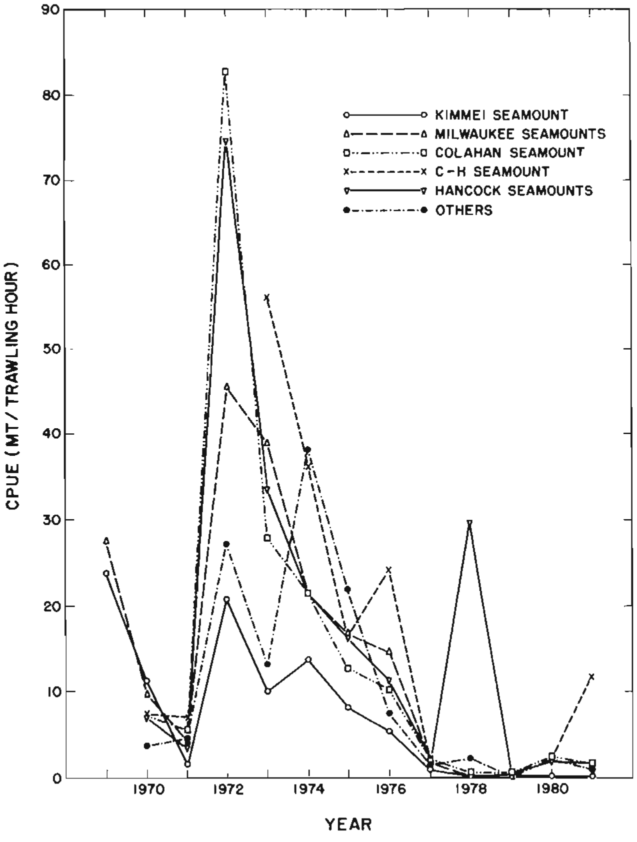


Figure 3.—Annual pelagic armorhead catch per unit of effort (CPUE) for Japanese trawlers on central North Pacific seamounts (by calendar year).

and CPUE may reflect differences in rate of maturation. The latter explanation seems less likely. However, without information on the age composition of the armorhead catches no reliable interpretations can be made.

The annual variability in armorhead CPUE is illustrated by Figure 5, in which yearly CPUE values are expressed as a proportion of the 1981 CPUE at each seamount. Peak CPUE values were in some cases two orders of magnitude greater than in the 1981 index period. Such high variability in abundance is frequently observed in stocks of pelagic fishes, and is usually ascribed to fluctuations in oceanographic processes important to survival of pelagic eggs and larvae. Thus one contending explanation for the apparent rise and fall of the armorhead stock is dramatic environment-driven fluctuation in year-class strength.

Another reasonable hypothesis is that trawling effort by Japanese and Soviet vessels during the 1970's reduced the armorhead spawning stock to such low levels that recruitment has been undermined. If this alternative is true, or if fishery-independent factors have driven spawning biomass down to such critical levels, then a restoration of catch and CPUE to higher levels might require a temporary relaxation of fishing effort.

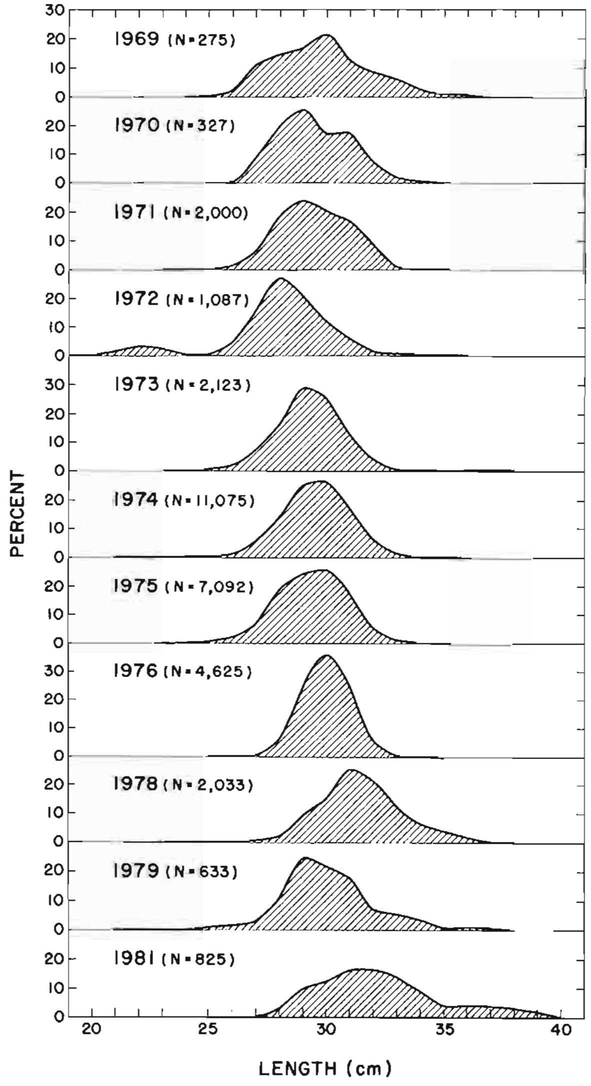


Figure 4.—Percentage frequency distributions of fork length for samples of pelagic armorhead taken by Japanese trawlers on Milwaukee Seamounts.

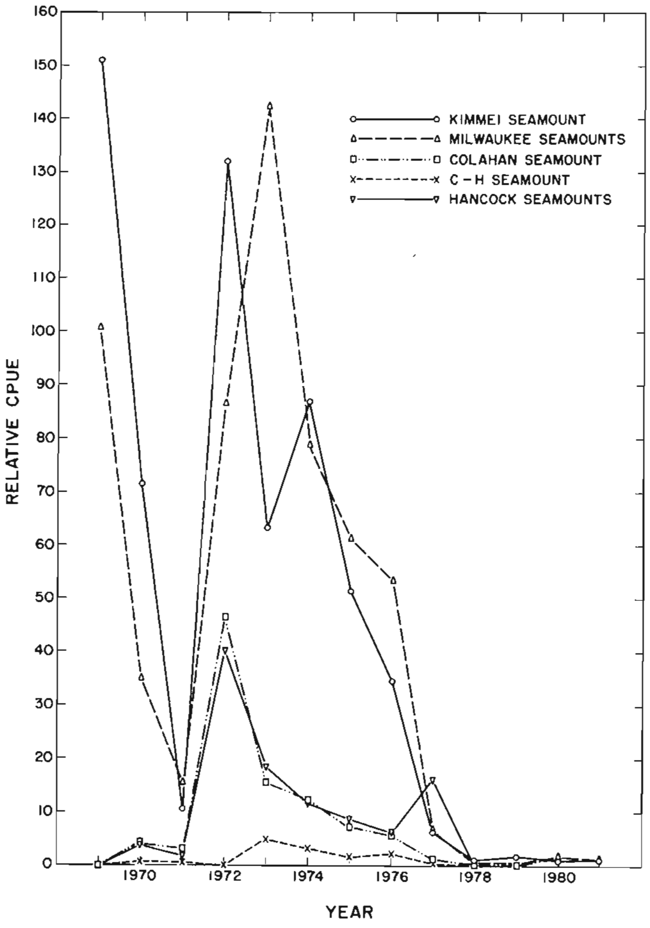


Figure 5.—Annual pelagic armorhead catch per unit of effort (CPUE) for Japanese trawlers on central North Pacific seamounts relative to CPUE in 1981 index period.

ANALYSIS OF STOCK DYNAMICS

To assess the condition of the armorhead stock and evaluate competing hypotheses relating to the impacts of fishing and environmental factors it is useful, if not essential, to construct a quantitative model of the stock dynamics. Using just the Japanese catch and effort statistics, we attempted to construct a model which would account for the observed behavior of the pelagic armorhead fishery and be reasonably consistent with available information and current thinking regarding armorhead life history. In doing so we recognized that our results might be seriously compromised by the absence of data on Soviet catches, and that our sketchy knowledge of armorhead biology would necessitate numerous assumptions.

Biological assumptions

As a basis for the modeling, we made the following assumptions concerning armorhead biology and life history:

1) The armorhead found on the seamounts are derived from a pool of pelagic larvae generated by a common parental spawning biomass. Offspring produced on individual seamounts are distributed widely in the North Pacific and mix thoroughly during their prerecruit stages.

2) Upon reaching sexual maturity at about 2 years of age, armorhead abandon the epipelagic zone inhabited by the juveniles and are recruited to spawning stocks occupying the tops of the seamounts. At the sizes found on the seamounts armorhead are known to be mature, and recent studies at the Honolulu Laboratory on sagittae, vertebral centra, spines, and other hard parts indicate that armorhead 26-32 cm FL are predominantly 2 years of age (J. H. Uchiyama, Southwest Fish. Center Honolulu Lab., unpubl. data). These estimates of age contradict earlier findings by Chikuni (1970), based on scales from two preserved specimens, which assign ages of 3 years to 22 cm fish and 6 years to 32 cm armorhead. Vasil'kov and Borets (1978) also estimated the ages of armorhead. Using a spectral analysis of scale thickness, they suggested that armorhead of 28-33 cm may be as old as 11 years.

3) Over a wide range in abundance of the armorhead spawning stock, the average recruitment is constant. Only at very low spawning stock levels is the average number of recruits stock-dependent. This set of assumptions is consistent with observations on the spawner-recruit relationships in other fishes with pelagic eggs and larvae, such as tunas.

4) The catchability coefficient (the instantaneous fishing mortality inflicted by a unit of trawling effort) may depend on the abundance of armorhead on the seamount. One possibility, for example, is that at low stock densities the catchability coefficient increases. This would be particularly likely if trawlers seek out and target individual schools of armorhead and if reduced armorhead stocks consist of fewer schools.

5) The seamounts are the only spawning ground of the armorhead, so that the CPUE of the trawlers, as some function of the exploitable biomass, provides a measure of the spawning stock.

6) The natural mortality rate of armorhead in the seamount spawning stocks is constant.

7) The temporal changes in armorhead biomass on the Milwaukee Seamounts are representative of trends in the spawning stock as a whole. This assumption seems reasonable enough, although the overall variation in CPUE at Milwaukee is somewhat greater than that at Colahan and Hancock.

8) The fraction of the total annual recruitment which settles out on Milwaukee is constant. Again, this seems generally consistent with the observed patterns of CPUE on the several seamounts.

Autoregressive stock model

With these assumptions, the temporal dynamics of the armorhead spawning stock residing on the seamounts and exploited by the fishery may be approximated by the following simple equation:

$$\underbrace{B_i}_{\substack{\text{Average}\\\text{spawning}\\\text{biomass in}\\\text{period } i}} = \underbrace{W_i}_{\substack{\text{Average}\\\text{weight of}\\\text{mature}\\\text{armorhead}\\\text{in period } i}} \{\underbrace{N_{i-1}\,S_{i-1,i}}_{\substack{\text{Average}\\\text{residual}\\\text{spawning}\\\text{stock from}\\\text{period } i\text{-1}}} + \underbrace{R_i\,S_i}_{\substack{\text{Average no.}\\\text{of recruits}\\\text{available in}\\\text{period } i}}\} + \underbrace{\lambda_i}_{\substack{\text{Random}\\\text{error}\\\text{term}}}$$

The average armorhead biomass in the i-th time period is assumed equal to the average biomass of fish surviving from the previous period, plus the average biomass of those newly recruited during the period, plus a random error term. The explicit dependence of spawning biomass in one period on the same random variable one period prior classifies this model as "autoregressive." Since the average abundance of armorhead during each interval is approximated by the abundance at the midpoint, the survival rate $S_{i-1,i}$ is considered to be a function of the natural mortality rate and trawling effort in periods i-1 and i, whereas S_i depends only on natural mortality and effort in period i. The total number of fish recruited in period i, R_i, is assumed to depend on the average armorhead spawning biomass δ time periods earlier. In particular, we assumed the following functions for the survival rates and recruitment:

$$S_{i-1,i} = e^{-\{M + [H(N_{i-1})\,E_{i-1} + H(N_i)\,E_i]/2\}}$$

$$S_i = e^{-\{M + H(N_i)\,E_i\}/2}$$

and $$R_i = \alpha \left\{1 - e^{-\beta N_{i-\delta}\, W_{i-\delta}}\right\} \varepsilon_i$$

Here α is the average recruitment expected at the highest levels of spawning biomass, and β determines the rate at which average recruitment declines as spawning stock is reduced. The term ε_i is a lognormal random "disturbance" representing the unexplained variability in recruitment.

In the survival functions, the natural mortality coefficient is denoted by M, and the nominal trawling effort in period i by E_i. The catchability coefficient in period i, $H(N_i)$ is written as a function of average stock size during the period, N_i. In particular, we considered the power function

$$H(N_i) = Q\,N_i^{\gamma}$$

now commonly used in models of schooling fish harvested contagiously. In many such cases it has been found that $\gamma < 0$, i.e., catchability is inversely related to average stock size. When $\gamma = 0$, catchability is constant.

The average individual weights in each year, W_i, were estimated from Japanese length-frequency statistics and a length-weight relationship computed from NMFS data. The resulting series of average weights was then smoothed before use in the model.

The random error term ε_i is assumed to have a mean of 1, but a variance which may depend on i and/or the spawning biomass in period i. Further, the ε_i are probably serially correlated. The distributions of the ε_i may also reflect oceanographic processes affecting the survival of armorhead eggs and larvae or the settlement of mature armorhead onto the seamounts. The sequence of error terms λ_i is assumed to have zero mean and a dispersion matrix which depends on a host of factors, including stochastic variation in recruitment, autocorrelation in the series of spawning biomass estimates, and random variation in the mortality processes.

To estimate parameters of the armorhead stock model we made the usual assumption that stock density was measured by some function of CPUE. In our case the appropriate function is

$$N_i = \left\{\frac{\text{CPUE}_i}{W_i\,Q}\right\}^{\frac{1}{\gamma+1}}$$

The complete nonlinear regression model is given in the Appendix.

Estimation procedures

Since there were five parameters to estimate (α, β, γ, Q, M), a long time series of observations was required. Neither annual nor semiannual data would provide sufficient degrees of freedom. Therefore the model was fit to monthly CPUE and effort data. A problem arose here because monthly CPUE time series were not complete, yet lagged spawning biomass estimates were needed for each time period. Instead of circumventing the problem by aggregating the monthly data we developed an iterative EM algorithm (see Dempster et al. 1977) which simultaneously predicted the values of missing observations and computed weighted least squares estimates of the model parameters.

Visual analysis of the Milwaukee Seamounts time series

Because the only suitably complete monthly CPUE time series was for Milwaukee Seamounts, we used those data exclusively for the trial fitting. Restriction of the analysis to Milwaukee Seamounts necessitated assumptions 7 and 8 above. Before attempting to fit the regression model with the EM algorithm, we inspected the monthly time series of CPUE and nominal trawling effort at Milwaukee and the annual CPUE series at all seamounts to see if the model was compatible with the data, to extract initial estimates for the model parameters and to see if we could anticipate any problems in the fitting. A byproduct of this cursory inspection was a preliminary evaluation of the impact of Japanese trawling on the armorhead stock.

The monthly CPUE for Milwaukee is shown in Figure 6, beginning in September 1969 and continuing for 146 months through October 1981. Neglecting the first 4 months, when only 12 h of trawling were done by Japanese vessels, we considered the series beginning in January 1970. In general the monthly data show a considerable amount of variation, but reliability of the CPUE statistics, measured by the corresponding trawling effort, also varies greatly. If the model is correct, declines in average CPUE from month to month are due to an excess of mortality over recruitment, and increases in CPUE reflect the reverse. Without actually fitting the model, it can be seen that the monthly time series of CPUE and Japanese effort (and their annual and semiannual counterparts; see Figs. 1, 3, and 7) are consistent with the proposed model from 1974 through 1981. That is, the general downward trend of CPUE during this period could have resulted from a recruitment which was directly dependent on spawning stock coupled with a catchability inversely related to stock size. But when examined in its entirety the situation appears more complex. Note that the comparatively high recruitments at all seamounts in 1973 were generated from relatively low spawning biomasses 2 years earlier whereas the peak spawning biomasses in 1972 led to relatively weak year-classes, suggesting either stock-independent recruitment or a dome-shaped stock recruitment relationship (e.g., a Ricker model). The latter alternative does not seem appropriate for armorhead. (The Soviet data also suggest that stock-independent recruitment fluctuations were large during the early 1970's; spawning stocks were apparently

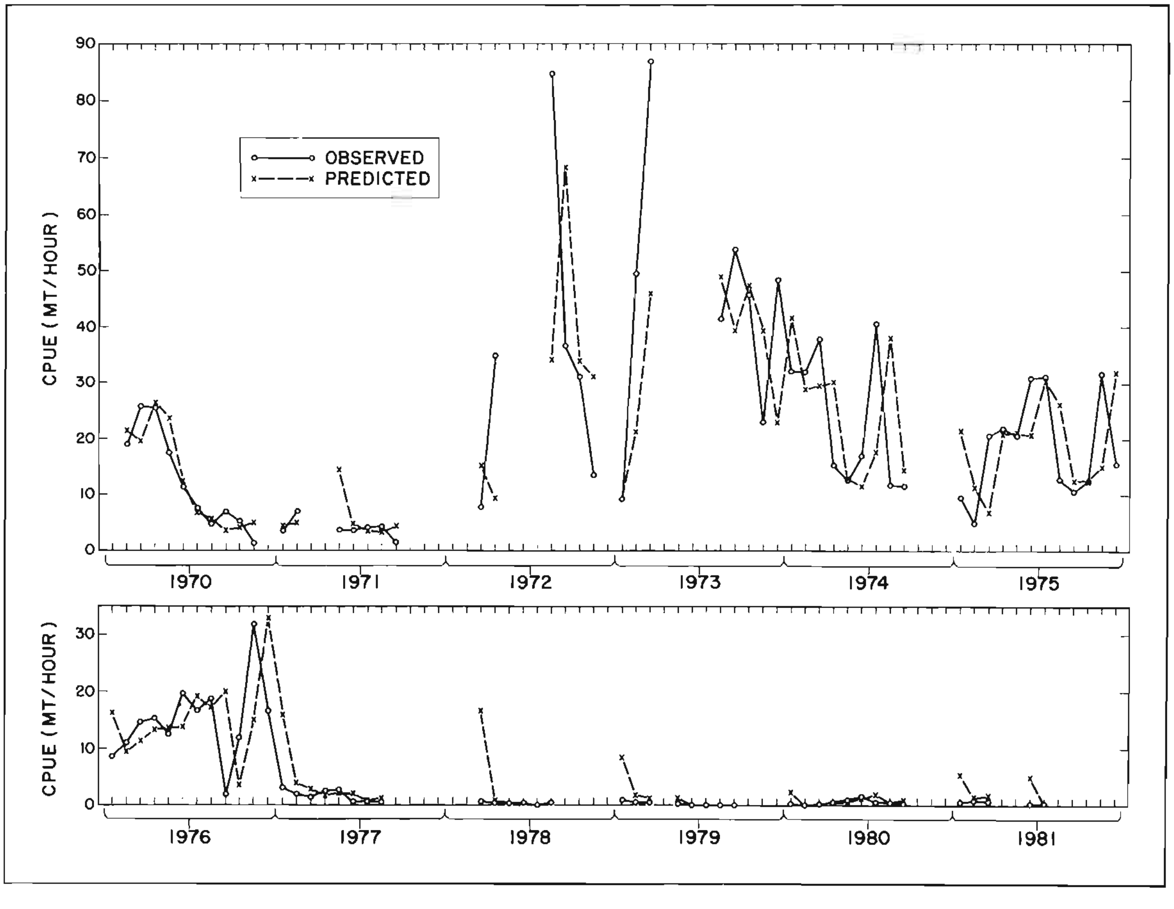


Figure 6.—Observed monthly pelagic armorhead catch per unit of effort (CPUE) by Japanese trawlers on Milwaukee Seamounts and predicted CPUE based on autoregressive model with Ricker spawner-recruit relationship.

about the same size in 1970 and 1973, but resulting recruitments in 1972 and 1975 differed by a factor of 2.5.)

