769

Property of
NOAA Miami Library
4301 Rickenbacker Causeway
Miami, Florida 33149

NOAA Technical Report NMFS SSRF-769

Krill and Its Utilization: A Review

John D. Kaylor and Robert J. Learson

July 1983

SH
11
A335
no.769

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

NOAA MIAMI BRANCH LIBRARY
OAOO SH 11.A335 no.769
Kaylor, John Krill and its utilization
3 9282 0000 6271 0

NOAA TECHNICAL REPORTS

National Marine Fisheries Service, Special Scientific Report—Fisheries

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 optimum use of the resources. 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 Special Scientific Report—Fisheries series was established in 1949. The series carries reports on scientific investigations that document long-term continuing programs of NMFS, or intensive scientific reports on studies of restricted scope. The reports may deal with applied fishery problems. The series is also used as a medium for the publication of bibliographies of a specialized scientific nature.

NOAA Technical Reports NMFS SSRF 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 D822, User Services Branch, Environmental Science Information Center, NOAA, Rockville, MD 20852. Recent SSRF's are:

726. The Gulf of Maine temperature structure between Bar Harbor, Maine, and Yarmouth, Nova Scotia, June 1975–November 1976. By Robert J. Pawlowski. December 1978, iii + 10 p., 14 figs., 1 table.

727. Expendable bathythermograph observations from the NMFS/MARAD Ship of Opportunity Program for 1975. By Steven K. Cook, Barclay P. Collins, and Christine S. Carty. January 1979, iv + 93 p., 2 figs., 13 tables, 54 app. figs.

728. Vertical sections of semimonthly mean temperature on the San Francisco-Honolulu route: From expendable bathythermograph observations, June 1966–December 1974. By J. F. T. Saur, L. E. Eber, D. R. McLain, and C. E. Dorman. January 1979, iii + 35 p., 4 figs., 1 table.

729. References for the identification of marine invertebrates on the southern Atlantic coast of the United States. By Richard E. Dowds. April 1979, iv + 37 p.

730. Surface circulation in the northwestern Gulf of Mexico as deduced from drift bottles. By Robert F. Temple and John A. Martin. May 1979, iii + 13 p., 8 figs., 4 tables.

731. Annotated bibliography and subject index on the shortnose sturgeon, *Acipenser brevirostrum*. By James G. Hoff. April 1979, iii + 16 p.

732. Assessment of the Northwest Atlantic mackerel, *Scomber scombrus*, stock. By Emory D. Anderson. April 1979, iv + 13 p., 9 figs., 15 tables.

733. Possible management procedures for increasing production of sockeye salmon smolts in the Naknek River system, Bristol Bay, Alaska. By Robert J. Ellis and William J. McNeil. April 1979, iii + 9 p., 4 figs., 11 tables.

734. Escape of king crab, *Paralithodes camtschatica*, from derelict pots. By William L. High and Donald D. Worlund. May 1979, iii + 11 p., 5 figs., 6 tables.

735. History of the fishery and summary statistics of the sockeye salmon, *Oncorhynchus nerka*, runs to the Chignik Lakes, Alaska, 1888–1966. By Michael L. Dahlberg. August 1979, iv + 16 p., 15 figs., 11 tables.

736. A historical and descriptive account of Pacific coast anadromous salmonid rearing facilities and a summary of their releases by region, 1960–76. By Roy J. Whale and Robert Z. Smith. September 1979, iv + 40 p., 15 figs., 25 tables.

737. Movements of pelagic dolphins (*Stenella* spp.) in the eastern tropical Pacific as indicated by results of tagging, with summary of tagging operations, 1969–76. By W. F. Perrin, W. E. Evans, and D. B. Holts. September 1979, iii + 14 p., 9 figs., 8 tables.

738. Environmental baselines in Long Island Sound, 1972–73. By R. N. Reid, A. B. Frame, and A. F. Draxler. December 1979, iv + 31 p., 40 figs., 6 tables.

739. Bottom-water temperature trends in the Middle Atlantic Bight during spring and autumn, 1964–76. By Clarence W. Davis. December 1979, iii + 13 p., 10 figs., 9 tables.

740. Food of fifteen northwest Atlantic gadiform fishes. By Richard W. Langton and Ray E. Bowman. February 1980, iv + 23 p., 3 figs., 11 tables.

741. Distribution of gammaridean Amphipoda (Crustacea) in the Middle Atlantic Bight region. By John J. Dickinson, Roland L. Wigley, Richard D. Brodeur, and Susan Brown-Leger. October 1980, vi + 46 p., 26 figs., 52 tables.

742. Water structure at Ocean Weather Station V, northwestern Pacific Ocean, 1966–71. By D. M. Husby and G. R. Seckel. October 1980, 18 figs., 4 tables.

743. Average density index for walleye pollock, *Theragra chalcogramma*, in the Bering Sea. By Loh-Lee Low and Ikuo Ikeda. November 1980, iii + 11 p., 3 figs., 9 tables.

744. Tunas, oceanography and meteorology of the Pacific, an annotated bibliography, 1950-78, by Paul N. Sund. March 1981, iii + 123 p.

745. Dorsal mantle length-total weight relationships of squids *Loligo pealei* and *Illex illecebrosus* from the Atlantic coast of the United States, by Anne M. T. Lange and Karen L. Johnson. March 1981, iii + 17 p., 5 figs., 6 tables.

746. Distribution of gammaridean Amphipoda (Crustacea) on Georges Bank, by John J. Dickinson and Roland L. Wigley. June 1981, iii + 25 p., 16 figs., 1 table.