Further analysis yields additional evidence of stock-independent recruitment. For example, relatively modest spawning stocks in 1970 and 1971 (measured by Japanese CPUE) apparently produced large recruitments in 1972 and 1973, whereas spawning stocks of approximately the same size in 1975 and 1976 were unproductive. (This conclusion would be weakened if Japanese trawler catchability increased between 1971 and 1972.) Although the Japanese trawling effort at some seamounts, such as Milwaukee and Kimmei, was substantially greater during the latter period, the difference in fishing intensity could not account for such disparities in the ratios of spawning biomass. (This argument considers only Japanese effort; if a complete record of Soviet effort statistics were available, the conclusion might differ.) Thus it is reasonable to suggest that stock-independent recruitment is the norm for armorhead, except at very low stock levels. The difficult problems are to determine what the critical level is, whether the spawning stock is now below this level and whether a curtailment of fishing would be effective in reversing the trend.

Trial fitting of the model

When the stock model was fit to the monthly Milwaukee time series, only a very poor fit could be obtained. The residuals suggested that the proposed flat-topped stock recruitment relationship was inconsistent with the data. In another attempt a dome-shaped Ricker stock-recruitment model accounted for about 77% of the variation in CPUE (Fig. 6). These results are consistent with the conclusions reached by simple visual inspection of the Japanese CPUE and effort time series. However, despite numerous attempts at fitting the model, stable convergence to a unique set of parameter estimates could not be achieved. Some of the problems in fitting the model are statistical. Consistent and efficient estimation of parameters in models with autocorrelated errors and lagged dependent variables requires that the complex covariance structure of the errors be correctly specified. In our case, it would be necessary to derive the structure analytically and estimate the resulting covariance matrix iteratively as a step in the EM algorithm. Some theoretical work along these lines has been done by Domowitz (1982) for situations involving complete time series, and has been applied to estimation of anchovy stock models.

Further work needs to be done to develop an iteratively reweighted estimation procedure which accounts for the error covariance structure. In our fitting of the model we used statistical weights equal to the nominal effort, assuming this at least provided a measure of the reliability of the spawning biomass indices.

Another problem is that the model is very likely misspecified, particularly regarding recruitment. Our analysis suggests to us that the greatest part of annual variation in recruitment is determined by "random" factors independent of spawning stock, i.e., the term ε_i is of overriding importance. In our simplistic model of recruitment we made use of the only relevant information available, that relating to biomass of the parent stock. However, improved prediction of recruitment might be possible with ancillary data on oceanographic processes, i.e., it might be possible to model ε_i. Two types of processes would likely be important; those that affect survival of armorhead eggs and larvae, and those that influence the congregation of armorhead in the seamount spawning habitat.

Perhaps the most critical problem with the analysis of the Japanese CPUE series is, of course, that only Japanese effort statistics were available. If fishing mortality is an important determinant of stock size, it will be essential to include effort data (or total catch data) from Soviet trawlers. These data will have to be detailed and comprehensive, so that a time series of monthly effort can be constructed for the duration of the fishery.

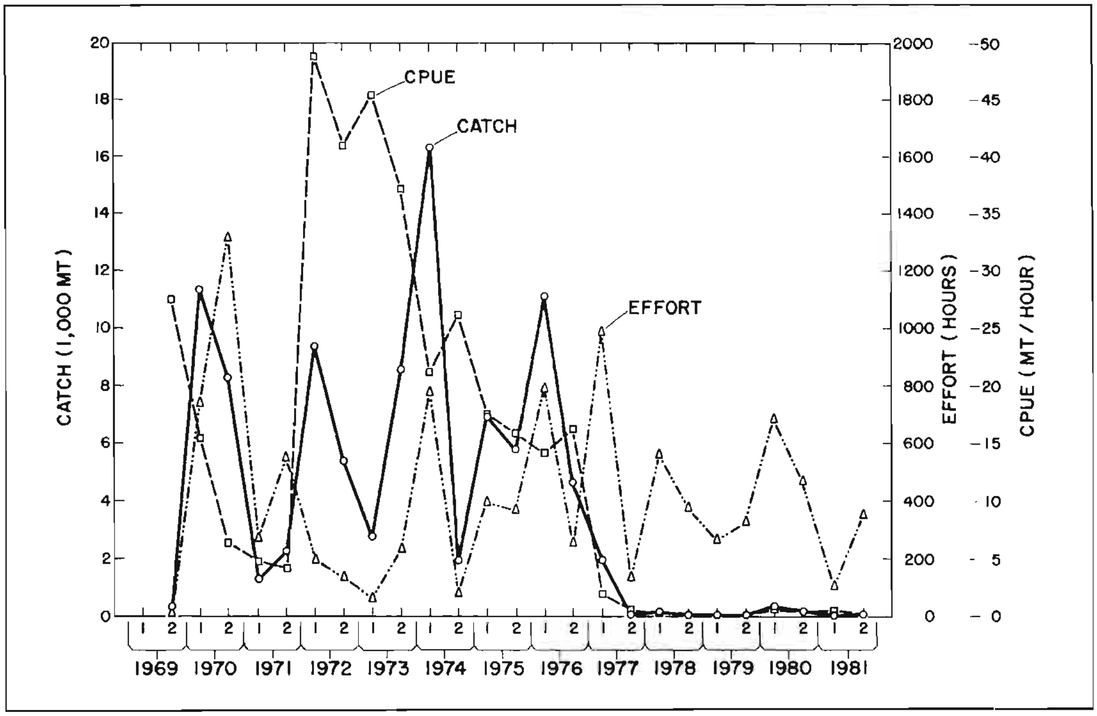


Figure 7.—Semiannual pelagic armorhead catch, effort, and catch per unit of effort (CPUE) for Japanese trawlers on Milwaukee Seamounts.

DIRECTIONS FOR FURTHER RESEARCH

Fish stock assessment is a fairly chancy business under the best of circumstances. It is particularly difficult for armorhead, where we are handicapped by an incomplete record of exploitation and a meager knowledge of basic biology and life history. At this stage our model of stock dynamics consists largely of assumptions, and little in the way of empirical facts. However, we take some comfort in the adage of Box (1979), who noted that "All models are wrong, but some may be useful." We believe our modeling exercise has been helpful, particularly in establishing a context for further investigations of the armorhead stock. Acquisition of more complete fishery statistics and additional biological and hydrographic studies will permit refinements and adjustments.

Several shortcomings of the armorhead stock assessment have been noted, suggesting avenues for further research. The foremost need obviously is to acquire a comprehensive record of the Soviet catch and effort, and repeat the analysis with the full set of fishery statistics. Until then it will not be possible to evaluate the impact of fishing on the armorhead stock.

In addition, we suggest that information on oceanographic processes be examined for clues to the variation in armorhead recruitment. Experience with other species suggests that this will be a difficult task, but worth the effort. Information concerning thermal structure and the behavior of currents in the region of the Emperor-Hawaiian Ridge seems to be in fair abundance, and it would be useful to attempt even rough models of the habitat of armorhead during their critical early stages and the environmental conditions affecting recruitment of adults to the seamounts. One specific objective would be to seek an explanation for the sudden collapse of the armorhead spawning biomass in 1978, and the apparent rise of alfonsin. A starting point may be the finding of Mizuno and White (1983), based on analysis of TRANSPAC XBT casts and IODC data from long. 130°E to 170°W that the Kuroshio meander weakened substantially beginning in 1978 or 1979, accompanied by a southward displacement of the Kuroshio Extension by 2° to lat. 34°N. Associated with this was increased instability in the meander and a doubling of eddy formation.

Other work needs to be done to establish the age distribution and the growth rates of armorhead. We assumed that the spawning stock consisted primarily of fish 2 years of age, so that the CPUE statistics not only provided a measure of spawning biomass in year *i* but also gave information on the recruitment produced by the parent stock in year *i*-2. If the larger armorhead on the seamounts are much older, say 5 or 6 years or more, different conclusions might be reached.

Our modeling made no specific mention of the striking morphological variation which has been noted in armorhead. As described by Humphreys and Tagami (1986), immature "fat-type" armorhead are characteristically found in the epipelagic waters of the northeastern Pacific, whereas mature "lean-type" fish occupy the seamounts. One reasonable hypothesis is that the fat-type armorhead are storing energy which is then expended later in reproduction. An important question for population dynamics and ecosystem energetics therefore is, "how long is the reproductive phase?" The autoregressive model simply subtracts mortality and adds recruitment from one period to the next, and makes no assumptions about the number of age groups in the spawning stock. However, if the age estimates by the Honolulu Laboratory are accurate, we are tempted to suggest that armorhead have a short life once they mature and recruit to the seamounts. Such an hypothesis is consistent with the predominance of lean-type armorhead in the spawning stock, and with the occurrence of emaciated, spent fish in the catches. Thus in some respects the life cycle of armorhead may resemble that of salmon or squid, and similar models of the population dynamics may be applicable.

Table 1.—**Pelagic armorhead, *Pentaceros richardsoni*, catch (metric tons), effort (hours of trawling), and catch per unit effort (CPUE) (metric tons/hour) by Japanese stern trawlers on the central North Pacific seamounts.**

Kimmei Seamount

Year/ Month	Catch	Effort	CPUE
1969			
Jan.	0	0	—
Feb.	0	0	—
Mar.	0	0	—
Apr.	0	0	—
May	0	0	—
June	0	0	—
July	0	0	—
Aug.	106	28	3.79
Sept.	648	55	11.78
Oct.	2,203	64	34.42
Nov.	2,140	60	35.67
Dec.	1,983	91	21.79
1970			
Jan.	2,485	146	17.02
Feb.	709	24	29.54
Mar.	0	0	—
Apr.	533	68	7.84
May	760	82	9.27
June	20	6	3.33
July	72	9	8.00
Aug.	496	109	4.55
Sept.	0	0	—
Oct.	63	14	4.50
Nov.	0	0	—
Dec.	0	0	—
1971			
Jan.	7	7	1.00
Feb.	0	0	—
Mar.	0	0	—
Apr.	0	0	—
May	88	28	3.14
June	0	0	—
July	0	0	—
Aug.	0	23	0.00
Sept.	0	0	—
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1972			
Jan.	0	0	—
Feb.	5	11	0.45
Mar.	0	0	—
Apr.	72	1	72.0
May	0	0	—
June	0	0	—
July	0	0	—
Aug.	0	0	—
Sept.	0	0	—
Oct.	0	0	—
Nov.	768	51	15.06
Dec.	1,170	34	34.41
1973			
Jan.	376	38	9.89
Feb.	148	22	6.73
Mar.	0	0	—
Apr.	0	0	—
May	0	0	—
June	0	0	—
July	0	0	—
Aug.	0	0	—
Sept.	149	6	24.83
Oct.	52	4	13.00
Nov.	124	10	12.40
Dec.	45	10	4.50
1974			
Jan.	0	0	—
Feb.	124	2	62.00
Mar.	88	6	14.67
Apr.	152	16	9.50
May	397	52	7.63
June	108	12	9.00
July	812	73	11.12
Aug.	1,561	92	16.97
Sept.	773	41	18.85
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1975			
Jan.	0	18	0.00
Feb.	1,071	93	11.52
Mar.	543	56	9.70
Apr.	96	25	3.84
May	0	0	—
June	0	0	—
July	31	11	2.82
Aug.	201	14	14.36
Sept.	877	142	6.18
Oct.	374	44	8.50
Nov.	168	30	5.60
Dec.	429	37	11.59
1976			
Jan.	2	1	2.00
Feb.	206	46	4.48
Mar.	69	10	6.90
Apr.	17	1	17.00
May	1,822	408	4.47
June	1,743	255	6.84
July	606	115	5.27
Aug.	754	181	4.17
Sept.	950	149	6.38
Oct.	50	20	2.50
Nov.	168	30	5.60
Dec.	429	37	11.59
1977			
Jan.	0	0	—
Feb.	155	87	1.78
Mar.	734	773	0.95
Apr.	143	202	0.71
May	160	127	1.26
June	9	30	0.30
July	6	14	0.43
Aug.	0	0	—
Sept.	0	0	—
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1978			
Jan.	0	0	—
Feb.	0	0	—
Mar.	0	0	—
Apr.	132	226	0.58
May	17	312	0.05
June	22	347	0.06
July	6	152	0.04
Aug.	3	83	0.04
Sept.	0	0	—
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1979			
Jan.	76	121	0.63
Feb.	88	189	0.47
Mar.	24	89	0.27
Apr.	1	15	0.07
May	6	66	0.09
June	1	29	0.03
July	1	58	0.02
Aug.	0	112	0.00
Sept.	2	51	0.04
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1980			
Jan.	1	26	0.04
Feb.	18	141	0.13
Mar.	35	166	0.21
Apr.	10	74	0.14
May	7	32	0.22
June	1	21	0.05
July	1	6	0.17
Aug.	0	5	0.00
Sept.	0	6	0.00
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1981			
Jan	0	4	0.00
Feb.	37	27	1.37
Mar.	12	127	0.09
Apr.	0	0	—
May	0	0	—
June	10	89	0.11
July	13	67	0.19
Aug.	3	32	0.09
Sept.	13	126	0.10
Oct.	1	94	0.01

Milwaukee Seamounts

Year/ Month	Catch	Effort	CPUE
1969			
Jan.	0	0	—
Feb.	0	0	—
Mar.	0	0	—
Apr.	0	0	—
May	0	0	—
June	0	0	—
July	0	0	—
Aug.	0	0	—
Sept.	323	10	32.30
Oct.	0	0	—
Nov.	7	2	3.50
Dec.	0	0	—
1970			
Jan.	544	26	20.92
Feb.	1,692	89	19.01
Mar.	1,188	46	25.83
Apr.	821	32	25.66
May	2,619	150	17.46
June	4,481	396	11.32
July	2,495	322	7.75
Aug.	1,073	222	4.83
Sept.	2,794	402	6.95
Oct.	1,885	361	5.22
Nov.	8	6	1.33
Dec.	0	0	—

Milwaukee Seamounts (*cont.*)

Year/ Month	Catch	Effort	CPUE
1971			
Jan.	68	19	3.58
Feb.	600	86	6.98
Mar.	0	0	—
Apr.	0	0	—
May	171	46	3.72
June	436	119	3.66
July	989	239	4.14
Aug.	1,213	284	4.27
Sept.	38	25	1.52
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1972			
Jan.	0	0	—
Feb.	0	0	—
Mar.	643	82	7.84
Apr.	2,722	78	34.90
May	6,103	34	179.50
June	0	0	—
July	0	0	—
Aug.	1,693	20	84.65
Sept.	2,120	58	36.55
Oct.	1,465	47	31.17
Nov.	81	6	13.50
Dec.	0	1	0.00
1973			
Jan.	459	24	19.13
Feb.	1,140	23	49.57
Mar.	1,129	13	86.85
Apr.	0	0	—
May	0	0	—
June	0	0	—
July	0	0	—
Aug.	785	19	41.32
Sept.	1,714	32	53.56
Oct.	2,146	47	45.66
Nov.	2,208	97	22.76
Dec.	1,691	35	48.31
1974			
Jan.	3,375	105	32.14
Feb.	2,911	91	31.99
Mar.	2,683	71	37.79
Apr.	2,957	194	15.24
May	2,434	196	12.42
June	1,979	117	16.91
July	1,498	37	40.49
Aug.	339	29	11.69
Sept.	92	8	11.50
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1975			
Jan	838	86	9.74
Feb.	199	40	4.98
Mar.	1,044	51	20.47
Apr.	1,748	80	21.85
May	2,209	108	20.45
June	870	28	31.07
July	1,594	51	31.25
Aug.	2,358	186	12.68
Sept.	782	75	10.43
Oct.	259	21	12.33
Nov.	540	17	31.76
Dec.	246	16	15.38