747. Movement, growth, and mortality of American lobsters, *Homarus americanus*, tagged along the coast of Maine, by Jay S. Krouse. September 1981, iii + 12 p., 10 figs., 8 tables.

748. Annotated bibliography of the conch genus *Strombus* (Gastropoda, Strombidae) in the western Atlantic Ocean, by George H. Darcy. September 1981, iii + 16 p.

749. Food of eight northwest Atlantic pleuronectiform fishes, by Richard W. Langton and Ray E. Bowman. September 1981, iii + 16 p., 1 fig., 8 tables.

750. World literature to fish hybrids with an analysis by family, species, and hybrid: Supplement 1, by Frank J. Schwartz. November 1981, iii + 507 p.

751. The barge *Ocean 250* gasoline spill, by Carolyn A. Griswold (editor). November 1981, iv + 30 p., 28 figs., 17 tables.

752. Movements of tagged summer flounder, *Paralichthys dentatus*, off southern New England, by F. E. Lux and F. E. Nichy. December 1981, iii + 16 p., 13 figs., 3 tables.

753. Factors influencing ocean catches of salmon, *Oncorhynchus* spp., off Washington and Vancouver Island, by R. A. Low, Jr. and S. B. Mathews. January 1982, iv + 12 p., 6 figs., 7 tables.

SH
11
A335
no.769

NOAA Technical Report NMFS SSRF-769

Krill and Its Utilization: A Review

John D. Kaylor and Robert J. Learson

July 1983

Property of
NOAA Miami Library
4301 Rickenbacker Causeway
Miami, Florida 33149

011106

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

The National Marine Fisheries Service (NMFS) does not approve, recommend or endorse any proprietary product or proprietary material mentioned in this publication. No reference shall be made to NMFS, or to this publication furnished by NMFS, in any advertising or sales promotion which would indicate or imply that NMFS approves, recommends or endorses any proprietary product or proprietary material mentioned herein, or which has as its purpose an intent to cause directly or indirectly the advertised product to be used or purchased because of this NMFS publication.

CONTENTS

Figure

Table

Krill and Its Utilization: A Review

JOHN D. KAYLOR and ROBERT J. LEARSON[1]

ABSTRACT

This article is based on a review of the literature on 1) the Antartic krill resource, 2) multinational efforts to use krill as food, and 3) technological, economic, and marketing aspects of krill. The decimation of baleen whales, significant krill predators, has brought about an apparent overabundance of this protein-rich crustacean. Since the krill biomass exceeds the world's annual tonnage of fishery products, a close examination of the potential of krill stocks is justified.

Krill is an extremely rich source of protein and fat, and there is the potential of valuable byproducts such as chitin and chitosan. However, the harvesting operation may prove to be one of somewhat low economic return. The technology of using krill to form various food products acceptable to western preferences is not yet well developed. Utilization technology seriously lags behind harvesting technology.

Finding the potential value of krill requires an appraisal of 1) feasibility of producing krill products with a reasonable degree of marketing acceptability, 2) the value of our lending technical assistance to some nation to achieve the above, and 3) the economic and international pressures that are likely to favor those nations that are already completely subsidized and have vertical integration of their fisheries.

It is widely believed that abundant, protein-rich krill could contribute substantially to the world protein food supplies. Owing to the lack of development of a krill product possessing wide appeal and the unknown economic return of this potential fishery, eventual success seems dependent on government-subsidized operations.

INTRODUCTION

The most abundant and yet relatively untapped marine food source in the world is the Antarctic krill, *Euphausia superba* Dana. This shrimp-like crustacean has several features that enhance its value for human food: 1) Biomass abundance that exceeds the world's present total annual catch of all fish and shellfish, 2) a high nutritive value, and 3) an ability to produce sustained annual harvests of tens of millions of metric tons annually.

These attributes prompted us to examine and review the feasibility of using krill for human consumption, animal consumption, and for other uses. Our approach was to first study the literature on krill dealing with Antarctic explorations dating from the years between World Wars I and II to the present. More importantly, we studied the literature on krill utilization generated in about the last dozen years, principally by the U.S.S.R., Japan, Poland, Federal Republic of Germany, and the Food and Agriculture Organization of the United Nations.

Although more than half a century has been spent in studying Antarctic krill, much is still unknown about it. Bakus et al. (1978) stated, "The most important information gaps appear to be the relationship between currents, surface rings, and krill distribution; the biology of all Antarctic krill species, feeding habits of *E. superba* in relation to its aggregation and the abundance of phytoplankton; the exact location of krill spawning areas; the causes and maintenance of swarming; longevity and mortality of krill; the rates of predation on krill by squid and fish; and the role of krill detritus in the Antarctic ecosystem."

Technologists have been trying since the early 1970's to produce acceptable krill products. Bardach and Pariser (1978) stated, "Japan and Russia have each invested about $200 million towards krill harvesting and utilization." Research expenses of this magnitude are prohibitive for private industry. Only nations can afford to speculate to this extent, still fail to produce reasonably marketable products, and still keep on spending for more research, both biological and technological, in hopes of attaining success.

A review of the many products that have been made from krill shows that whole or nearly intact krill tail meat is the only product that meets with generally wide acceptance (Grantham 1977). Successful peeling at a high rate of speed and with a high yield, so far has eluded the various investigators.

While accurate figures on the economic return are not available, we are certain that no krill expedition can be economically successful unless it is equipped to process as many products as possible from krill in addition to producing tail meats. These operations would require a high degree of technology using sophisticated processes and equipment. Some processes such as solvent extraction and acid-alkali treatments aboard a moving ship will present hazards over and above those to be expected ashore.