Table 1.—*Continued.*

Year/ Month	Catch	Effort	CPUE
1976			
Jan.	883	103	8.57
Feb.	1,058	97	10.91
Mar.	2,070	141	14.68
Apr.	4,389	288	15.24
May	787	63	12.49
June	1,910	97	19.69
July	1,716	104	16.50
Aug.	1,178	63	18.70
Sept.	50	26	1.92
Oct.	299	25	11.96
Nov.	540	17	31.76
Dec.	278	17	16.35
1977			
Jan.	428	139	3.08
Feb.	122	65	1.88
Mar.	85	65	1.31
Apr.	540	226	2.39
May	617	237	2.60
June	156	254	0.61
July	69	114	0.61
Aug.	8	19	0.42
Sept.	0	0	—
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1978			
Jan.	0	0	—
Feb.	0	0	—
Mar.	22	45	0.49
Apr.	45	133	0.34
May	29	191	0.15
June	38	192	0.20
July	38	335	0.11
Aug.	11	41	0.27
Sept.	0	0	—
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1979			
Jan.	11	13	0.85
Feb.	11	25	0.44
Mar.	9	31	0.29
Apr.	0	0	—
May	11	108	0.10
June	9	85	0.11
July	13	89	0.15
Aug.	9	92	0.10
Sept.	14	144	0.10
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1980			
Jan.	25	113	0.22
Feb.	11	102	0.11
Mar.	31	131	0.24
Apr.	59	157	0.38
May	61	78	0.78
June	173	104	1.66
July	54	150	0.36
Aug.	84	195	0.43
Sept.	38	120	0.32
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—

Year/ Month	Catch	Effort	CPUE
1981			
Jan	3	6	0.50
Feb.	30	43	0.70
Mar.	12	18	0.67
Apr.	0	0	—
May	0	0	—
June	8	36	0.22
July	34	112	0.30
Aug.	29	178	0.16
Sept.	8	59	0.14
Oct.	0	2	0.00

Colahan Seamount

Year/ Month	Catch	Effort	CPUE
1970			
Jan.	0	0	—
Feb.	0	0	—
Mar.	0	0	—
Apr.	0	0	—
May	206	57	3.61
June	466	42	11.10
July	202	23	8.78
Aug.	3	2	1.50
Sept.	0	0	—
Oct.	39	4	9.75
Nov.	0	0	—
Dec.	0	0	—
1971			
Jan.	0	0	—
Feb.	0	0	—
Mar.	0	0	—
Apr.	0	0	—
May	367	58	6.33
June	339	59	5.75
July	0	0	—
Aug.	0	0	—
Sept.	482	96	5.02
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1972			
Jan.	0	0	—
Feb.	0	0	—
Mar.	0	0	—
Apr.	0	0	—
May	0	0	—
June	6,552	32	204.75
July	3,815	52	73.37
Aug.	1,212	15	80.80
Sept.	1,265	34	37.21
Oct.	0	0	—
Nov.	700	24	29.17
Dec.	621	14	44.36
1973			
Jan.	169	23	7.35
Feb.	108	2	54.00
Mar.	563	13	43.31
Apr.	791	9	87.89
May	0	0	—
June	644	28	23.00
July	0	0	—
Aug.	482	14	34.43
Sept.	240	16	15.00
Oct.	132	3	44.00
Nov.	1,058	40	26.45
Dec.	732	28	26.14

Colahan Seamount (*cont.*)

Year/ Month	Catch	Effort	CPUE
1974			
Jan.	142	9	15.78
Feb.	407	12	33.92
Mar.	255	5	51.00
Apr.	300	15	20.00
May	0	0	—
June	95	11	8.64
July	0	0	—
Aug.	137	7	19.57
Sept.	71	6	11.83
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1975			
Jan.	202	12	16.83
Feb.	143	23	6.22
Mar.	0	0	—
Apr.	148	11	13.45
May	0	0	—
June	0	0	—
July	0	0	—
Aug.	143	14	10.21
Sept.	394	34	11.59
Oct.	175	13	13.46
Nov.	483	22	21.95
Dec.	102	11	9.27
1976			
Jan.	130	21	6.19
Feb.	41	7	5.86
Mar.	23	8	2.88
Apr.	0	0	—
May	50	4	12.50
June	213	8	26.63
July	0	3	0.00
Aug.	0	4	0.00
Sept.	169	24	7.04
Oct.	117	18	6.50
Nov.	483	22	21.95
Dec.	102	11	9.27
1977			
Jan	6	1	6.00
Feb.	33	18	1.83
Mar.	0	0	—
Apr.	5	8	0.63
May	29	7	4.14
June	1	1	1.00
July	0	0	—
Aug.	0	0	—
Sept.	0	0	—
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1978			
Jan.	0	0	—
Feb.	0	0	—
Mar.	16	32	0.50
Apr.	37	51	0.73
May	27	10	2.70
June	8	30	0.27
July	1	13	0.08
Aug.	2	12	0.17
Sept.	0	0	—
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—

Year/ Month	Catch	Effort	CPUE
1979			
Jan.	28	22	1.27
Feb.	0	4	0.00
Mar.	0	0	—
Apr.	0	0	—
May	4	29	0.14
June	20	25	0.80
July	15	28	0.54
Aug.	6	12	0.50
Sept.	2	9	0.22
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1980			
Jan.	1	7	0.14
Feb.	0	0	—
Mar.	0	0	—
Apr.	0	0	—
May	244	48	5.08
June	41	18	2.28
July	96	26	3.69
Aug.	39	54	0.72
Sept.	12	27	0.44
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1981			
Jan.	116	10	11.60
Feb.	55	22	2.50
Mar.	16	9	1.78
Apr.	0	0	—
May	0	0	—
June	6	20	0.30
July	4	32	0.13
Aug.	2	8	0.25
Sept.	9	12	0.75
Oct.	0	4	0.00

C-H Seamount

Year/ Month	Catch	Effort	CPUE
1970			
Jan.	0	0	—
Feb.	0	0	—
Mar.	0	0	—
Apr.	0	0	—
May	0	0	—
June	0	0	—
July	91	5	18.20
Aug.	0	0	—
Sept.	0	0	—
Oct.	0	0	—
Nov.	102	21	4.86
Dec.	0	0	—
1971			
Jan.	0	0	—
Feb.	0	0	—
Mar.	0	0	—
Apr.	0	0	—
May	130	23	5.65
June	212	26	8.15
July	0	0	—
Aug.	0	0	—
Sept.	0	0	—
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—

Table 1.—*Continued.*

Year/ Month	Catch	Effort	CPUE	Year/ Month	Catch	Effort	CPUE	Year/ Month	Catch	Effort	CPUE	Year/ Month	Catch	Effort	CPUE
C-H Seamount (*cont.*)								**Hancock Seamounts** (*cont.*)							
1973				1978				1971				1976			
Jan.	0	0	—	Jan.	0	0	—	Jan.	0	0	—	Jan.	112	22	5.09
Feb.	0	0	—	Feb.	0	0	—	Feb.	0	0	—	Feb.	47	4	11.75
Mar.	0	0	—	Mar.	0	0	—	Mar.	0	0	—	Mar.	24	4	6.00
Apr.	0	0	—	Apr.	0	0	—	Apr.	0	0	—	Apr.	0	0	—
May	0	0	—	May	3	5	0.60	May	81	23	3.52	May	0	0	—
June	81	3	27.00	June	1	13	0.08	June	0	0	—	June	163	21	7.76
July	0	0	—	July	0	0	—	July	0	0	—	July	0	0	—
Aug.	469	6	78.17	Aug.	0	0	—	Aug.	0	0	—	Aug.	0	0	—
Sept.	536	9	59.56	Sept.	0	0	—	Sept.	0	0	—	Sept.	30	4	7.50
Oct.	252	4	63.00	Oct.	0	0	—	Oct.	0	0	—	Oct.	67	8	8.38
Nov.	701	14	50.07	Nov.	0	0	—	Nov.	0	0	—	Nov.	404	16	25.25
Dec.	492	9	54.67	Dec.	0	0	—	Dec.	0	0	—	Dec.	265	19	13.95
1974				1979				1972				1977			
Jan.	0	0	—	Jan.	0	0	—	Jan.	0	0	—	Jan.	53	10	5.30
Feb.	283	8	35.38	Feb.	0	0	—	Feb.	0	0	—	Feb.	17	19	0.89
Mar.	154	3	51.33	Mar.	0	0	—	Mar.	0	0	—	Mar.	0	0	—
Apr.	0	0	—	Apr.	0	0	—	Apr.	0	0	—	Apr.	0	0	—
May	0	0	—	May	0	0	—	May	0	0	—	May	0	0	—
June	0	0	—	June	2	3	0.67	June	0	0	—	June	0	0	—
July	0	0	—	July	2	2	1.00	July	1,870	24	77.92	July	0	0	—
Aug.	251	8	31.38	Aug.	0	0	—	Aug.	0	0	—	Aug.	0	0	—
Sept.	0	0	—	Sept.	0	0	—	Sept.	0	0	—	Sept.	0	0	—
Oct.	0	0	—	Oct.	0	0	—	Oct.	0	0	—	Oct.	0	0	—
Nov.	0	0	—	Nov.	0	0	—	Nov.	783	13	60.23	Nov.	0	0	—
Dec.	0	0	—	Dec.	0	0	—	Dec.	705	8	88.13	Dec.	0	0	—
1975				1980				1973				1978			
Jan.	123	4	30.75	Jan.	0	0	—	Jan.	1,320	26	50.77	Jan.	0	0	—
Feb.	0	0	—	Feb.	0	0	—	Feb.	614	5	122.80	Feb.	0	0	—
Mar.	0	0	—	Mar.	0	0	—	Mar.	886	15	59.07	Mar.	0	0	—
Apr.	0	0	—	Apr.	0	0	—	Apr.	0	0	—	Apr.	0	0	—
May	0	0	—	May	37	6	6.17	May	0	0	—	May	178	6	29.67
June	0	0	—	June	4	1	4.00	June	593	12	49.42	June	0	0	—
July	0	0	—	July	1	5	0.20	July	2,296	75	30.61	July	0	0	—
Aug.	62	2	31.00	Aug.	13	10	1.30	Aug.	843	51	16.53	Aug.	0	0	—
Sept.	453	35	12.94	Sept.	8	8	1.00	Sept.	340	7	48.57	Sept.	0	0	—
Oct.	0	0	—	Oct.	0	0	—	Oct.	138	3	46.00	Oct.	0	0	—
Nov.	72	1	72.00	Nov.	0	0	—	Nov.	581	30	19.37	Nov.	0	0	—
Dec.	52	4	13.00	Dec.	0	0	—	Dec.	393	15	26.20	Dec.	0	0	—
1976				1981				1974				1979			
Jan.	63	2	31.50	Jan.	51	5	10.20	Jan.	205	11	18.64	Jan.	0	0	—
Feb.	25	3	8.33	Feb.	99	7	14.14	Feb.	0	0	—	Feb.	0	0	—
Mar.	0	0	—	Mar.	0	0	—	Mar.	219	3	73.00	Mar.	0	0	—
Apr.	0	0	—	Apr.	0	0	—	Apr.	75	6	12.50	Apr.	0	0	—
May	0	0	—	May	0	0	—	May	14	1	14.00	May	23	10	2.30
June	0	0	—	June	2	1	2.00	June	72	4	18.00	June	39	61	0.64
July	0	0	—	July	0	0	—	July	0	0	—	July	5	22	0.23
Aug.	0	0	—	Aug.	0	0	—	Aug.	0	0	—	Aug.	0	0	—
Sept.	0	0	—	Sept.	0	0	—	Sept.	39	4	9.75	Sept.	0	0	—
Oct.	176	6	29.33	Oct.	0	0	—	Oct.	0	0	—	Oct.	0	0	—
Nov.	72	1	72.00					Nov.	0	0	—	Nov.	0	0	—
Dec.	52	4	13.00	**Hancock Seamounts**				Dec.	0	0	—	Dec.	0	0	—
1977				1970				1975				1980			
Jan.	0	0	—	Jan.	0	0	—	Jan.	0	0	—	Jan.	0	0	—
Feb.	0	0	—	Feb.	0	0	—	Feb.	0	0	—	Feb.	0	0	—
Mar.	0	0	—	Mar.	0	0	—	Mar.	0	0	—	Mar.	0	0	—
Apr.	10	6	1.67	Apr.	0	0	—	Apr.	0	0	—	Apr.	0	0	—
May	12	3	4.00	May	41	7	5.86	May	0	0	—	May	0	0	—
June	1	4	0.25	June	15	2	7.50	June	0	0	—	June	0	0	—
July	0	0	—	July	34	4	8.50	July	0	0	—	July	0	0	—
Aug.	0	0	—	Aug.	90	4	22.50	Aug.	169	17	9.94	Aug.	42	11	3.82
Sept.	0	0	—	Sept.	0	0	—	Sept.	265	14	18.93	Sept.	189	102	1.85
Oct.	0	0	—	Oct.	0	0	—	Oct.	218	12	18.17	Oct.	0	0	—
Nov.	0	0	—	Nov.	140	28	5.00	Nov.	404	19	21.26	Nov.	0	0	—
Dec.	0	0	—	Dec.	0	0	—	Dec.	265	19	13.95	Dec.	0	0	—

Table 1.—*Continued.*

Year/ Month	Catch	Effort	CPUE
1981			
Jan.	0	0	—
Feb.	0	0	—
Mar.	0	0	—
Apr.	0	0	—
May	0	0	—
June	234	46	5.09
July	0	0	—
Aug.	39	61	0.64
Sept.	130	114	1.14
Oct.	0	0	—
Others			
1970			
Jan.	0	0	—
Feb.	0	0	—
Mar.	0	0	—
Apr.	0	0	—
May	0	0	—
June	0	0	—
July	0	0	—
Aug.	0	0	—
Sept.	0	0	—
Oct.	0	0	—
Nov.	95	25	3.80
Dec.	0	0	—
1971			
Jan.	0	0	—
Feb.	0	0	—
Mar.	0	0	—
Apr.	0	0	—
May	6	6	1.00
June	319	61	5.23
July	0	0	—
Aug.	0	4	0.00
Sept.	0	0	—
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1972			
Jan.	0	0	—
Feb.	5	2	2.50
Mar.	29	5	5.80
Apr.	0	0	—
May	0	0	—
June	25	1	25.00
July	0	0	—
Aug.	123	2	61.50
Sept.	0	0	—
Oct.	0	0	—
Nov.	0	0	—
Dec.	117	1	117.00
1973			
Jan.	21	13	1.62
Feb.	2	14	0.14
Mar.	0	0	—
Apr.	0	0	—
May	0	0	—
June	167	6	27.83
July	169	6	28.17
Aug.	15	3	5.00
Sept.	0	0	—
Oct.	138	1	138.00
Nov.	187	12	15.58
Dec.	42	1	42.00

Year/ Month	Catch	Effort	CPUE
Others (*cont.*)			
1974			
Jan.	0	0	—
Feb.	64	1	64.00
Mar.	571	6	95.17
Apr.	23	2	11.50
May	57	1	57.00
June	83	8	10.38
July	235	7	33.57
Aug.	0	0	—
Sept.	72	4	18.00
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1975			
Jan.	0	5	0.00
Feb.	0	0	—
Mar.	0	0	—
Apr.	63	3	21.00
May	0	0	—
June	151	5	30.20
July	0	0	—
Aug.	774	35	22.11
Sept.	184	5	36.80
Oct.	241	12	20.08
Nov.	0	0	—
Dec.	32	1	32.00
1976			
Jan.	97	16	6.06
Feb.	39	2	19.50
Mar.	34	7	4.86
Apr.	0	0	—
May	132	28	4.71
June	245	29	8.45
July	71	11	6.46
Aug.	181	15	12.07
Sept.	141	19	7.42
Oct.	59	4	14.75
Nov.	0	3	0.00
Dec.	0	0	—
1977			
Jan.	0	0	—
Feb.	13	9	1.44
Mar.	0	6	0.00
Apr.	8	8	1.00
May	26	6	4.33
June	6	7	0.86
July	0	0	—
Aug.	0	0	—
Sept.	0	0	—
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1978			
Jan.	0	0	—
Feb.	0	0	—
Mar.	0	0	—
Apr.	12	27	0.44
May	231	38	6.08
June	1	13	0.08
July	0	21	0.00
Aug.	0	5	0.00
Sept.	0	0	—
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—

Year/ Month	Catch	Effort	CPUE
1979			
Jan.	0	0	—
Feb.	0	2	0.00
Mar.	0	0	—
Apr.	0	0	—
May	11	17	0.65
June	43	96	0.45
July	14	48	0.29
Aug.	0	0	—
Sept.	0	0	—
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1980			
Jan.	0	0	—
Feb.	2	5	0.40
Mar.	0	0	—
Apr.	0	0	—
May	0	0	—
June	0	0	—
July	0	0	—
Aug.	293	71	4.13
Sept.	212	155	1.37
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1981			
Jan.	0	0	—
Feb.	22	8	2.75
Mar.	0	0	—
Apr.	0	0	—
May	0	0	—
June	150	33	4.55
July	12	34	0.35
Aug.	12	58	0.21
Sept.	38	126	0.30
Oct.	1	1	1.00
Total			
1969			
Jan.	0	0	—
Feb.	0	0	—
Mar.	0	0	—
Apr.	0	0	—
May	0	0	—
June	0	0	—
July	0	0	—
Aug.	106	28	3.79
Sept.	971	65	14.94
Oct.	2,203	64	34.42
Nov.	2,147	62	34.63
Dec.	1,983	91	21.79
1970			
Jan.	3,029	172	17.61
Feb.	2,401	113	21.25
Mar.	1,188	46	25.83
Apr.	1,354	100	13.54
May	3,626	296	12.25
June	4,982	446	11.17
July	2,894	363	7.97
Aug.	1,662	337	4.93
Sept.	2,794	402	6.95
Oct.	1,987	379	5.24
Nov.	345	80	4.31
Dec.	0	0	—

Year/ Month	Catch	Effort	CPUE
Total (*cont.*)			
1971			
Jan.	75	26	2.89
Feb.	600	86	6.98
Mar.	0	0	—
Apr.	0	0	—
May	843	184	4.58
June	1,306	265	4.93
July	989	239	4.14
Aug.	1,213	311	3.90
Sept.	520	121	4.30
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1972			
Jan.	0	0	—
Feb.	10	13	0.77
Mar.	672	87	7.72
Apr.	2,794	79	35.37
May	6,103	34	179.50
June	6,577	33	199.30
July	5,685	76	74.80
Aug.	3,028	37	81.84
Sept.	3,385	92	36.79
Oct.	1,465	47	31.17
Nov.	2,332	94	24.81
Dec.	2,613	58	45.05
1973			
Jan.	2,345	124	18.91
Feb.	2,012	66	30.49
Mar.	2,578	41	62.88
Apr.	791	9	87.89
May	0	0	—
June	1,485	49	30.31
July	2,465	81	30.43
Aug.	2,594	93	27.89
Sept.	2,979	70	42.56
Oct.	2,858	62	46.10
Nov.	4,859	203	23.94
Dec.	3,395	98	34.64
1974			
Jan.	3,722	125	29.78
Feb.	3,789	114	33.24
Mar.	3,970	94	42.23
Apr.	3,507	233	15.05
May	2,902	250	11.61
June	2,337	152	15.38
July	2,545	117	21.75
Aug.	2,288	136	16.82
Sept.	1,047	63	16.62
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1975			
Jan.	1,163	125	9.30
Feb.	1,413	156	9.06
Mar.	1,587	107	14.83
Apr.	2,055	119	17.27
May	2,209	108	20.45
June	1,021	33	30.94
July	1,625	62	26.21
Aug.	3,707	268	13.83
Sept.	2,955	305	9.69
Oct.	1,267	102	12.42
Nov.	1,667	89	18.73
Dec.	1,126	88	12.80

Table 1.—*Continued.*

Year/ Month	Catch	Effort	CPUE	Year/ Month	Catch	Effort	CPUE
Total *(cont.)*							
1976				1979			
Jan.	1,287	165	7.80	Jan.	115	156	0.74
Feb.	1,416	159	8.91	Feb.	99	220	0.45
Mar.	2,220	170	13.06	Mar.	33	120	0.28
Apr.	4,406	289	15.25	Apr.	1	15	0.07
May	2,791	503	5.55	May	55	230	0.24
June	4,274	410	10.42	June	114	299	0.38
July	2,393	233	10.27	July	50	247	0.20
Aug.	2,113	263	8.03	Aug.	15	216	0.07
Sept.	1,340	222	6.04	Sept.	18	204	0.09
Oct.	768	81	9.48	Oct.	0	0	—
Nov.	1,667	89	18.73	Nov.	0	0	—
Dec.	1,126	88	12.80	Dec.	0	0	—
1977				1980			
Jan.	487	150	3.25	Jan.	27	146	0.18
Feb.	340	198	1.72	Feb.	31	248	0.13
Mar.	819	844	0.97	Mar.	66	297	0.22
Apr.	706	450	1.57	Apr.	69	231	0.30
May	844	380	2.22	May	349	164	2.13
June	173	296	0.58	June	219	144	1.52
July	75	128	0.59	July	152	187	0.81
Aug.	8	19	0.42	Aug.	471	346	1.36
Sept.	0	0	—	Sept.	459	418	1.10
Oct.	0	0	—	Oct.	0	0	—
Nov.	0	0	—	Nov.	0	0	—
Dec.	0	0	—	Dec.	0	0	-
1978				1981			
Jan.	0	0	—	Jan.	170	25	6.80
Feb.	0	0	—	Feb.	243	107	2.27
Mar.	38	77	0.49	Mar.	40	154	0.26
Apr.	226	437	0.52	Apr.	0	0	—
May	485	562	0.86	May	0	0	—
June	70	595	0.12	June	410	225	1.82
July	45	521	0.09	July	63	245	0.26
Aug.	16	141	0.11	Aug.	85	337	0.25
Sept.	0	0	—	Sept.	198	437	0.45
Oct.	0	0	—	Oct.	2	101	0.02
Nov.	0	0	—				
Dec.	0	0	--				

CITATIONS

BOEHLERT, G. W.

1986. Productivity and population maintenance of seamount resources and future research directions. *In* R. N. Uchida, S. Hayasi, and G. W. Boehlert (editors), Environment and resources of seamounts in the North Pacific, p. 95-102. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 43.

BOX, G. E. P.

1979. Robustness in the strategy of scientific model building. *In* R. C. Laurer and G. N. Wilkinson (editors), Robustness in statistics, p. 201-236. Acad. Press, N.Y.

CHIKUNI, S.

1970. The "phantom fish," "kusakari tsubodai"—an outline. Enyo (Far Seas) Fish. Res. Lab. News 3:1-4. [In Jpn.] (Engl. transl. by J. H. Shohara, Natl. Mar. Fish. Serv., NOAA, Terminal Island, CA 90731, 7 p.)

DEMPSTER, A. P., N. M. LAIRD, and D. B. RUBIN.

1977. Maximum likelihood from incomplete data via the EM algorithm. J. R. Stat. Soc., Ser. B, 39:1-38.

DOMOWITZ, I.

1982. Nonlinear regression with heterogeneous observations. Admin. Rep. LJ-82-20, Southwest Fisheries Center La Jolla Laboratory, National Marine Fisheries Service, NOAA, La Jolla, CA 92038, 13 p.

HUMPHREYS, R. L., Jr., and D. T. TAGAMI.

1986. Review and current status of research on the biology and ecology of the genus *Pseudopentaceros*. *In* R. N. Uchida, S. Hayasi, and G. W. Boehlert (editors), Environment and resources of seamounts in the North Pacific, p. 55-62. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 43.

MIZUNO, K., and W. B. WHITE.

1983. Annual and interannual variability in the Kuroshio Current system. *In* L. Magaard, P. Muller, and R. Pujalet (editors), The role of eddies in the general ocean circulation, p. 283-310. Hawaii Inst. Geophys. Spec. Publ.

SAKIURA, H. (translator).

1972. The pelagic armorhead, *Pentaceros richardsoni*, fishing grounds off the Hawaiian Islands, as viewed by the Soviets (So-Ren kara mita Hawaii oki kusakari tsubodai gyojyo). [In Jpn.] Suisan Shuho (The Fishing & Food Industry Weekly) 658:28-31, June 15, 1972. (Engl. transl. by T. Otsu, 1977, 7 p., Transl. No. 17; available Southwest Fish. Cent. Honolulu Lab., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396.)

TAKAHASHI, Y., and T. SASAKI.

1977. Trawl fishery in the central North Pacific seamounts (Kita Taiheiyo chubu kaizan ni okeru tororu gyogyo). Hokuyo soko-uo gyogyo—Shiryo (3) (Northern waters groundfish fishery—Data (3)). [In Jpn.] Division of Northern Waters Groundfish Resources, Far Seas Fish. Res. Lab., 45 p. (Engl. transl. by T. Otsu, 1977, 49 p., Transl. No. 22; available Southwest Fish. Cent. Honolulu Laboratory, Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396.)

VASIL'KOV, V. P., and L. A. BORETS.

1978. Determining the age of boarfishes by spectrophotometric analysis of scale structure. Sov. J. Mar. Biol. 4(1):545-548.

Appendix

Parameters of the autoregressive stock model

Parameters of the autoregressive stock model were estimated iteratively by minimizing the weighted sum of squares

$$\Phi = \sum_{i=1}^{n} E_i \, [\mathrm{CPUE}_i - \widehat{\mathrm{CPUE}_i}]^2$$

where n = total number of data points in the time series. The squared residuals were weighted by effort, E_i, so that time periods with no observation of CPUE (i.e., $E_i = 0$) did not contribute to Φ and had no bearing on the parameter estimation.

Predicted CPUE's for every time period (including those with zero effort) were computed at each iteration by

$$\widehat{\mathrm{CPUE}_i} = \left\{ \left(\frac{W_i}{W_{i-1}} \right)^{a} \mathrm{CPUE}_{i-1}^{a} \, S_{i-1,i} + R_i \, Q^a \, W_i^a \, S_i \right\}^{\frac{1}{a}}$$

where

$$S_{i-1,i} = \mathrm{e}^{-(M+F_{i-1,i})}$$

$$S_i = \mathrm{e}^{-(M+F_i)/2}$$

$$R_i = \alpha \left[1 - \mathrm{e}^{-\beta P_{i-\delta}} \right]$$

and the auxilliary variables are defined as

$$F_{i-1,i} = Q^a \left[\left(\frac{\mathrm{CPUE}_{i-1}}{W_{i-1}} \right)^{b} E_{i-1} + \left(\frac{\mathrm{CPUE}_i}{W_i} \right)^{b} E_i \right] /2$$

$$F_i = Q^a \left(\frac{\mathrm{CPUE}_i}{W_i} \right)^{b} E_i$$

$$P_{i-\delta} = W_{i-\delta}^{b} \left(\frac{\mathrm{CPUE}_{i-\delta}}{Q} \right)^{a}$$

$$a = 1/(\gamma + 1)$$

$$b = \gamma/(\gamma + 1).$$

Lagged spawning biomasses for the first δ time periods in the observed series were assumed equal to the spawning biomass in period 1.

A Review of the Fishery and Catch-per-cruise for Alfonsin Stocks in the Vicinity of Izu Islands

KOICHI YAMAMOTO
Shizuoka Prefectural Fisheries Experimental Station
Izu Branch, Shizuoka, 425 Japan

ABSTRACT

Alfonsin, *Beryx splendens*, fisheries in the vicinity of the Izu Islands have developed rapidly in recent years; this increase can largely be attributed to increased fishing grounds. The number of boats fishing for alfonsin also increased rapidly between 1980 and 1982. The alfonsin fishing grounds, which had been restricted to nearby waters around Izu Oshima and Hachijo Shima until the 1960's, were expanded to include more distant waters since about 1970. Improvement in gear type and fishing methods and expansion of the fishing grounds have led to increased catches of alfonsin in recent years, and the annual catch, which ranged between 300 and 500 metric tons (MT) before 1974, reached 6,600 MT in 1982.

Available catch records were examined to assess trends in stock abundance at two fishing grounds. Two peaks were observed in the mean annual catch per unit effort (CPUE), one before, and a second after 1978, when the method of fishing was changed. The CPUE first peaked in 1976 in both fishing grounds, whereas the second peak occurred at Tori Shima in 1980 and at Aoga Shima in 1981. The frequency distribution of CPUE does not show any particular tendency that the alfonsin stocks decreased at both fishing grounds in recent years. It was suggested that the alfonsin stock in Tori Shima fishing grounds may have declined in recent years because the CPUE decreased since 1981. The situation is complicated by changes in harvesting technology, difficulty in measuring real fishing effort, and in marked growth in fishing effort. Further stock assessment studies should be conducted so that an effective management scheme can be designed for these local but important fish stocks.

INTRODUCTION

Stocks of kinmedai or alfonsin, *Beryx splendens*, are an important resource for coastal fisheries in the Izu Island region. The fishery has recently expanded, and the result has been an increased catch. The present report deals with alfonsin stocks exploited by the fishing fleet based at Shimoda on the Izu Peninsula. The fishery covers major fishing grounds in the Izu Islands and southwestern Japan (Fig. 1). Using available data, I consider the alfonsin stocks in the major fishing grounds off Aoga Shima and Tori Shima.

REVIEW OF THE FISHERY

Alfonsin landings, which ranged between 300 and 500 metric tons (MT) until 1974, increased to more than 1,000 MT in 1975, rose sharply to 2,800 MT by 1979, and reached 6,600 MT in 1982. The total value of the 1982 catch reached approximately $16 million.

Vessels engaged in alfonsin fishing typically range between 19 and 120 gross tons (GT) but most are about 50-60 GT. The fleet size at Shimoda varied between 16 and 28 boats until 1980, then increased dramatically to 53 boats in 1981 and 69 boats in 1982. Each fishing trip or cruise lasts about 10 days. Usually, each boat makes 11-12 cruises per year.

Fishing method

The method of fishing for alfonsin changed drastically in 1978. The pre-1978 fishing method used a vertical line with barrels which is called "taru-nagashi" (barrel drifting line). It consisted of a vertical mainline which was buoyed by a wooden barrel 45 cm in diameter. The vertical mainline, made of No. 80 nylon, stretched about 300 m. From it, 30-50 No. 30 nylon branch lines 80 cm long were fastened at intervals of about 1 m. Fifty to one hundred mainlines, bound to a horizontal rope, were set from the upstream side of the seamounts (Fig. 2). The fishermen pulled each mainline when its barrel drifted past the fishing site.

A "vertical bottom longline," introduced in 1978 for alfonsin fishing, is similar to the traditional longline used for puffer. The gear consists of a buoy rope 10 mm in diameter, a ground rope 12 mm in diameter, about 150 branch lines of No. 30 or 80 nylon, corresponding buoys and weights, 30 to 50 gangions of No. 28 nylon attached to each branch line, and main ropes and flags. The buoy line and ground line stretch for about 6 km and transect the fishing ground. The bottom longline assures higher probability of encountering fish and thus producing higher catches than the drift line, although the former frequently snags on bottom outcroppings and is lost. The new fishing method spread in all fishing vessels during a very short period from 1978 to 1979.

Fishing grounds

The alfonsin fishing boats based at Shimoda operated nearby around Izu Oshima and Hachijo Shima since the 1950's. In 1970, the fishing grounds expanded southward to the vicinity of Aoga Shima. Exploitation of the stocks around Tori Shima also contributed significantly to profitability of the fishery. Furthermore, additional fishing grounds were located in other areas such as off Amami Oshima in 1978 and off Omaezaki (Fig. 1).

In 1982, the Aoga Shima ground produced 4,551 MT of alfon-

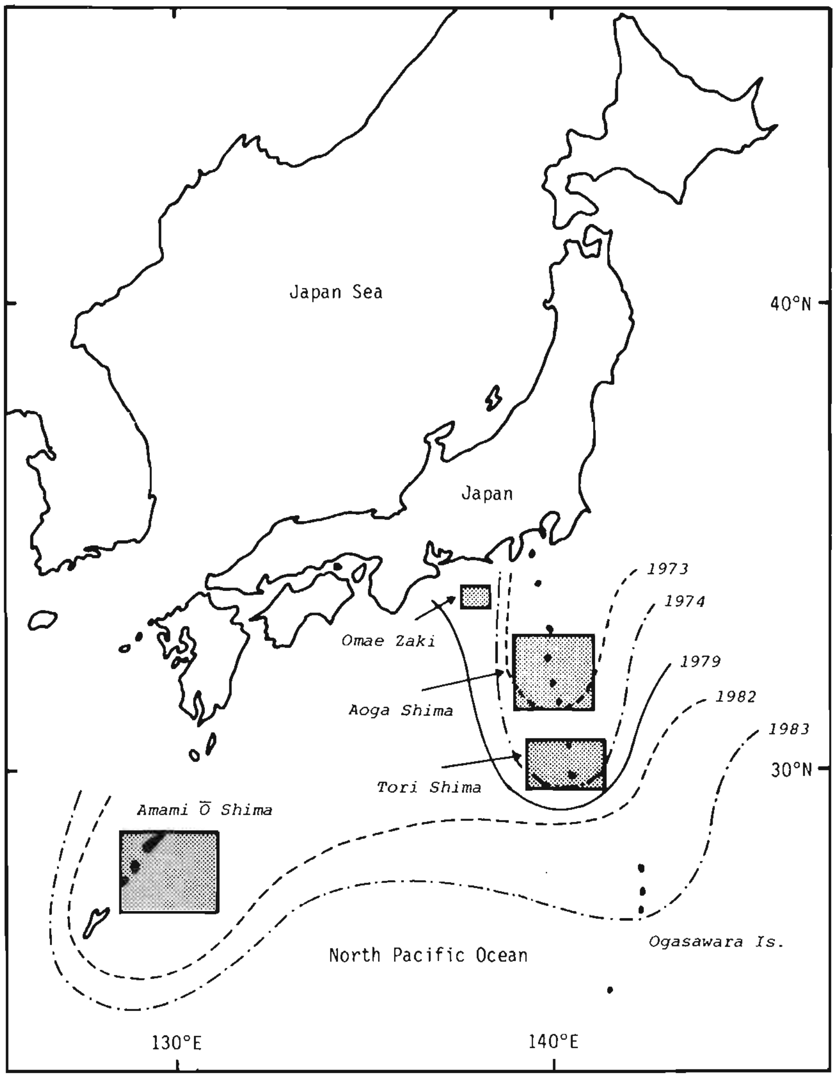


Figure 1.—Fishing grounds of alfonsin exploited by fishing vessels based at Shimoda fishing port. A numeral shows the year when the fishing ground was expanded.

sin which represented 71% of the total catch from the major grounds, exclusive of the traditional fishing areas around Izu Oshima and Hachijo Shima. By adding the catch of 423 MT (7%) made around Tori Shima, the annual production from the major grounds approached 5,000 MT. Contributions from the other areas were 837 MT (13%) from the Omaezaki ground and 549 MT (9%) from the Amami Oshima ground.

STATUS OF STOCKS

Increase in the number of vessels, improvement in fishing methods, and expansion of the fishing grounds stimulated rapid development of the alfonsin fishery. At the same time, there was a growing concern about overfishing the stock. Catch and effort statistics of the alfonsin fishery in the major grounds around Aoga Shima and Tori Shima were examined, taking into account four criteria proposed by Kubo and Yoshihara (1955) for evaluating the status of stocks; these criteria are i) the relationship of catch and effort, ii) the trends in annual catch per unit effort (CPUE), iii) the frequency distribution of CPUE, and iv) the coefficient of variation (CV) of CPUE.