From a political standpoint, some of the advanced nations simply will not wait once they have perfected their food technology studies. We firmly believe that in <5 yr Japan, Poland, and the U.S.S.R. will be satisfied that they can exploit krill. Unlike our concept of feasibility, theirs embraces more than economics.

This article represents a five-part approach to the overall study. The first part concerns the krill resource itself—its distribution, magnitude, biological aspects, and pressures both present and anticipated. The second deals with the harvesting of krill including location and detection, harvesting, and the natural restrictions on an unlimited fishery. The third discusses the processing technology including fabrication into many forms for human consumption, for animal food, and for byproduct use in the form of various chemical products. The fourth deals with marketing krill. This includes a description of the types of food products made from krill by various nationals, development of domestic or foreign markets, and the need for market research and economic analyses. The last part deals with the problems that can possibly be expected to arise. Our intent is merely to call attention to their existence rather than to attempt to solve the problems they may present. We present our conclusions based upon a technological approach to utilization of

[1]Northeast Fisheries Center Gloucester Laboratory, National Marine Fisheries Service, NOAA, Emerson Avenue, Gloucester, MA 01930.

a potential but remote food resource. We acknowledge that as members of the world's greatest food exporting nation, we stand in no present need for krill and all that it may promise. As fishery technologists, however, from a nation that is a major importer of fish and fish products, we cannot ignore the activities of other nations.

THE KRILL RESOURCE

The Norwegian noun "kril" means "young fry of fish" but is generally interpreted to mean "whale food." This term was used by Norwegian whalers originally to apply to a particular shrimp-like euphausid known scientifically as *Meganyctiphanes norvegicus* that is common to North Atlantic waters. It was the basic food of baleen whales that were hunted in the 1800's. Shortly after the 1900's, whaling interests shifted to Antarctic waters where baleen whales fed upon related euphausids, chief among which was *Euphausia superba* which was later dubbed "krill." There is no known reason for the extra "l" in krill.

The South Atlantic krill differs from its North Atlantic relative in that it is larger and feeds upon phytoplankton chiefly in the form of algae, principally diatoms. The northern krill reverses the feeding role and preys upon animal life in the form of copepods although both can, under certain circumstances, reverse their roles.

For the purposes of this report, the term "krill" will mean *Euphausia superba* that is common to Antarctic waters[2]. Krill have transparent bodies and are highly luminescent at night as they bear light-producing organs on the outer side of the eyestalk, on the underside of the first four abdominal segments, and two pairs under the thorax (Hardy 1967). The carapace is enlarged and connected with all the segments of the thorax except the last. The eyes are mounted on the eyestalks, and the heart and gills are in the thorax. Both sexes have well developed swimmerets. In the female the egg pouch is located at the rear on the thorax. They are 3 to 6 cm long, and the color of living specimens is pink to brilliant red. (In dense swarms, they give the appearance of a sea of tomato soup.) Their weight ranges from 0.3 to 1.2 g.

Distribution

While krill is circumpolar in distribution, its concentration is asymmetric. Figure 1 shows a much heavier concentration in the polar Atlantic than in the polar Indian or Pacific Oceans. Historically, the greatest concentrations of baleen whales has always been in the Atlantic sector between long. 60°W and 30°E, and it is natural that the concentration of whales would be in proportion to the amount of food that they could obtain for the limited time they feed upon krill before the whales disperse.

The reasons for the concentration of krill are not yet completely understood. Soviet scientists have shown that young and mature krill are seldom found together (Makarov 1970). Usually mature krill are found to the north, and the young are found to the south. The dividing point between young and mature is placed at 1 to 1.5 yr of age, and it is the young which comprise most of the stock. The Soviets hold that the separation of the young and mature krill is due to a seasonal migration which is occasioned by the difference in horizontal movement. They maintain that the young are carried to the south as a result of their vertical migration to the depths. Mature krill that do not engage in deep vertical migrations are swept to the north. The vertical distribution of adult krill is about 90% between the surface and 100 m. Daily, vertical migrations do occur with daytime concentrations occurring between 10 and 40 m, as opposed to nighttime concentrations located from the surface to a depth of 10 m (Marr 1962).

Magnitude and Potential Yield

Estimates of the magnitude of the stock and its potential yield vary considerably because *E. superba* has a remarkably long life (25-48 mo) for a euphausid. The lack of reliable data on the productivity of Antarctic krill makes estimations of magnitude of stocks and annual yields debatable. For example, Langunov et al. (1973) placed the potential annual catch at 100 million t (metric tons), yet Gulland (1970) estimated it to be 200 million t. Using a 1 yr life span in relation to the standing crop biomass, Gulland arrived at approximately a 75 million t annual production. Allen (1971) revised Gulland's estimate by assuming a 4-yr life span of *E. superba* and claimed that the annual production figure should be 150 million t. Not all parts of the Antarctic where krill occur are as readily exploitable as the Atlantic sector, thus tending to make the total potential yield figure somewhat uncertain. A conservative estimate would place the annual harvestable yield at several tens of millions of metric tons.

Harvesting Feasibility

As used here, the term "harvesting feasibility" refers solely to the presence of concentrations of krill that would make a krill fishery successful in respect to rate and size of catch. It is a peculiarity of krill that they are marked by a very strong habit of concentrating in dense masses, so dense that they impart a discoloration to the water intense enough to be sensed by remote satellites (El Sayed 1975). The unexplained phenomenon of dense concentrations is further complicated by the fact that individuals in a particular subdivision of a patch called a "swarm" possess the same degree of maturity. One large patch of krill may be composed of several swarms of krill, and each swarm will consist entirely of either adults or juveniles with very little admixture.