Total catch of alfonsin increased together with a rise in the number of cruises in 1973-82 in the Aoga Shima and Tori Shima grounds. This increase in catch, however, did not signal any symptom of depletion of the stocks. The annual catch per cruise of alfonsin showed clear peaks before 1978 in the Aoga Shima and Tori Shima grounds (Fig. 3). During the pre-1978 period, when the "barrel drifting line" was commonly employed, the CPUE peaked in 1976. After introduction of the "vertical bottom longline" in 1978, a minor peak in catch per cruise was recorded in 1980 for the Tori Shima ground and in 1981 in the Aoga Shima ground. Since then, the CPUE showed a declining trend, indicating a possible reduction of the stocks.

The frequency distributions of catch per cruise of alfonsin in the Aoga Shima and Tori Shima grounds are shown in Figures 4 and 5, respectively. The distribution of CPUE from the Aoga Shima ground was nearly normal in 1973 at the beginning of exploitation; however, numbers of low CPUE's in subsequent years up to 1977 had increased gradually and resembled an exponential curve in 1978. The distributions for 1979-81 and 1983 again approximated normal curves, but an exponential-type distribution occurred in 1982. A plot of the CPUE from the Tori Shima ground in 1974 and 1975 also appeared to approximate normal curves and the tendency seemed to hold from 1979 to 1983 as well, although data were insufficient for a definitive conclusion.

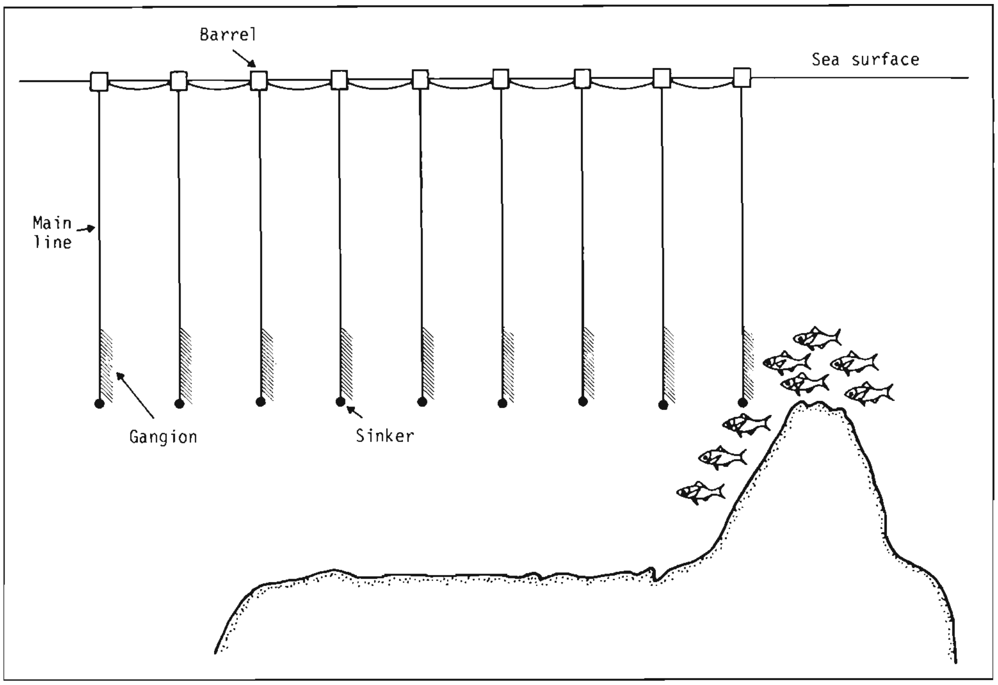


Figure 2.—Schematic presentation of "Taru nagashi" (barrel drifting line).

Kubo and Yoshihara (1955) reported that frequency distributions of CPUE data changed from normal to exponential when a stock declined. The alfonsin catch data in the Aoga Shima and Tori Shima grounds suggested that such a tendency did not exist. However, it was of concern because of the possibility that the stock in the Tori Shima ground was in danger of becoming depleted in future years judging from the decrease in CPUE.

The CV of catch per cruise data rose sharply in 1982 (Fig. 6) in the two fishing grounds under discussion. The CV in the Aoga Shima ground fluctuated within a fairly narrow range between 1.0 and 1.8 from 1973 to 1981 but rose abruptly to 3.5 in 1982. The data, although fragmented, indicated that a similar trend existed on the Tori Shima ground. The CV ranged between 0.88 and 1.56 for 5 years including 1974-75, 1979, and 1980-81 but rose to 3.4 in 1982 (Fig. 6). Possible reasons include the greater number of large catches in 1982 (Fig. 5), and also the inclusion of many new boats having little experience in the fishery which may have contributed to the high number of low CPUE points in that year. Based on the criterion of Kubo and Yoshihara (1955), the rise of CV suggested possible depletion of the alfonsin stocks in 1982. It should be noted, however, that the CV showed a decline in 1983 (Fig. 6).

Figure 3.—Catch per cruise of alfonsin in the Aoga Shima and Tori Shima fishing grounds, 1973-83.

CONCLUSIONS

Some criteria examined suggested that the alfonsin stocks in the Tori Shima ground may have declined in recent years. The situation is complicated, however, by changes in harvesting technology, difficulty in measuring real fishing effort, and in marked growth in fishing effort. Based on these preliminary results, it was concluded that the alfonsin stocks should be carefully monitored, because there is a possibility that the recent expansion of fishing activities may have had detrimental effects on the stocks. Assessment studies should be conducted for this local but important fish resource to provide effective management schemes.

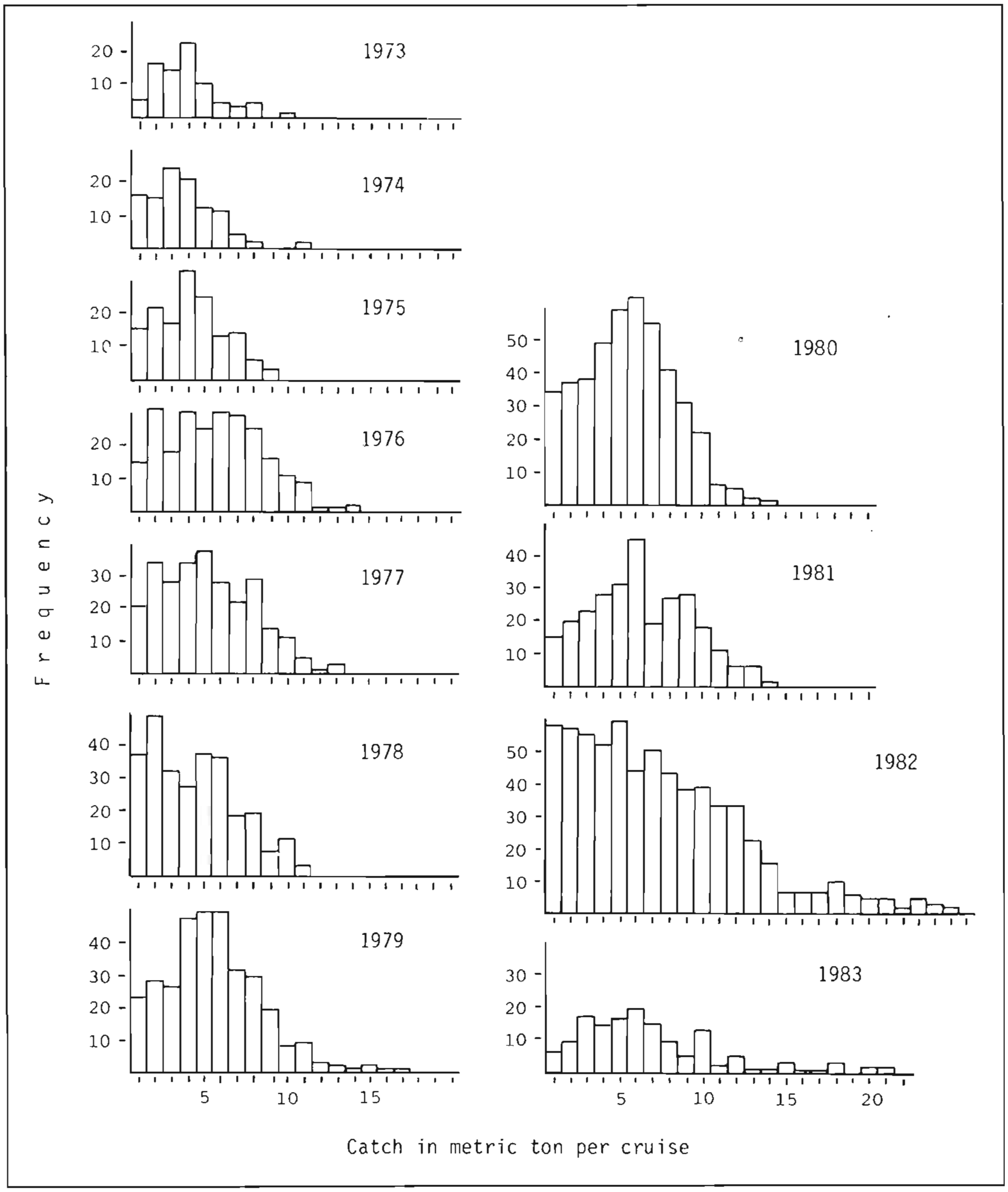


Figure 4.—Frequency distribution of catch-per-cruise data of alfonsin in the Aoga Shima fishing ground, 1973-83.

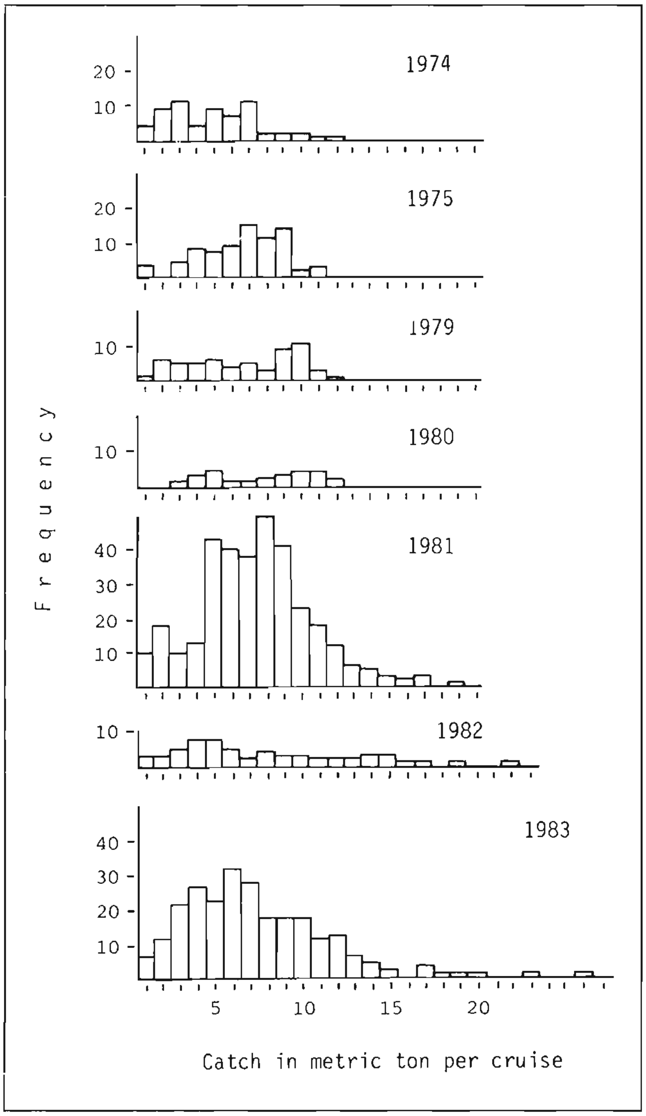


Figure 5.—Frequency distribution of catch-per-cruise data of alfonsin in the Tori Shima fishing ground, 1974, 1975, and 1979-83.

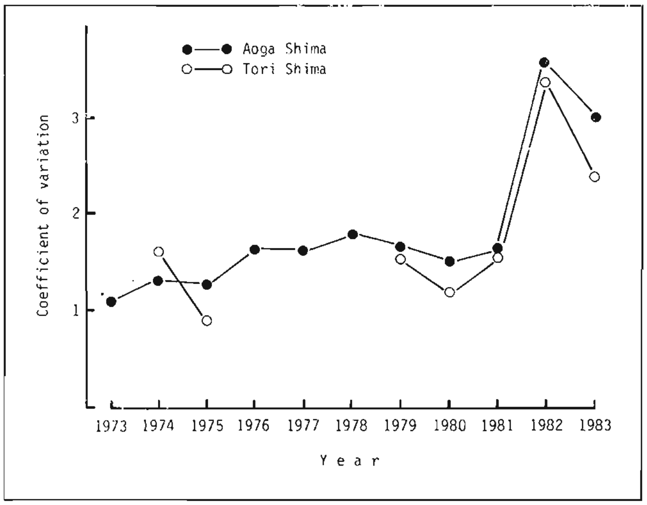


Figure 6.—Coefficient of variation of catch-per-cruise of alfonsin in the Aoga Shima and Tori Shima fishing grounds, 1973-83.

CITATION

KUBO, I., and T. YOSHIHARA.
1955. Suisan shigengaku (science of fishery resources). [In Jpn.] Kyoritu Shuppan, Tokyo, 30 p.

Session 5. Summary

RICHARD N. UCHIDA and SIGEITI HAYASI

In the first paper in this session on stock assessment, Wetherall evaluated the condition of the pelagic armorhead stock using a nonlinear autoregressive model of the stock dynamics. Application of the model was hampered by unavailability of crucial statistics on the catches by Soviet trawlers, statistical difficulties in parameter estimation, and likely model misspecification.

Based only on Japanese catch and effort statistics, Wetherall's preliminary analysis suggested that high variability in recruitment was the chief cause of fluctuations in fishing success. The collapse of the fishery in 1978 could not easily be ascribed to excessive trawling effort. Behavior of the fishery in its early years suggested that stock independent recruitment is the norm for pelagic armorhead except at very low stock levels. Because the spawning stock is now severely depressed, a sharp reduction in fishing mortality is worth considering as a way to accelerate the stock's recovery.

In the second paper, Yamamoto presented an assessment of the stock of alfonsin in the vicinity of the Izu Islands. He noted a drastic change in fishing methods in 1978, from the "drifting barrel operation" to the more efficient "vertical bottom longline" type of fishing. His analysis revealed that the alfonsin stocks inhabiting grounds around Aoga Shima and Tori Shima have declined in recent years, possibly as a result of expansion of fishing.

In the ensuing general discussion, Wetherall pointed out that for the central North Pacific seamount fishery, the decline in catch per unit effort (CPUE) for pelagic armorhead may give an exaggerated picture of the actual armorhead stock decline, if there has been a change in trawling strategy to target alfonsin. The importance of documenting the history of trawling practices and possible changes in fishing strategy and tactics was emphasized.

To a question on the level of the spawning stock of pelagic armorhead, Wetherall replied that the stock is very much depressed, probably by at least an order of magnitude below its condition before the collapse. In related discussions, he added that he has not specifically studied any density-dependent responses of pelagic armorhead, but noted that the average size of armorhead in the catch increased when CPUE dropped drastically, suggesting the possibility of density-dependent growth in the prerecruit stages.

It was suggested during the discussion that the preexploitation stock of pelagic armorhead was probably small because the seamounts provided only limited habitat.

To a question on whether the pelagic armorhead stock assessment model is completely dependent on catch data, Wetherall replied that the model is based on the type of data now available, but is sufficiently flexible to allow modification as more information is acquired. Wetherall pointed out that the model explicitly considered only the adult stage of the pelagic armorhead and does not yet use input on the early life history phases. Conceptually, to model the prerecruit phases information on oceanographic processes and early life conditions might be incorporated, but such elaborations of the armorhead stock model would require very costly and sophisticated research and may never be feasible.

In discussions of the potential of tagging pelagic armorhead for population studies, scientists from the Honolulu Laboratory reported on their experiences in this area and indicated that such tagging is not practical. Armorhead caught on handlines are in poor condition when brought aboard, and when held in baitwells on the research vessel, or tagged and held for observation, they soon die.

It was suggested that future armorhead studies should be directed toward a critical examination of productivity over the seamounts and a study of factors affecting the distribution, development and survival of eggs, larvae, and other early life stages. Additionally, studies should focus on age composition of the seamount armorhead population. It was pointed out that through age determination it would be possible to critically examine aspects of the life history presented in an earlier session. Age and growth studies at the Honolulu Laboratory have just begun, but if the results of preliminary work are validated, life history models of pelagic armorhead could change significantly from those now described in the literature. For example, it may be found that the "fat" pelagic stage of armorhead is indeed recruited to the seamount population at an age of 2 years, as the stock model tentatively assumes. It may also be found that there is a narrow range of ages in the spawning stock, and few older individuals. If so, one might speculate that death soon after spawning is highly probable, if not certain.

In the general discussion regarding alfonsin, it was remarked that the percentage of alfonsin in the ichthyofauna is relatively large in the Emperor Seamount area compared to its representation elsewhere in its range. It was also noted that the catch of alfonsin from the Emperor Seamounts in recent years has been larger than that made in Japanese coastal waters. The relationship between alfonsin stocks in the two areas is unknown. In particular, it is not known to what degree alfonsin yields on the seamounts might be affected by fishing effort and biological production elsewhere.

Productivity and Population Maintenance of Seamount Resources and Future Research Directions

GEORGE W. BOEHLERT
Southwest Fisheries Center Honolulu Laboratory
National Marine Fisheries Service, NOAA
Honolulu, Hawaii 96822-2396

ABSTRACT

Seamounts represent ocean features whose potential for biological resources has been largely overlooked. The recent discovery of abundant fish resources in the southern Emperor Seamounts region, however, has led to fisheries development and exploitation. We have little understanding of basic biological and population characteristics such as recruitment patterns, age distribution, the stock-recruit relationship, natural mortality, and trophic relationships among seamount species to form the basis for appropriate management. Seamount fisheries differ in many respects from other fisheries so that innovative methods are needed to evaluate resource characteristics. Available information suggests that interaction of seamounts with ocean currents results in flow complexities including Taylor columns and eddies which may either increase productivity or aggregate prey organisms. Thus, seamounts may play important roles in the concentration of biological resources. Understanding the productivity and sustainability of these resources requires multidisciplinary approaches involving physical and biological oceanographic research.

INTRODUCTION

Seamounts are a dominant feature of the geomorphology of the Pacific Ocean, yet they have received relatively little study. Logistic constraints have generally limited biological investigations to small-scale efforts designed to consider the fauna present in particular locations (Pratt 1967; Raymore 1982). In the northern and central Pacific, however, the discovery of exploitable biological resources has intensified the study of the value and sustainability of seamount fishery resources in the Gulf of Alaska (Hughes 1981) and in the southern Emperor-northern Hawaiian Ridge (SE-NHR) region (Humphreys et al. 1984). Seamounts in the Gulf of Alaska have fish populations similar to those in coastal waters but unexpectedly high densities of several species of crabs (Hughes 1981), but no directed fishery has developed to exploit these resources. In the SE-NHR seamount group (Fig. 1) the development of a fishery preceded fisheries research. Since that time, new fisheries have developed, including those for bottom fishes besides pelagic armorhead, *Pseudopentaceros wheeleri* (Humphreys et al. 1984), precious corals (Grigg 1982), albacore (Yasui 1986), skipjack tuna (Inoue 1983), and squid.

Traditional fisheries research is difficult to conduct on seamounts. Seamounts are generally remote, making seasonal, repeated sampling difficult. Often, the fine-scale topography of the shallow portions of the seamounts is poorly known, although bathymetric studies continue (Smoot 1985). In the SE-NHR seamounts relatively little is known about the life history and ecology of the dominant species, their habitats, and the associated ecosystem; thus new approaches will be necessary to assess and determine the sustainability of the resource.

Although limited in area, seamounts may serve as locations for concentration and transfer of energy from the pelagic to demersal ecosystems. Demersal resources of seamounts may maintain high biomasses as a result of localized enhancement or concentration of the productivity of overlying waters. Our understanding of this productivity is largely at the hypothetical stage and few data exist. It is thus difficult to draw conclusions about possible mechanisms that maintain these large demersal populations. If productivity is indeed high, one can understand how large populations of fishes, deriving nutrition from overlying waters, could develop over time. A major concern, however, is the sustainability of these populations. On mid-Pacific seamounts, currently depressed populations of pelagic armorhead may not allow us to estimate the maximum sustainable yield. Recruitment rates and variability, the stock-recruitment relationships, and the basic ecological processes associated with seamount populations are unknown. Further, it is difficult to find other populations with which to make valid comparisons. Fish populations of seamounts are geographically isolated, but no evidence exists to suggest that stocks of dominant species are independent between seamounts. These issues will be important to address as we consider further research on seamount resources. It is the purpose of this paper to discuss hypotheses about the maintenance of seamount populations and to suggest future research.

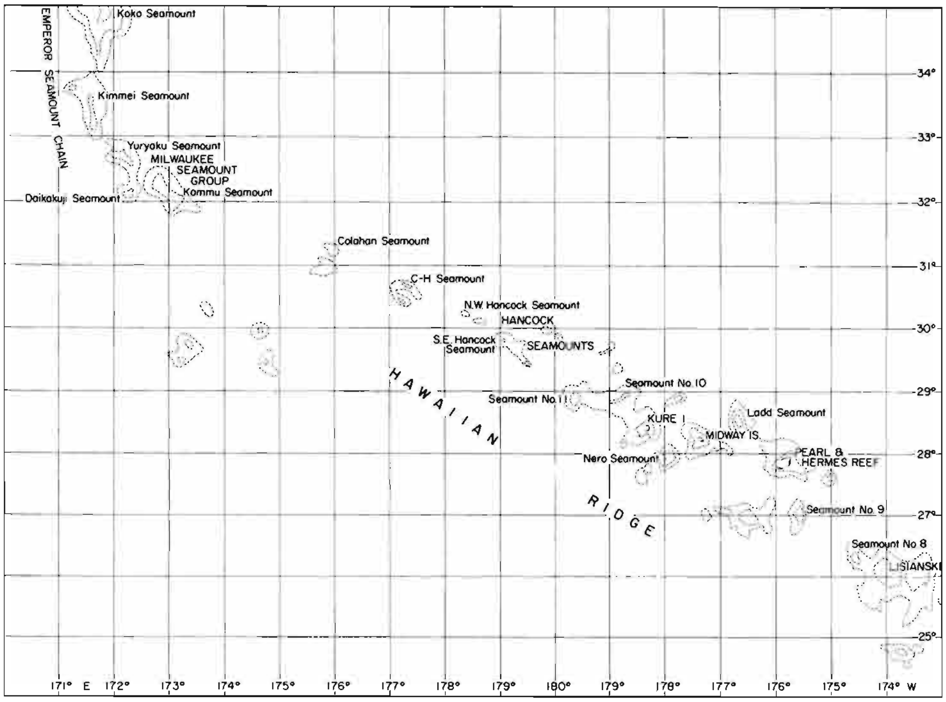


Figure 1.—The southern Emperor-northern Hawaiian Ridge seamounts. The range of the armorhead and alfonsin are largely restricted to the north by the depth of the seamounts and to the south most likely by temperature. Current flow in this region is dominated by easterly flow from the Kuroshio north of the subtropical front, but this front can vary seasonally (and interannually) between lat. 28° and 32°N (Roden 1970); south of the front, westerly flow may be observed.

ENHANCED PRODUCTIVITY OVER SEAMOUNTS

The idea that productivity is enhanced over submarine banks and seamounts is associated with complexities of physical oceanography and is derived, in large part, from the work of Uda and Ishino (1958). They suggested that topographically generated eddies enhance productivity, which is reflected in increased fish catch. In this section I will consider the evidence for increased productivity and the potential for advection and concentration of pelagic productivity from other areas to the seamount regions.

Waters overlying seamounts are often characterized by high standing stocks of plankton (Uda and Ishino 1958; Fedosova 1974; Bezrukov and Natarov 1976). Several ideas exist about the high productivity in the region of seamounts. The effects of seafloor topography on ocean currrents have been reviewed by Hogg (1980). Generally oceanography around seamounts is complicated. Taylor columns, semistationary eddies located above seamounts, have been theoretically predicted for several decades (Taylor 1917; Huppert and Bryan 1976) and actually observed over some seamounts (Owens and Hogg 1980; Richardson 1980). Taylor columns may also be generated over the SE-NHR seamounts, where eddies have been observed (Bezrukov and Natarov 1976; Cheney et al. 1980), but most oceanographic surveys sample too large a grid to detect these open-ocean mesoscale phenomena (Roden 1986). Eddies shed downstream of the seamounts, however, are an important source of variability in the oceanography of the North Pacific (Royer 1978).

Taylor columns may be important in maintaining planktonic populations and may indeed produce increased primary and secondary productivity. From a theoretical standpoint, Taylor column formation is a function of current strength, seamount morphology, stratification of the water column, and latitude (Huppert 1975). Anticyclonic flow around the seamount should exist, with cold water at its center; warm water cyclonic eddies would remain in the vicinity of the seamount at low current speeds and are shed downstream at higher current speeds (Owens and Hogg 1980). The upwelled cold water could bring nutrients to the euphotic zone, resulting in increased productivity. The stationary nature of this eddy over the seamount would also decrease the probability of advection of this productivity from the seamount, making it available to seamount populations. Some support for these arguments is provided by a comparison of waters over seamounts with adjacent waters; differences have been noted in chlorophyll content (Genin and Boehlert 1985), plankton biomass (Bezrukov and Natarov 1976), ichthyoplankton (Nellen 1973; Boehlert 1985), and micronekton (Boehlert and Seki 1984). On a small seamount in the Marianas, however, Genin and Boehlert (1985) showed that the phenomenon seemed to be transitory, but dependent upon the oncoming current strength and the morphology of the seamount.

Uda and Ishino (1958) suggested that increased pelagic productivity may enhance productivity on banks and seamounts, and stated "the concentrated areas of food animals including nekton, plankton and benthic fauna are fertilized by upwelling and accumulated or hydrobiologically limited by convergence." Indeed, the densities of pelagic armorhead alone produced catch rates of some 96 metric tons (MT) per trawling hour on Colahan Seamount in 1972 (Humphreys et al. 1984). Estimated standing stock of this species in the SE-NHR seamount region was as high as 396,000 MT in 1969 (Borets 1975; see Table 1). This species, which forms aggregations off the bottom during daytime and feeds on macroplanktonic and micronektonic animals, is considered to be semidemersal at the seamounts. The biomass of prey organisms necessary to support such a large localized predator population must be immense; it is doubtful that the standing stock under average conditions of the North Pacific Ocean could support this biomass of pelagic armorhead. An analogy may be drawn with surface schooling tunas, which apparently depend upon fronts for prey aggregation (Murphy and Shomura 1972).

Table 1.—Catch and effort from the Japanese and Soviet fisheries for armorhead, *Pseudopentaceros wheeleri*, on the SE-NHR seamounts and estimates of boarfish stock size, 1968-75. Data are from Takahashi and Sasaki (1977) for the Japanese data and Borets (1975) for the Soviet data. Soviet catch data have been converted to weight from numbers by assuming a mean weight of 0.5 kg/fish. Note the difference in units of effort between the Japanese and Soviet data.

Indices	1968	1969	1970	1971	1972	1973	1974	1975
Japanese data								
Catch (10^3 MT)	—	3.28	30.0	5.9	29.9	25.0	34.5	19.0
Fishing effort (trawling hours)	—	157	2,807	1.304	496	740	1,583	1,377
Soviet data								
Catch (10^3 MT)	49.5	162.5	145.0	17.0	98.0	170.5	39.5	46.5
Fishing effort (vessel days)	1,069	3,282	3,516	467	1,883	4,044	1,589	2,047
Stock size (10^3 MT)	310.5	396.0	329.5	221.5	364.0	355.5	173.0	160.5
Recruitment (10^3 MT)	180.5	148	77.5	193.5	140	35	51	—

Mechanisms which aggregate food organisms produced elsewhere may also contribute to energy flow on seamounts. Pereyra et al. (1969), for example, observed concentrations of demersal yellowtail rockfish, *Sebastes flavidus*, feeding in areas where midwater organisms were being advected onto the continental shelf. Isaacs and Schwartzlose (1965) observed a similar pattern on an offshore bank and suggested that such fish populations thus may not be limited by local productivity, but rather depend upon oceanic productivity and advection or hydrographic aggregation of prey sources. Midwater fishes and other organisms in scattering layers may reach very high densities during daytime (Backus et al. 1968). Alldredge and Hamner (1980) described a hydrodynamic aggregation of plankton some fortyfold over mean densities in an eddy system near a coastal headland and suggested that it may have important effects upon fish distributions. Similarly, Olson and Backus (1985) provide data and model a concentrating mechanism for midwater fishes at fronts. Interaction of currents with coastal headlands or undersea banks may be responsible for dense aggregations of several species of fishes, including widow rockfish, *Sebastes entomelas*, in the northeastern Pacific and orange roughy, *Hoplostethus atlanticus*, off New Zealand (Robertson and Grimes 1983).

Similar mechanisms of aggregation probably exist for seamounts. Hamner and Hauri (1981) have described the aggregation mechanism for a small reef, which may be analogous to an isolated seamount. In open ocean areas, where eddies have been studied, the results are equivocal; Hall and Quill (1983) observed increased sound scattering inside as compared to outside an eddy in two out of three instances. Most studies of ocean eddies, however, deal with moving eddies which often differ faunistically from the surrounding water (Griffiths and Brandt 1983) and may thus differ from those in seamount areas. Eddy research is a relatively new field and the effects on the biota are poorly understood (Owen 1981; Angel and Fasham 1983). Pelagic sampling of seamount-generated mesoscale eddies, especially for prey consumed by dominant species, will be important for understanding the mechanisms of enrichment. High abundances of micronekton may exist over seamounts, but these species may be seamount-associated rather than pelagic, such as the sternoptychid fish *Maurolicus muelleri* and the mysid *Gnathophausia longispina* over Hancock Seamount (Boehlert and Seki (1984).

MECHANISMS OF RECRUITMENT OF DEMERSAL POPULATIONS

Understanding recruitment mechanisms and variability will be critical to understanding the sustainability of seamount resources. Given the high density of virgin stocks (Table 1) and their apparent reliance on prey produced elsewhere, it is probable that space is not limiting, at least for pelagic armorhead. For pelagic armorhead, it is probable that recruitment varies from year to year in response to physical variability. Wetherall and Yong (1986) suggested that recruitment is independent of stock size over a wide range of stock sizes, and that interannual variability in recruitment is probably responsible for fluctuations in population size. This is supported in part by calculations of recruitment from Borets (1975; Table 1). One of the first suggestions of a mechanism for recruitment in seamount populations invoked the concept of stationary Taylor columns over seamounts for maintenance of pelagic larvae (Shomura and Barkley 1979). This is an extension of the ideas on the conservation of insular plankton described by Boden (1952). Others have suggested that seamount populations are derived from upstream source populations; the distances proposed have been as great as 1,100 nmi (Lutjeharms and Heydorn 1981b). This could be the case for the populations of *M. muelleri* on Hancock Seamount; large populations are present in waters of Japan (Okiyama 1981) and advection in the Kuroshio could bring them to the area of the seamount in 100-200 days (K. Mizuno, Tohoku Regional Fish. Res. Lab., Shiogama, Japan). Similar advective mechanisms may link the seamount population of alfonsin, *Beryx splendens*, to that in Japan.

Potential recruitment mechanisms must be a function of the physical oceanography and life histories of the species concerned. The physical oceanography of the SE-NHR region, including dominant effects of the North Pacific Current and the Kuroshio Extension, is complex (Fig. 1). The existence of eddies in the region has been discussed. As the currents impinge upon the Emperor Seamounts, there is a change in the hydrographic pattern, including major differences in dynamic height perturbations and current flow east as compared to west of the chain (Roden 1977; Roden et al. 1982). The region of the SE-NHR seamounts, however, is also in the subtropical Pacific front. This front is best developed from late fall to early summer (Roden 1980) and eddies are shed along the front (Roden 1981). Mizuno and White (1983) have demonstrated that interannual variations exist in the latitudinal position of the Kuroshio, and thus the position of the front, resulting in variability in eddy production. Further south, at lat. 20°-24°N, is the Subtropical Countercurrent, which could conceivably transport pelagic eggs and larvae back to Japanese waters (Uda 1970).

Whereas the effects of seamounts on large scale flow have been described, the smaller scale effects have been largely inferred due to the scale of sampling (Roden 1986). Flow perturbations in the regions of the seamounts suggest eddy formation, and indeed satellite-tracked drifters have become trapped in eddies over seamounts (Cheney et al. 1980; Richardson 1980; Lutjeharms and Heydorn 1981b). Current flow patterns over the seamounts may thus vary with seamount morphology, ocean current strength, and season.

From a biological standpoint, research must be initiated to fill important gaps in our knowledge of the life history and behavior of the species of interest. Larval, pelagic, juvenile (Borets 1979) and benthic adult pelagic armorhead and alfonsin have been captured, but distribution of the intervening stages is unclear; in any case, the pelagic young stages of both species are relatively rare.

Humphreys et al. (1984) have described the current knowledge on life histories of pelagic armorhead and alfonsin. Young alfonsin apparently are recruited to the seamounts at an age of approximately 1 year after a pelagic larval stage (Chikuni 1971). It has been suggested that pelagic armorhead are recruited to seamounts after a largely pelagic existence, but the duration of this period is in question. Soviet scientists have suggested that recruitment to the seamounts occurs at an age of 6-9 years (Vasil'kov and Borets 1978), whereas the Japanese suggested that recruitment occurs at ages of 4-5 (Chikuni 1971). These ages were determined from different methods of scale reading. Our best estimates of age at recruitment for more recent samples suggest ages of 2-3 years, and the majority of recruits are 2-year olds (J. H. Uchiyama, Southwest Fish. Center Honolulu Lab.). All of these samples, however, have been taken with sampling gear for larger fish; virtually no sampling has been conducted on the seamounts which would collect small juveniles of either species. The recent discovery of large scale nursery areas for juvenile rockfish, *Sebastes* spp., in untrawlable areas in the coastal waters of Alaska required the use of a research submersible (Carlson and Straty 1981). In situ observation from a submersible, photographic transects, or other unconventional sampling techniques may thus be necessary to assess the presence and abundance of these important life history stages and to allow a fuller understanding of the recruitment process.

Knowing the duration of the pelagic period will allow better suggestions of recruitment mechanisms. The recruitment mechanism using Taylor columns as suggested by Shomura and Barkley (1979), for example, would probably require a relatively short-lived pelagic dispersal stage but could result in localized stocks or populations on individual seamounts. Eide (1979) noted trapped eddies over banks on the continental shelf off Norway, and Sundby (1984) suggested that these features allow retention of pelagic cod eggs and larvae sufficiently long for recruitment. A similar mechanism has been suggested for Georges Bank (Smith and Morse 1985). Alternatively, some species may have very extensive pelagic dispersal stages with different recruitment mechanisms, thus resulting in mixed stocks. Lutjeharms and Heydorn (1981b) suggested that rock lobster, *Jasus tristani*, is recruited to Vema Seamount after 9 months of pelagic drifting over some 1,100 nmi. Despite the long distance over which recruitment occurs, however, the mechanism is sufficiently robust to allow large-scale recruitment of depleted populations in relatively short periods of time (Lutjeharms and Heydorn 1981a).