The density of the patches of swarming krill are not evenly distributed in the water column. Some may easily be spotted visually near the surface, and others may be located as deep as 100 m by electronic sensing devices. Regardless of their depth, it is agreed by both scientists and practical fishermen who have been observers of the habits of krill, that the concentrations would support a high rate and volume of catch.

Political and International Pressures

For years Argentina, Australia, Chile, France, Great Britain, New Zealand, and Norway have made territorial claims in Antarctica. Many nations (U.S.A., U.S.S.R., Japan, Sweden, Belgium, and Federal Republic of Germany) have made Antarctic explorations without lodging such territorial claims. The United States, in spite of the years of exploration by Admiral Richard Byrd and others, has chosen not to make such demands in agreement with the policy announced by Secretary of State Charles Evans Hughes in 1924: "It is the opinion of this Department that the discovery of lands unknown to civilization, even when coupled with a formal taking of possession, does not support a valid claim of sovereignty, unless the discovery is followed by an actual settlement of the discovered

[2]Other species of Antarctic euphausids are: *crystallorphias, frigida, hanseni, longirostris, lucens, similis, spinifera, triacantha,* and *vallentini.*

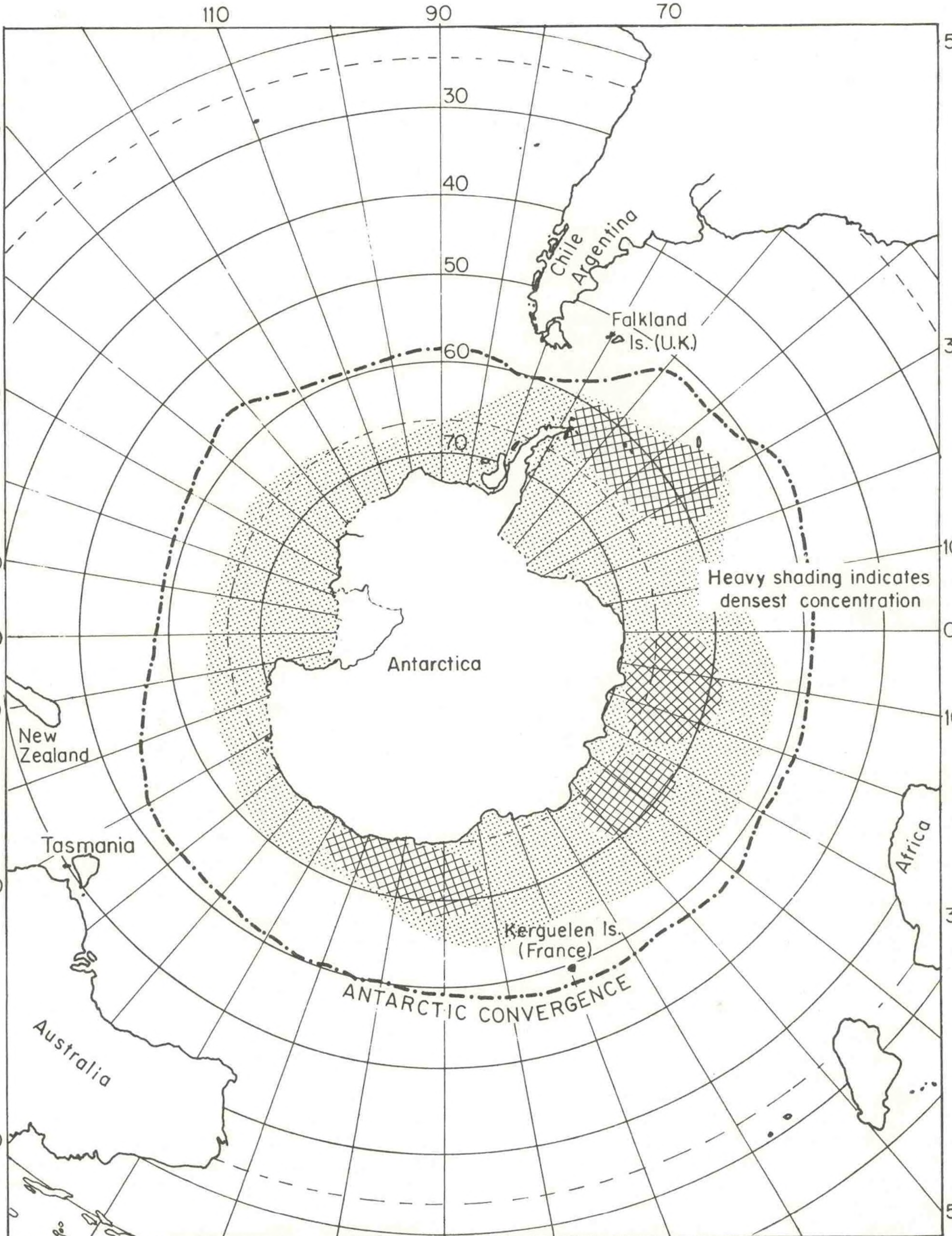

Figure 1.—Distribution of krill in the Southern Ocean. (Source: Joyner et al. 1974.)

country" (Ford 1981). This is a policy that has been reiterated many times, even when U.S. astronauts landed on the moon in 1969. Instead of claiming the moon for the United States alone, it was claimed for all mankind.