The geographic distribution of a species may often provide an idea of the length of larval life and dispersal capabilities. Pelagic armorhead have now been divided to Northern and Southern Hemisphere species (*Pseudopentaceros wheeleri* and *P. richardsoni*, respectively; Hardy 1983). *Pseudopentaceros wheeleri* has been captured throughout the North Pacific (Fujii 1986) but is abundant only in localized regions such as the SE-NHR seamounts. The presumed long pelagic period of this species (2-3 years) allows such long-range dispersal but calls into question the mechanism of recruitment to the population centers. It may be that the physical factors responsible for enhancing productivity or aggregating prey over seamounts may also provide clues to their locations. If our interpretation of the long pelagic period is correct, it is probable that a single stock exists on the seamounts, as preliminary electrophoretic results suggest.

It is of interest to note that the orange roughy, *Hoplostethus atlanticus*, another deepwater fishery species, has a distribution pattern analogous to that of the pelagic armorhead (Robertson and Grimes 1983). Thus effects associated with other topographic features such as banks and islands (Uda and Ishino 1958) should also be investigated.

FUTURE RESEARCH DIRECTIONS

I will divide my suggestions of future research to those addressing strictly resource-associated questions and those of a more general nature dealing with mechanistic questions. The latter research areas, which I would define as relating to the general phenomena of high productivity or enrichment over seamounts, are generally beyond the logistic and financial contraints of the resource agencies and will need to be approached on a larger, multidisciplinary scale. The resource questions, although related, by necessity take a somewhat narrower approach, using available research vessels and fisheries data.

Research related to the resource issues must address the basic questions necessary for management of the fishery and will require a combination of research on stock structure, reproduction and behavioral biology, life history, and population assessment. Research on stock structure and species separation (particularly for *Pseudopentaceros*) should begin immediately to complete the preliminary work done and to allow interpretation and planning of other work. The research design should include work on pelagic armorhead and alfonsin. For pelagic armorhead, the questions include stock differences among seamounts (which preliminary electrophoretic information suggests do not differ), between fat and lean types, and between benthic and pelagic groups. It would also be of interest to compare Northern and Southern Hemisphere specimens to aid in our understanding of the taxonomic issues and species descriptions recently published by Hardy (1983). For the alfonsin, no work has been conducted to date on stock differentiation, but it would be interesting to determine if stock differences exist among seamounts and also the relationship of seamount and the western Pacific populations described by Yamamoto (1986). The apparent transport of Japanese sardine, *Sardinops melanosticta*, to the Emperor Seamounts (Yasui 1986), provides a mechanism for transport of early life stages of alfonsin from Japanese waters to the seamount region.

As described above, a wide variety of research on life history and biology of the dominant species will be of interest. The conceptual model of pelagic armorhead life history proposed by Humphreys and Tagami (1986), for example, has many unknowns which could be tested. Another key area of interest will be a study of the spawning and early life history of the two dominant species. Pelagic armorhead spawn during winter, alfonsin during summer. Do the larval distributions differ in response to the seasonal differences in physical oceanography? Can larvae be captured in sufficient numbers to meaningfully describe the effects of currents on distribution and dispersion? Plankton surveys should be conducted which consider the vertical distribution as it relates to water column structure and horizontal distribution as it relates to the seamounts and current flow patterns. What are the recruitment strategies of these two species? Is recruitment seasonal, as is spawning? Is the Taylor column concept realistic as a mechanism for the maintenance of pelagic populations? Many of these questions can only be addressed with the help of sophisticated analysis of physical oceanography to support our understanding of the biological oceanography.

Research must also be conducted to develop a better understanding of the habitat on the seamounts and the behavior of the dominant species. What is the diel activity pattern of each species? Our current ideas of the age at recruitment are based upon captures in experimental and commercial gear, which are notoriously poor for capturing juvenile stages. It is possible that younger specimens are recruited to the seamounts but are not available to our current sampling. Alfonsin may segregate to different habitats by age or size, as described by Seki and Tagami (1986). Submersible research could elucidate several aspects of the biology, habitat, and behavior of alfonsin and pelagic armorhead on the seamounts and allow a more comprehensive understanding of data collected using conventional shipboard methods. In several areas, for example, fish are apparently abundant in regions with high relief which prevent effective trawling operations (Yamamoto et al. 1978). Survey of these areas may allow more complete assessment of the populations and also provide information on the presence of juveniles and the nature of juvenile habitat (Uzmann et al. 1977; Carlson and Straty 1981).

Population age structure must also be determined. Based upon the ages determined in different studies, it is apparent that age validation work must be completed before a full study is undertaken. In armorhead, we must develop growth curves which will include the rare, larger specimens as well as curves based upon the dominant commercial sizes, which are apparently dominated by 2- and 3-year olds. Also, capture of the smallest specimens, whether in surface collections or from submersible benthic juvenile habitat will be necessary to aid our understanding of the growth dynamics; what percentage of somatic growth occurs before recruitment to seamounts? By considering the variability in age structure from year to year and the relationship with fish morphology, we may be able to estimate the variability in recruitment from year to year. If armorhead recruitment to seamounts occurs at later ages, as currently appears probable, then there are several points in the life history where variability in recruitment or year class strength could be influenced. Very strong recruitment, for example, apparently occurred in 1972 (Borets 1975; Takahashi and Sasaki 1977; Wetherall and Yong 1986). What is the role of recruitment variability in population abundance? Can we identify environmental features which may be responsible for recruitment variability? Physical and biological factors during the pelagic phase may play a role. Based on data from 11 years between 1969 and 1981 (in Humphreys et al. 1984), there is a negative correlation ($r = -0.77$) between catch per unit effort and mean length of armorhead. This suggests that density-dependent growth may occur in the pelagic environment.

Continued data collection will be necessary for population assessment. The fisheries-dependent model developed by Wetherall and Yong (1986) should be refined as more data become available and as the above research results allow better interpretation of existing data. Some level of continued fishing effort is desirable to allow model updating, stock monitoring, and development of biomass estimates. As ancillary goals, however, we should attempt some level of fisheries-independent resource assessment. At present, we have no ideas on changes in catchability that may have occurred through the history of the fishery. We should pay particular attention to methods such as hydroacoustic assessment, which could provide further information on the behavior of the species as well as fishery-independent assessment which could cover relatively large areas during daytime when the fish are unavailable to the trawl.

A major resource-related question concerns the trophic relationship of pelagic and demersal species. Preliminary work suggests that pelagic armorhead and alfonsin share similar prey resources. Is this resource base also common with the dominant pelagic species, including albacore, skipjack tuna, and squid? If so, have stocks of any of these potential competitors increased as pelagic armorhead stocks declined? The increased catch of alfonsin is suggested by Sasaki (1986) to reflect a change in targeted species by fishermen. We should also consider the speculation raised in the workshop discussion by Sasaki, namely, that pelagic armorhead use seamounts for spawning and that the "fat" condition developed in the pelagic environment deteriorates there due to lack of food. This speculation could be treated as a testable hypothesis, namely that insufficient food resources exist to maintain the virgin populations. An ecosystem model of a specific seamount would provide a means of addressing these issues.

The questions of seamount productivity should be addressed as a mechanistic phenomenon in a multidisciplinary fashion with key contributions from biological and physical oceanography. The general research question is "What are the factors important in maintaining large populations on seamounts?" This question should be addressed, as mentioned above, as one of productivity versus advection and convergence. Not all seamounts or banks would be classified as highly productive. Is the pattern of the SE-NHR seamounts a general phenomenon, with the energy simply channeled to other trophic levels or ecosystems, or are there specific features necessary for a highly productive seamount? If the latter is true, what are the features necessary to define a productive versus a non-productive seamount? If we can define these features, it may be possible to describe areas in the sea where fisheries production may be unexpectedly high. The deep sea has traditionally been viewed as relatively low in production and biomass, but the development of the orange roughy fishery in New Zealand at depths from 800 to 1,200 m is currently providing an annual harvest in excess of 30,000 MT (Robertson and Grimes 1983). Thus knowledge of the factors important in productivity of deeper waters may aid in searching deepwater areas where resource exploration has not been conducted.

Research of this nature will require a variety of research disciplines. First, physical oceanographic studies based on closely spaced sampling grids as proposed by Roden (1986) will need to determine the conditions for development of eddies, Taylor columns, fronts, and other mesoscale features of flow complexity. Also, since we are interested in productivity effects in the euphotic zone, we must consider how these effects transfer into the mixed layer. Further research with moored current meter arrays, satellite- or radio-tracked drogues, and remote sensing will allow definition of the seasonal nature of variability in these mesoscale features. Are these features consistent within season, from year to year? What role is played by interannual variability of the kind described by Mizuno and White (1983)? Given the bottom topography and information on ocean currents, can one predict locations of eddies or gyres?

A variety of research on the biological oceanography of the water columns over seamounts is also of interest. What is the variability of primary productivity in the region of seamounts? Can a signal be detected in the levels of primary productivity associated with seamounts and if so, what is the residence time and consistency of such productivity? If enhanced productivity is present, however, further work will be necessary to demonstrate whether it is advected away or remains in the region for transfer to higher trophic levels of both fishes and benthos. Also, if there is no signal in primary productivity, can we assume that convergence and aggregation are responsible for seamounts with high biomass? As this question is considered, it should be related to areas other than seamounts, including banks (Uda and Ishino 1958), coastal headlands (Alldredge and Hamner 1980), and islands (Boden 1952; Hamner and Hauri 1981), where similar phenomena may occur.

Secondary productivity studies and descriptions of the spatial distribution and abundance of plankton and nekton will also be necessary. What is the mechanism of vertical flux of materials from surface waters to the seamounts? The dominant fish species of the SE-NHR seamounts apparently forage in the water column (Sakiura 1972; Borets 1979); is the mechanism of vertical transport a biologically mediated one? Do the benthos of seamounts show enrichment relative to shelf-slope biomass values, and if so, what is the energy source? We should undertake trophic studies which will allow better description of the ecosystem interactions in seamount regions. In this manner, preliminary models of the energy flow and higher trophic level production could be estimated. Does the combination of virgin stocks of demersal seamount populations and the pelagic populations require higher energy levels than average regional primary productivity would indicate? This may be a productive preliminary approach to assessing research questions on seamount oceanography.

In conclusion, seamounts represent an ocean feature whose potential for biological resources has been largely overlooked. Although seamounts may never represent a major contribution to world fishery resources, rational exploitation of the seamount resources requires a great deal of information before we can expect management to sustain populations. The armorhead is characterized by a broad feeding range, a wide variety of prey organisms, rapid growth, and early maturity. These features suggest that proper management of this resource could result in a significant, sustainable yield. The scientific questions associated with seamount oceanography and productivity are important to understanding the dynamics of seamount ecosystems.

CITATIONS

ALLDREDGE, A. L., and W. M. HAMNER.
1980. Recurring aggregations of zooplankton by a tidal current. Estuarine Coastal Mar. Sci. 10:31-37.

ANGEL, M. V., and M. J. R. FASHAM.
1983. Eddies and biological processes. *In* A. R. Robinson (editor), Eddies in marine science, p. 492-541. Springer Verlag, N.Y.

BACKUS, R. H., J. E. CRADDOCK, R. L. HAEDRICH, D. L. SHORES, J. M. TEAL, A. S. WING, G. W. MEAD, and W. D. CLARKE.
1968. *Ceratoscopelus maderensis*: Peculiar sound-scattering layer identified with this myctophid fish. Science (Wash. D.C.) 160:991-993.

BEZRUKOV, Y. F., and V. V. NATAROV.
1976. Formation of abiotic conditions over the submarine eminences of some regions of the Pacific Ocean. [In Russ.] Izv. Pac. Sci. Res. Inst. Fish. Oceanogr. (TINRO) 100:93-99. (Engl. transl. by W. G. Van Campen, 1983; available Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, Honolulu, HI 96822-2396.)

BODEN, B. P.
1952. Natural conservation of insular plankton. Nature 169:697.

BOEHLERT, G. W.
1985. Effects of Southeast Hancock Seamount on the pelagic ecosystem. [Abstr.] EOS, Trans. Am. Geophys. Union 66:1336.

BOEHLERT, G. W., and M. P. SEKI.
1984. Enhanced micronekton abundance over mid-Pacific seamounts. [Abstr.] EOS, Trans. Am. Geophys. Union 65:928.

BORETS, L. A.
1975. Some results of studies on the biology of the boarfish (*Pentaceros richardsoni* Smith). [In Russ.] Invest. Biol. Fish. Fish. Oceanogr. TINRO, Vladivostok 6:82-90. (Engl. transl. by W. G. Van Campen, 1984, 9 p., Transl. No. 97; available Southwest Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396.)
1979. The population structure of the boarfish, *Pentaceros richardsoni*, from the Emperor Seamounts and the Hawaiian Ridge. J. Ichthyol. 19(3):15-20.

CARLSON, H. R., and R. R. STRATY.
1981. Habitat and nursery grounds of Pacific rockfish, *Sebastes* spp., in rocky coastal areas of southeastern Alaska. Mar. Fish. Rev. 43(7):13-19.

CHENEY, R. E., P. L. RICHARDSON, and K. NAGASAKA.
1980. Tracking a Kuroshio cold ring with a free-drifting surface buoy. Deep-Sea Res. 27A:641-654.

CHIKUNI, S.
1971. Groundfish on the seamounts in the North Pacific. [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 19:1-14. (Fish. Res. Board Can. Transl. No. 2130.)

EIDE, L. I.
1979. Evidence of a topographically trapped vortex on the Norwegian continental shelf. Deep-Sea Res. 26:601-621.

FEDOSOVA, R. A.
1974. Distribution of some copepod species in the vicinity of the underwater Hawaiian Ridge. Oceanology 14:724-727.

FUJII, E.
1986. The zoogeographical features of fishes in the vicinity of seamounts. *In* R. N. Uchida, S. Hayasi, and G. W. Boehlert (editors), Environment and resources of seamounts in the North Pacific, p. 67-69. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 43.

GENIN, A., and G. W. BOEHLERT.
1985. Dynamics of temperature and chlorophyll structures above a seamount: An oceanic experiment. J. Mar. Res. 43:907-924.

GRIFFITHS, F. B., and S. B. BRANDT.
1983. Mesopelagic crustacea in and around a warm-core eddy in the Tasman Sea off Eastern Australia. Aust. J. Mar. Freshwater Res. 34:609-623.

GRIGG, R. W.
1982. Precious coral in the Pacific; economics and development potential. INFOFISH Marketing Dig. 2:8-11.

HALL, M., and A. F. QUILL.
1983. Biological sound scattering in an ocean eddy. Aust. J. Mar. Freshwater Res. 34:563-572.

HAMNER, W. M., and I. R. HAURI.
1981. Effects of island mass: Water flow and plankton pattern around a reef in the Great Barrier Reef lagoon, Australia. Limnol. Oceanogr. 26:1084-1102.

HARDY, G. S.
1983. A revision of the fishes of the Family Pentacerotidae (Perciformes). N.Z. J. Zool. 10:177-220.

HOGG, N. G.
1980. Effects of bottom topography on ocean currents. *In* GARP Publication Series 23:167-205. WMO-ICSU.

HUGHES, S. E.
1981. Initial U.S. exploration of nine Gulf of Alaska seamounts and their associated fish and shellfish resources. Mar. Fish. Rev. 43 (1):26-33.

HUMPHREYS, R. L., Jr., and D. T. TAGAMI.
1986. Review and current status of research on the biology and ecology of pelagic armorhead. *In* R. N. Uchida, S. Hayasi, and G. W. Boehlert (editors), Environment and resources of seamounts in the North Pacific, p. 55-62. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 43.

HUMPHREYS, R. L., Jr., D. T. TAGAMI, and M. P. SEKI.
1984. Seamount fishery resources within the southern Emperor-northern Hawaiian Ridge area. *In* R. W. Grigg, and K. Y. Tanoue (editors), Proceedings of the Symposium on Resource Investigations in the Northwestern Hawaiian Islands, Vol. 1, May 25-27, 1983, University of Hawaii, Honolulu, Hawaii, p. 283-327. UNIHI-SEAGRANT-MR-84-01.

HUPPERT, H. E.
1975. Some remarks on the initiation of inertial Taylor columns. J. Fluid Mech. 67:312-347.

HUPPERT, H. E., and K. BRYAN.
1976. Topographically generated eddies. Deep-Sea Res. 23:655-679.

INOUE, M.
1983. Exploitation of fishing grounds of southward migrants of fall skipjacks in the northwestern Pacific Ocean. [In Jpn., Engl. summ.] J. Fac. Mar. Sci. Tech., Tokai Univ. 17:121-130.

ISAACS, J. D., and R. A. SCHWARTZLOSE.
1965. Migrant sound scatterers: Interactions with the sea floor. Science (Wash. D.C.) 150:1810-1813.

LUTJEHARMS, J. R. E., and A. E. F. HEYDORN.
1981a. Recruitment of rock lobster on Vema Seamount from the islands of Tristan da Cunha. Deep-Sea Res. 28A:1237.

LUTJEHARMS, J. R. E., and A. E. F. HEYDORN.
1981b. The rock-lobster (*Jasus tristani*) on Vema Seamount: Drifting buoys suggest a possible recruiting mechanism. Deep-Sea Res. 28A: 631-636.

MIZUNO, L., and W. B. WHITE.
1983. Annual and interannual variability in the Kuroshio Current system. J. Phys. Oceanogr. 13:1847-1867.

MURPHY, G. I., and R. S. SHOMURA.
1972. Pre-exploitation abundance of tunas in the equatorial central Pacific. Fish. Bull., U.S. 70:875-913.

NELLEN, W.
1973. Untersuchungen zur Verteilung von Fischlarven und Plankton im Gebiet der Grossen Meteorbank (Investigations on the distribution of fish larvae and plankton near and above the Great Meteor Seamount.) Meteor Forschungsergeb. Reihe D-Biol. 13:47-69.

OKIYAMA, M.
1981. Abundance and distribution of eggs and larvae of a sternoptychid fish, *Maurolicus muelleri*, in the Japan Sea, with comments on the strategy for successful larval life. Rapp. P-V. Réun. Cons. Int. Explor. Mer 178:246-247.