It was in this spirit that the United States persuaded Argentina, Australia, Belgium, Chile, France, Japan, New Zealand, Norway, South Africa, United Kingdom, and the U.S.S.R. to sign the Antarctic Treaty in 1959 which became effective in June 1961. Poland later became signatory, thus becoming the 13th member. This remarkable treaty reserved an entire continent for free and nonpolitical scientific investigation.

Later, Brazil, Bulgaria, Czechoslovakia, Denmark, Federal Republic of Germany, German Democratic Republic, Netherlands, and Romania became signatories. It is highly unlikely that the original land-claiming signatories of Antarctica at the time of signing ever considered extending the Antarctic Treaty into the contiguous seas. With the recent worldwide practice of extending national jurisdiction seaward for 200 mi for fishery management purposes, a point of disagreement might possibly intrude on an otherwise amicable arrangement among the signatories.

The area of greatest abundance of krill lies not far from areas claimed by several nations. It is conceivable that after 1990 when the present Antarctic Treaty expires claims may be made to extend the jurisdiction of one or more nations seaward by 200 mi. Serious discord and overlapping conflicting claims might well result not only for the potential fisheries but also for unproved petroleum reserves. The dispute between Argentina and Chile with respect to the Beagle Channel claims of each nation might well be a precursor of what may come.

LOCATING AND HARVESTING KRILL

The location (bringing a vessel to an area where there is a high probability of catch) of krill by experienced fishermen is no more difficult than it is for any other fishery (Eddie 1977). For the relatively short summer period when climatic conditions favor a krill fishery, usually dense swarms of krill are known to inhabit certain areas more than others. Historically, the southern Atlantic, more than the southern Pacific or the southern Indian Ocean, has been the haunt of baleen whales. The chief areas of krill abundance have been over the shelves and slopes and deeper water near South Georgia, in the northern part of the Weddell Sea, in the Scotia Sea north of the Orkney Islands, the South Sandwich Islands, the South Shetland Islands, in the Bransfield Strait, and in the Bellinghausen Sea (El Sayed and McWhinney 1979). Unpredictable occurrence of swarms is commonplace. In the 1979-80 season the krill crop failed to materialize in the South Georgia area. Yet, during 1980-81 First International Biomass Experiment (FIBEX) observers detected a mass of krill estimated at 10 million t near the South Shetland Islands. As Alverson (1979) stated "substantial year-to-year variations in population sizes occur which are the result of recruitment failure or changes in behavior or both." Surface fishing strategy, in addition to visual location of swarms of krill, also depends upon the presence of other natural indicator predators such as birds, seals, and whales.

The detection of deeper lying quantities of krill seems to be most effective with the vertical echo sounder. The frequency of the acoustic transmission used is between 100 and 200 kHz. For stocks of krill not visible on or near the surface, fishing echo sounders can be used to detect the fish which are feeding upon krill. Experienced fishing skippers have, in some cases, been able to distinguish between desirable krill and unwanted salpas (Eddie 1977). As yet, it has not been possible to use echo sounders to distinguish between krill of different sizes. The capability of acoustic devices to discriminate between sizes of krill may depend on frequency, frequency variation, beam width, and pulse length. It is generally agreed by both scientists and experienced skippers that with the present stocks of krill, location and detection, by and large, are not much different from regular fishing operations (Eddie 1977).

An unusual attempt at krill detection was reported to have been developed by Japanese scientists of Tokyo University of Fisheries for the 1978-79 exploration. A miniature model plane with a wing span of about 2 m would be launched from the bow of the University research vessel *Umitaka Maru.* The model plane would have a payload of 1.5 kg and would carry two motor-driven cameras and a transmitter capable of taking a total of 30 color and black-and-white photographs. The plane would be able to ascend to about 1,200 m and reach a speed of about 83 km/h. Recovery of the plane would be made with netting on the windward side of the deck. The plane's engine revolutions, rudder, elevator, and two cameras would be controlled from the deck of the ship by a hand-held transmitter (Anonymous 1979).

Several methods of capturing krill have been tried with varying degrees of success. Efforts have been made to use single-boat and two-boat purse seines, but efforts to use any kind of purse seines have been given up because 1) it is expensive and very difficult to repair seines, and 2) purse seining is primarily a good weather operation. The summer weather in the Antarctic is usually foul and very often dangerously windy for this method of capture. The most effective methods appear to be variations in surface-midwater trawls.

Early attempts at harvesting krill were based on the assumption that patches of krill were to be found chiefly at or near the surface of the ocean. It was also assumed that krill could take evasive action to avoid an approaching net or ship. (The 1981 FIBEX cruise confirmed that krill can avoid the nets.) It was considered that a ship plowing through a swarm would scatter the krill and that the best way to catch them would be to tow a surface trawl with a mouth opening wider than the trawler. Another method was to use an outrigger on each side of the trawler each one of which towed a surface trawl. An additional method was to tow a trawl on the surface and have the ship move in a curved path so that the trawl would not follow in the wake of the trawler. Another method was to affix a net to a metal frame that would form an inflexible mouth opening of the net. The whole arrangement was suspended from the side of the ship and some attempts even included the principle of continuous discharge by pump and flexible hose to a screen on the trawler deck. The screen retained the krill and the seawater escaped via the scuppers. Again, this type of catching-unloading is good only for surface krill, and it operates reasonably well only in calm weather which is a scarce commodity in the Antarctic (Eddie 1977).

Only recently (1970's) was it appreciated that patches of krill could be located well below the ocean surface in large quantities. By means of echo sounders and well designed krill trawls in the hands of skilled fishing captains, it has been established that aimed midwater trawls shot by single trawlers are the most efficient krill catchers (except whales).

Practical catching rates can be achieved by using much smaller trawls than are used in conventional fisheries. The increased drag caused by the use of small mesh in order to contain the krill without escapement, necessitates the use of smaller trawl nets. An alternative is to use a relatively large mesh trawl with a fine mesh liner. Mesh sizes for krill have ranged from as little as 8 mm (stretched) to as great as 12 to 24 mm.

The consensus of skilled skippers is that surface-midwater trawls as presently used are entirely satisfactory. The reason for their confidence is that the catching rate is, at present at least, enormously higher than the processing-preservation rate. Catching technology far outruns utilization technology.

Natural Restrictions

In any consideration of Antarctic fishing, it should be realized that nature has imposed restrictions on successful fishing on a year-round basis. The first is ice. During the Antarctic "winter" (May to November) about 22 million km^2 (60% of the total oceanic area) is covered by ice. Fishing during the winter is very difficult although the Soviets and the Poles have accomplished it. In the milder "summer" period (December to April), the ice cover is reduced to 4 million km^2 or 11% of the oceanic area. This 150-d period is the longest that is feasible for fishing of any kind, and even then the weather in early spring and late autumn is inclement.

A second less important hindrance is the constant high wind. The chief contrast to the Arctic Ocean, latitude for latitude, is the extremely high wind velocity. In this respect, it has been postulated that it may not be "beyond the bounds of possibility to conceive of a floating plant, anchored in deep water, powered by the ever-blowing westerly winds, uninhabited and automatic, and visited at intervals of months for the removal of the crustacean sludge extracted by mechanical separation. Such development would seem more promising than direct fishery in antarctic waters" (Bertram and Blyth 1956).

Fishermen and scientists have chosen to ignore the above suggestion of automated equipment powered by the ever-blowing wind. They have, instead, relied on adaptations of conventional fishery techniques. One advantage of free fishing is being able to actively seek planktonic patches of krill rather than passively waiting for krill to be drifted to the automated plant. A second advantage is the choice of product forms that can be made with human supervision.

Financial Assistance

It is highly significant that all of the nations that have sent exploratory krill operations in the last decade have been official representatives of their respective governments—either directly as government employees or as contractors to a government agency. Most prominent have been the U.S.S.R., Japan, Poland, and the Federal Republic of Germany. To a lesser extent, Chile, the United Kingdom, the German Democratic Republic, Norway, and Taiwan have experimented with krill.

The cost to outfit, crew, and operate a large ship thousands of miles away from its home port is so great that private industry cannot afford it. At present, the costs are so staggering compared with the returns that only completely government-subsidized krill explorations can be undertaken. The United Kingdom has already gone on record stating that the disadvantages of a krill operation exceed the advantages (Anonymous 1976). Further, it has stated that it would prefer to investigate the possibility of exploiting blue whiting stocks close to its shores although in very deep water.

The position of West Germany is somewhat complicated by the fact that West German processors have expressed criticism of the explorations. They definitely prefer "closer-to-home research with more immediate prospects of tangible results" (Anonymous 1977). Chile and Argentina are in the advantageous position of being able, theoretically at least, to establish land-based operations at their southern extremity. The economics and feasibility of building facilities in this desolate area of the world would have to be carefully weighed against the use of factory ships.

Norway and Taiwan interests are so deeply committed to conventional fishery operations that can be performed at a profit that it is considered unlikely that they will be serious contenders in this fishery. Japanese efforts to the present have been carried out jointly between private industry and the Japan Marine Resource Research Center. A refrigerated transport owned jointly by several companies accompanied by large trawlers to act as krill catchers was subsidized by the Fisheries Agency of Japan. If Japanese food technologists have not improved upon the final product forms of krill by the mid-1980's, it is likely that Japanese government subsidies will either cease or be greatly reduced. The aim will be to shift financial responsibility upon industry.

The U.S.S.R. has spent more years and effort than any other nation in krill research and utilization. The determination and persistence of Soviet scientists may soon result in products that will be acceptable in world markets. Poland's interest, while spanning only about 6 yr, is intense and the Poles have become competent. In the hope of resolving a quality control problem, the Northeast Fisheries Center, Gloucester Laboratory, sent an observer to the Antarctic aboard the Polish Research Vessel *Professor Siedlecki* during its 1978-79 expedition.

The United States has not shown an interest in krill harvesting or utilization in the recent past nor is it likely to in the near future. There are several reasons for its abstention from this type of fishery. The first is that we do not have any pressing need for this source of protein and fat since we are the world's largest exporter of food. The second is that as yet no product made from krill has been acceptable to western tastes and no demand exists. A third is that the private sector has no incentive to invest in the krill fishery because of prohibitive costs of maintaining a fleet in such a remote area. A fourth reason is that Americans will not willingly accept employment which requires their being away from home for such extended periods. Government subsidy such as is done by Russia and Poland would not work with Americans unless there were enormous benefits comparable with those which resulted from the construction of the Alaskan oil pipeline.

PROCESSING TECHNOLOGY

Composition

As with any fishery resource, the protein, fat, mineral, and vitamin content are related to physiological condition, age, diet, and sex of the particular animal. Grantham (1977) has summarized the results of 20 papers which report values for the proximate composition of whole krill (Table 1).

Table 1.—Proximate composition of whole *Euphausia superba:* Summary of literature values.

	% Dry weight			% Wet weight		
	Moisture %	Crude[1] protein	Crude fat	Ash	Crude[1] protein	Crude fat
Average	80.1	65.1	14.2	13.9	13.0	2.8
Mean maximum	83.1	77.5	26.0	16.7	15.4	5.1
Mean minimum	77.9	59.7	6.7	11.7	11.9	1.3

[1] Total nitrogen x 6.25, includes nonprotein material. (Source: Grantham 1977.)