OLSON, D. B., and R. H. BACKUS.
1985. The concentrating of organisms at fronts: a cold-water fish and a warm-core Gulf Stream ring. J. Mar. Res. 43:113-137.

OWEN, R. W.
1981. Fronts and eddies in the sea: Mechanisms, interactions, and biological effects. *In* A. R. Longhurst (editor), Analysis of marine ecosystems, p. 197-233. Acad. Press, N.Y.

OWENS, W. B., and N. G. HOGG.
1980. Oceanic observations of stratified Taylor columns near a bump. Deep-Sea Res. 27A:1029-1045.

PEREYRA, W. T., W. G. PEARCY, and F. E. CARVEY, Jr.
1969. *Sebastodes flavidus*, a shelf rockfish feeding on mesopelagic fauna, with consideration of the ecological implications. J. Fish. Res. Board Can. 26:2211-2215.

PRATT, R. M.
1967. Photography of seamounts. *In* J. B. Hersey (editor), Deep-sea photography, p. 145-158. Johns Hopkins Oceanogr. Stud. 3. Johns Hopkins Press, Baltimore.

RAYMORE, P. A., Jr.
1982. Photographic investigations on three seamounts in the Gulf of Alaska. Pac. Sci. 36:15-34.

RICHARDSON, P. L.
1980. Anticyclonic eddies generated near the Corner Rise seamounts. J. Mar. Res. 38:673-686.

ROBERTSON, D. A., and P. J. GRIMES.
1983. The New Zealand orange roughy fishery. *In* J. L. Taylor and G. G. Baird (editors), New Zealand finfish fisheries: The resources and their management, p. 15-20. Trade Publ. Ltd., Auckland. [Also Proceedings, Conference on New Zealand Fishery Resources.]

RODEN, G. I.
1970. Aspects of the mid-Pacific transition zone. J. Geophys. Res. 75:1097-1109.
1977. Long wave disturbances of dynamic height in the North Pacific. J. Phys. Oceanogr. 7:41-49.
1980. On the subtropical frontal zone north of Hawaii during winter. J. Phys. Oceanogr. 10:342-362.
1981. Mesoscale thermohaline, sound velocity and baroclinic flow structure of the Pacific subtropical front during the winter of 1980. J. Phys. Oceanogr. 11:658-675.
1986. Aspects of oceanic flow and thermohaline structure in the vicinity of seamounts. *In* R. N. Uchida, S. Hayasi, and G. W. Boehlert (editors), Environment and resources of seamounts in the North Pacific, p. 3-12. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 43.

RODEN, G. I., B. A. TAFT, and C. C. EBBSEMEYER.
1982. Oceanographic aspects of the Emperor Seamounts region. J. Geophys. Res. 87:9537-9552.

ROYER, T. C.
1978. Ocean eddies generated by seamounts in the North Pacific. Science (Wash. D.C.) 199:1063-1064.

SAKIURA, H. (translator).
1972. The pelagic armorhead, *Pentaceros richardsoni*, fishing grounds off the Hawaiian Islands, as viewed by the Soviets (So-Ren kara mita Hawaii oki kusakari tsubodai gyojyo). [In Jpn.] Suisan Shuho (The Fishing & Food Industry Weekly) 658:28-31. (Engl. transl. by T. Otsu, 1977, 7 p., Transl. No. 17; available Southwest Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396.)

SASAKI, T.
1986. Development and present status of Japanese trawl fisheries in the vicinity of seamounts. *In* R. N. Uchida, S. Hayasi, and G. W. Boehlert (editors), Environment and resources of seamounts in the North Pacific, p. 21-30. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 43.

SEKI, M. P., and D. T. TAGAMI.
1986. Review and present status of handline and bottom longline fisheries for alfonsin. *In* R. N. Uchida, S. Hayasi, and G. W. Boehlert (editors), Environment and resources of seamounts in the North Pacific, p. 31-35. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 43.

SHOMURA, R. S., and R. A. BARKLEY.
1979. Ecosystem dynamics of seamounts –a working hypothesis. *In* Proc. 4th Symp. Co-op. Study of the Kuroshio and Adjacent Regions, p. 789-790. Saikon Publ. Co., Tokyo, Japan.

SMITH, W. G., and W. W. MORSE.
1985. Retention of larval haddock *Melanogrammus aeglefinus* in the Georges Bank region, a gyre-influenced spawning area. Mar. Ecol. Prog. Ser. 24:1-13.

SMOOT, N. C.
1985. Guyot and seamount morphology and tectonics of the Hawaiian-Emperor elbow by multi-beam sonar. Mar. Geol. 64:203-215.

SUNDBY, S.
1984. Influence of bottom topography on the circulation at the continental shelf off northern Norway. Fiskeridir. Skr. Ser. Havunders. 17:501-519.

TAKAHASHI, Y., and T. SASAKI.
1977. Trawl fishery in the central North Pacific seamounts (Kita Taiheiyo chubu kaizan ni okeru tororu gyogyo). Northern waters groundfish fishery—data (3) (Hokuyo soko-uo gyogyo—Shiryo (3)). [In Jpn.] Div. Northern Waters Groundfish Resour., Far Seas Fish. Res. Lab., 45 p. (Engl. transl. by T. Otsu, 1977, 49 p., Transl. No. 22; available Southwest Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu HI 96822-2396.)

TAYLOR, G. I.
1917. Notion of solids in fluids when the flow is not irrotational. Proc. R. Soc. Edinb. Sect. A93:99-113.

UDA, M.
1970. Fishery oceanographic studies of frontal eddies and transport associated with the Kuroshio system including the "subtropical countercurrent." *In* J. C. Marr (editor), The Kuroshio, p. 593-604. East-West Center Press, Honolulu.

UDA, M., and M. ISHINO.
1958. Enrichment pattern resulting from eddy systems in relation to fishing grounds. J. Tokyo Univ. Fish. 44:105-129.

UZMANN, J. R., R. A. COOPER, R. B. THEROUX, and R. L. WIGLEY.
1977. Synoptic comparison of three sampling techniques for estimating abundance and distribution of selected megafauna: Submersible vs camera sled vs otter trawl. Mar. Fish. Rev. 39(12):11-19.

VASIL'KOV, V. P., and L. A. BORETS.
1978. Determining the age of boarfishes by spectrophotometric analysis of scale structure. Sov. J. Mar. Biol. 4(1):545-548.

WETHERALL, J. A., and M. Y. Y. YONG.
1986. Problems in assessing the pelagic armorhead stock on the central North Pacific seamounts. *In* R. N. Uchida, S. Hayasi, and G. W. Boehlert (editors), Environment and resources of seamounts in the North Pacific, p. 73-85. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 43.

YAMAMOTO, K.
1986. A review of the fishery and catch per cruise for alfonsin stocks in the vicinity of Izu islands. *In* R. N. Uchida, S. Hayasi, and G. W. Boehlert (editors), Environment and resources of seamounts in the North Pacific, p. 87-91. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 43.

YAMAMOTO, S., K. ISHII, S. SASKI, and T. MEGURO.
1978. Outlines of fisheries investigation on the Emperor Seamounts by the RV *Hokusei Maru* in 1977 and some technical problems. [In Jpn.] Bull. Jpn. Soc. Fish. Oceanogr. 33:56-64. (Engl. transl. by T. Otsu, 1984, 24 p., Transl. No. 91; available Southwest Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu HI 96822-2396.)

YASUI, M.
1986. Albacore, *Thunnus alalunga*, pole-and-line fishery around the Emperor Seamounts. *In* R. N. Uchida, S. Hayasi, and G. W. Boehlert (editors), Environment and resources of seamounts in the North Pacific, p. 37-40. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 43.

Session 6. Summary

RICHARD N. UCHIDA and SIGEITI HAYASI

The single paper presented in this session reviewed gaps in our knowledge about seamount populations, discussed the reasons for enhanced productivity over seamounts including Taylor column formation, and looked at potential recruitment mechanisms of demersal populations. Much of the presentation addressed future research directions including resource-associated questions and mechanistic questions.

Resource issues that need to be addressed include research on stock structure, reproduction and behavioral biology, life history, and population assessment. Furthermore, research must be conducted to gain a better understanding of the trophic relationship of pelagic and demersal species.

Mechanistic questions would address such problems as factors important in maintaining large populations on seamounts, sampling strategy to measure physical parameters, and determining primary and secondary productivity and their variability in the vicinity of seamounts.

During the ensuing discussion, a question posed was whether studies should be concentrated on extreme edges of seamount chains or on all of them within the chain. The reply indicated that research should be centered around several seamounts in one area of the chain rather than to confine it to the extremes or to expand the investigation to try to cover everything within the chain. From the standpoint of physical oceanographic research, it was brought out that good results could be obtained from sampling just two or three selected seamounts which would provide comparative data on different kinds of interaction one is likely to see between currents and seamounts.

Discussion brought out that seamount investigation should not be construed as research on an isolated ecosystem. Rather, the investigators should include other seamounts to get an accurate picture of the total ecosystem in the vicinity of seamounts. In describing where pelagic armorhead and alfonsin would fit into the ecosystem, it was suggested that these two species would probably be included in a demersal-benthos ecosystem.

A question of whether pelagic armorhead is epipelagic or mesopelagic stimulated much discussion. Small to large pelagic armorhead can be found at shallow depths of less than 200 m in the pelagic environment. This brought out a question of whether "fat" fish can be actually thought of as pelagic, as advocated by the hypothesized life history and also whether lean fish are pelagic at some point. Sasaki replied that he did not think that "lean" fish were in the pelagic phase.

Attention was then focused on prey items of the pelagic armorhead and alfonsin. Because many prey items were also found associated with the deep scattering layer, it was pointed out that both species can obtain food energy from the pelagic as well as the benthic regime.

It was also brought out that juvenile pelagic armorhead have been found in dense aggregations by whaling ships in the Gulf of Alaska and that stomach contents from whales included this species. It was suggested that in studying the transfer of energy among seamount-associated resources, a more productive approach would be to back calculate the biological production from higher to lower trophic levels than vice versa.

The discussion session was also opened to allow a brief presentation of the results of a study on aspects of seamount ecology in waters off the Southern California Bight and in the mid-Pacific. Genin reported that the physical phenomena induced by the presence of a seamount would primarily affect the benthic and epibenthic communities on these and adjacent seamounts rather than the local epipelagic realm. Intense current sweeping past the seamount summit would prevent sediment accumulation but would enhance the filtering rate of suspension feeders which dominated the benthic community over the seamount.

Appendix
List of Participants

Aizawa, M.	Tokyo University Museum, Japan
Alton, M. S.	Northwest and Alaska Fisheries Center, National Marine Fisheries Service, NOAA, Seattle, WA 98115-0070
Aoki, I.	Faculty of Marine Science and Technology, Tokai University, Shimizu, Shizuoka, 424 Japan
Aoki, M.	Faculty of Marine Science and Technology, Tokai University, Shimizu, Shizuoka, 424 Japan
Barrett, I.	Southwest Fisheries Center, National Marine Fisheries Service, NOAA, La Jolla, CA 92038-0271
Bartoo, N.	Southwest Fisheries Center, National Marine Fisheries Service, NOAA, La Jolla, CA 92038-0271
Boehlert, G. W.	Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, Honolulu, HI 96822-2396
Chung, H.	Taiwan Fisheries Research Institute, Keelung, Taipei, Republic of China
Fujii, E.	Tokai Regional Fisheries Research Laboratory, Tokyo, 104 Japan
Fuyuki, K.	Nichiro Gyogyo Co., Ltd., Trawl Department, Tokyo, 100 Japan
Genin, A.	Scripps Institution of Oceanography, University of California, La Jolla, CA 92093
Grigg, R. W.	Hawaii Institute of Marine Biology, University of Hawaii, Kaneohe, HI 96744
Hanamoto, E.	Kanagawa Prefectural Fisheries Experimental Station, Miura, Kanagawa, 238-02 Japan
Hatanaka, H.	Far Seas Fisheries Research Laboratory, Shimizu, Shizuoka, 424 Japan
Hayasi, S.	Far Seas Fisheries Research Laboratory, Shimizu, Shizuoka, 424 Japan
Hirakawa, M.	Kyokuyo Co., Ltd., Trawl Department No. 2, Tokyo, 100 Japan
Honda, M.	Fisheries and Production Division, Taiyo Fishery Co., Ltd., Tokyo, 100 Japan
Humphreys, R. L., Jr.	Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, Honolulu, HI 96822-2396
Ichii, T.	Far Seas Fisheries Research Laboratory, Shimizu, Shizuoka, 424 Japan
Ikeda, I.	Far Seas Fisheries Research Laboratory, Shimizu, Shizuoka, 424 Japan
Imai, A.	Faculty of Agriculture, University of Tokyo, Tokyo, 113 Japan
Inada, T.	Japan Marine Fishery Resource Research Center, Tokyo, 102 Japan
Inoue, M.	Faculty of Marine Science and Technology, Tokai University, Shimizu, Shizuoka, 424 Japan
Iwasaki, Y.	Shimizu Branch of Customs, Administration Office, Shimizu, Shizuoka, 424 Japan
Kami, H. T.	Government of Guam, Department of Agriculture, Division of Aquatic and Wildlife Resources, Guam, Mariana Islands 96921
Kase, H.	Taiyo Fishery, Fisheries and Production Division, Co., Ltd., Tokyo, 100 Japan
Katsuyama, K.	Far Seas Fisheries Research Laboratory, Shimizu, Shizuoka, 424 Japan
Kawahara, S.	Far Seas Fisheries Research Laboratory, Shimizu, Shizuoka, 424 Japan
Keister, L.	*Townsend Cromwell*, National Ocean Service, NOAA, Snug Harbor, Honolulu, HI 96817
Kikawa, S.	Far Seas Fisheries Research Laboratory, Shimizu, Shizuoka, 424 Japan
Koami, H.	Sea Sphere Research Institute, Yaizu, Japan
Kobayashi, H.	Faculty Marine Science and Technology, Tokai University, Shimizu, Shizuoka, 424 Japan
Kono, H.	Faculty of Agriculture, Tokyo University, Tokyo, 113 Japan
Kono, H.	Far Seas Fisheries Research Laboratory, Shimizu, Shizuoka, 424 Japan
Kume, S.	Far Seas Fisheries Research Laboratory, Shimizu, Shizuoka, 424 Japan
Kuroiwa, M.	Japan Marine Fishery Resource Research Center, Tokyo, 102 Japan

Matsumura, S.	Far Seas Fisheries Research Laboratory, Shimizu, Shizuoka, 424 Japan
Miyabe, N.	Far Seas Fisheries Research Laboratory, Shimizu, Shizuoka, 424 Japan
Mori, M.	Japanese Fisheries Agency, Research Division, Research Department, Chiyoda-ku, Tokyo, 100 Japan
Nakamura, I.	Misaki Marine Biological Institute, Faculty of Agriculture, Kyoto University, Kyoto, 625 Japan
Nishikawa, Y.	Far Seas Fisheries Research Laboratory, Shimizu, Shizuoka, 424 Japan
Ohsumi, S.	Far Seas Fisheries Research Laboratory, Shimizu, Shizuoka, 424 Japan
Okada, K.	Far Seas Fisheries Research Laboratory, Shimizu, Shizuoka, 424 Japan
Otaki, H.	Far Seas Fisheries Research Laboratory, Shimizu, Shizuoka, 424 Japan
Polovina, J. J.	Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, Honolulu, HI 96822-2396
Roden, G. I.	University of Washington, School of Oceanography, WB-10, Seattle, WA 98195
Saito, N.	Faculty of Marine Science and Technology, Tokai University, Shimizu, Shizuoka, 424 Japan
Sasaki, T.	Far Seas Fisheries Research Laboratory, Shimizu, Shizuoka, 424 Japan
Sato, T.	Far Seas Fisheries Research Laboratory, Shimizu, Shizuoka, 424 Japan
Sato, Y.	Yokohama National University, Yokohama, 240 Japan
Seki, M. P.	Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, Honolulu, HI 96822-2396
Shimadzu, Y.	Far Seas Fisheries Research Laboratory, Shimizu, Shizuoka, 424 Japan
Shomura, R. S.	Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, Honolulu, HI 96822-2396
Suzuki, Z.	Far Seas Fisheries Research Laboratory, Shimizu, Shizuoka, 424 Japan
Tagami, D. T.	Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, Honolulu, HI 96822-2396
Takizawa, K.	Hokoku Suisan Co., Ltd., Tokyo, 104 Japan
Teshima, K.	Far Seas Fisheries Research Laboratory, Shimizu, Shizuoka, 424 Japan
Uchida, R. N.	Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, Honolulu, HI 96822-2396
Ueyanagi, S.	Faculty of Marine Science and Technology, Tokai University, Shimizu, Shizuoka, 424 Japan
Uozumi, Y.	Far Seas Fisheries Research Laboratory, Shimizu, Shizuoka, 424 Japan
Uto, M.	Far Seas Fisheries Research Laboratory, Shimizu, Shizuoka, 424 Japan
Watanabe, M.	Nihon Suisan Co., Ltd., Trawl Department, Tokyo, 100 Japan
Wetherall, J. A.	Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, Honolulu, HI 96822-2396
Yamakawa, S.	University of Tokyo, Faculty of Agriculture, Tokyo, 113 Japan
Yamamoto, K.	Shizuoka Prefectural Fisheries Experimental Station, Izu Branch, Shizuoka, 425 Japan
Yamanaka, H.	Far Seas Fisheries Research Laboratory, Shimizu, Shizuoka, 424 Japan
Yamanaka, I.	Japan Fisheries Information Center, Tokyo, 110 Japan
Yasui, M.	Shizuoka Prefectural Fisheries Experimental Station, Izu Branch, Shizuoka, 425 Japan
Yukinawa, M.	Far Seas Fisheries Research Laboratory, Shimizu, Shizuoka, 424 Japan