The proportionate percentage of body components of whole krill according to Grantham (1977) are about 28% tail meat, about 34% cephalothorax, and about 26% carapace. The remaining 12% is exudate lost on separation of the body parts.

Protein.—According to Grantham (1977), the 13% wet weight of protein appearing in Table 1 comprises about 8.5% true protein and 2.5% free amino acids. Volatile bases, chitin, and nucleic acids account for the remainder of the nitrogen. Krill exhibits a high content (46%) of the essential amino acids, thus making krill an extremely rich source of amino acids.

Fat.—The literature reports that although the amount of fat in krill will vary with season, the composition of krill fat seems to remain quite constant. Krill fat has a high content of complex (phospho) lipids (50%), about 30-40% neutral fats (glycerides) and about 8% unsaponifiable fat. Unlike other Antarctic zooplankters, krill contains no waxes during the winter period and probably feeds on detritus in the absence of primary production (algae). According to Grantham (1977), about 70% of the fatty acids are unsaturated with the three essential fatty acids—linoleic, linolenic, and arachidonic—totaling about 5%.

Vitamins.—Significant amounts of vitamin A and the B complex group occur in krill with lesser amounts of E and D. Astaxanthin, the vitamin A precursor, is found to be high in the exoskeleton and is particularly rich in the eyes. The characteristic color of krill is due to the presence of this pigment.

Minerals.—Krill contains 28 elements in its mineral composition and is a particularly rich source of calcium, iron, magnesium, and phosphorus. Fluoride has been reported present by Bykov (1975) but Soevik and Braekkan (1979) reported that values for fluoride in krill greatly exceed the upper permissible limit of 100 mg/kg calculated as sodium fluoride established by the U.S. Food and Drug Administration (FDA) for fish protein concentrate (FPC) in 1967. They conclude that "The present values for fluoride in krill exceed this limit by more than seven times for the freeze dried and extracted meat, and 24 times for the entire shellfish. This would make krill in any form, even peeled, fail to comply with requirements for human consumption."

This warning may not be applicable because there is an essential difference between krill and FPC. The latter is a highly concentrated processed fish product arrived at by sophisticated chemical processes. In its most desirable form of tail meat, krill is a naturally occurring crustacean with no added fluoride within the meaning of the Federal Food, Drug and Cosmetic Act. In mid-1981 the FDA announced that it had decided that the edible tail meat of krill would be regarded as a food and not a food additive. It also stated that the amount of fluoride (14 ppm) in krill did not render the krill injurious to health.

Calorific value.—The reported literature values for the proximate composition of krill have been concerned with whole krill rather than the edible tail meat. Chekunova and Rynkova (1974) have determined that juvenile and adult krill have calorific values of 1.0 and 1.1 kcal/g wet weight, respectively.

Chitin.—According to Mauchline and Fisher (1969), the exoskeleton of krill accounts for about 10% of its dry weight. The high content of chitin—about 40% of the dry weight (Yanase 1975)—makes chitin a potentially valuable byproduct.

Autolytic Degradation of Whole Krill

Krill is one of the most perishable of marine products owing to the presence of very active enzymes which initiate several forms of degradation including rapid and severe autolysis. This is somewhat noteworthy in view of the generally low temperature conditions that prevail during the catching period. Mean air temperature in the areas most likely to be fished in January is about 5 °C (41 °F). Lagunov et al. (1973) stated that at a storage temperature of 5 °-7 °C the volatile base nitrogen content increases from 5-6 mg % to 17 mg % in 24 h and accelerates to 66 mg % in 72 h. Accompanying this change are a pronounced textural change from firm to flaccid, high drip losses, and sensory depreciation. When stored more than 40 cm deep at 5 °-7 °C (41 °-45 °F), the internal organs are ruptured and release the highly active enzymes. Even shallow heaps of krill stored exposed on deck will generate significant heating.

At relatively cool temperatures of about 10 °C (50 °F) in a matter of a few hours on deck, various discoloration patterns develop. The krill become pale in color and lose their usual crustacean transparency; they soon change to a yellow-grayish color accompanied by what is termed "black spot," in the shrimp industry, of the tissue beneath the exoskeleton of both the abdomen and cephalothorax. The color degradation can even affect the end product. Another fairly common color change is that occasioned by the incomplete digestion of chlorophyll-containing phytoplankton in the stomach or filtering apparatus. The result is a greenish tinge imparted to the final product in addition to a disagreeable flavor change (Grantham 1977).

If these were not enough, there is also a microbiological transition that must be reckoned with. Like most marine fish, krill have a low bacterial content at the moment of catching but soon afford an excellent medium for bacterial growth once the krill die and are landed on deck or stored. Concommitant with this normal bacterial buildup in krill, Sieburth (1959, 1960, 1961) has found that krill feeding upon certain species of phytoplankton contain an antibacterial component that has been identified as acrylic acid. At present, not enough is known of this antibacterial agent to take advantage of its apparent unusual properties.

To most fishery people, the storage temperatures mentioned above (5 °-7 °C) seem unduly high in an Antarctic environment when compared with normal North Atlantic fishery operations. Under good conditions of operation of the latter, gutted fish are stored in ice in such a fashion that fish temperatures of $<$ 2 °C are soon achieved and maintained or even lowered before discharge of the cargo. Polish investigators have tried holding krill at 0 °C and $<$ 1°C, but, although some extension of storage life was obtained, the amount of extended storage life was not considered worth the effort.

International Efforts and Food Product Forms

The nations that have worked with krill as a potential food source have generally agreed that efforts should be made to use krill as a food for direct human consumption rather than as feed for animals. The conversion of krill presents technological problems of a serious nature owing to the small size of the animal and the possession of active enzymes which cause rapid autolysis.

It is agreed among the Russian, Polish, and West German investigators that krill should not be held at 10 °C (50 °F) for more than an hour before processing or held longer than 3 h at 0 °-7 °C (32 °-45 °F). Any increase in either temperature or holding period results in undesirable autolysis. Krill should be piled $<$ 30 cm (12 in) deep, and immature krill should be handled faster and piled shallower because they are more prone to degradation than mature krill.

Regardless of the method of pretreatment, it is the marketability of the form of the finished product that matters. In this respect, it is interesting to review the final product forms developed by various national interests bearing in mind that intrinsically krill do not possess any particular merits or attributes over other crustaceans or finfish. In fact, were it not for their tremendous abundance and nutritional potential, krill would not be the object of various national surveys.

U.S.S.R.—The Soviet Union first started its investigations of krill stocks in the Antarctic summer of 1961-62 with the research vessel *Muksun*. Since then, the greatest amount of research has been carried out by the research vessel *Akademik Knipovich*. The Soviets have almost exclusively directed their efforts to the production of a paste made from krill as follows:

1) Press raw krill for its liquid protein fraction.
2) Collect juice under controlled conditions of time and temperature.
3) Heat juice to coagulate the protein.
4) Separate coagulated protein from liquid fraction.
5) Condense, coagulate, and package.
6) Freeze and store.

The krill paste has a sweetish delicate flavor similar to shrimp and is pink in color. The chief use so far has been as an additive. It has been found to go well with cheese, butter, mayonnaise, and various vegetables. It can also fortify such foods as salads, stuffed eggs, and dumplings. Attempts have been made to make sausages with as much as 60% krill paste.

Trade sources (Anonymous 1977c) stated that a 5-yr agreement had been concluded between a Norwegian fish soup manufacturer, Rieber and Son of Bergen, and the Soviet Union's Ministry of Fisheries. Under the terms of the agreement, they will exchange information on the production of krill paste for sandwiches and as an additive in other foods, especially dried soups. The Soviet investigators have patented three products made from krill paste as follows: 1) U.S.S.R. Patent 258,846 (1970) "Shrimp Butter." This product contains krill paste, butter, and flavoring. 2) U.S.S.R. Patent 390,804 (1974) Snack Product. This product contains mussels, malt extract, rye wort, krill paste, and a gelling agent. 3) U.S.S.R. Patent 284,589 (1970) Krill Sausage. This product contains krill paste, sodium alginate, dried milk, salt, and spices.

In an effort to diversify krill products, the Russians have investigated methods of separating krill meat from the exoskeleton. The krill are cooked and dried in a fluidized bed with short wave infrared radiation. The shells are mechanically broken and removed. The meat and other internal organs are separated by flotation in freshwater at 5°-10°C. The process has been patented under U.S.S.R. Patent 581,918 (1977).

It would appear that Soviet investigators are now deemphasizing their work on krill paste and are experimenting with krill products embodying whole or nearly whole krill tail meats. Grantham (1977) indicated that the krill paste was no longer being marketed in the U.S.S.R. but other sources indicate that limited quantities (500-800 t) are being used annually in various products.

Japan.—Small, dried whole shrimp called sakura-ebi (*Sergestes phosphoreus*) about the size of adolescent krill, are very commonly eaten in Japan. In recent cruises to the Antarctic, the Japanese cooked and froze whole krill aboard ship and dried it ashore later. The krill product apparently has not yet received as much acceptance as the regular sakura-ebi. It is interesting to note in this respect the food laws of Japan require that a distinction in labeling of krill be made in order to avoid deception to the consumer.

Frozen raw krill has been offered as well as the boiled, dried product since early 1978. The product is thawed and consumed raw shell-on as sashimi (a general term for raw seafood) or it may be used as a flavoring ingredient for other dishes. It is also used as an ingredient in sushi which is made by fermentation of pickled krill, boiled rice, and salt. In restaurants, the raw krill may be served with boiled rice flavored with vinegar. Preliminary reports indicate that the response is encouraging.

Other product forms are frozen attrition-peeled tail meats which are designed to simulate small frozen peeled shrimp. No reports have been obtained on the reception this product has been accorded. Considerable experimentation has been done with krill muscle processed by meat-bone separators. The minced product may be used in many ways similar to minced fish. One form of minced krill may be washed, and to the resultant product sugar and starch may be added to form a base for krill kamaboko. The latter is a hardened jellied product usually not favored outside Japan.

The 1977-78 catch for Japan was reported to be 21,000 t. The chief products prepared aboard ship were peeled frozen krill, frozen raw krill, boiled frozen krill, and krill meal. No information is available as to how the krill was peeled, but one ship of the Japanese fleet was reported to have had a shipboard facility to produce individually quick-frozen krill.

Chile.—Like Argentina, Chile is nearer to abundant krill stocks by many hundred miles than any other nation. Reports available from the Office of International Fisheries Affairs of the National Marine Fisheries Service indicate that Chile's first efforts in krill exploration were made in 1975. In April of that year, the 640 t vessel *Valparaiso* landed 40 t of frozen krill. The Chilean Institute of Fisheries Development (IFDP) reported good results with peeling machines used aboard ship and ashore (make of machines not known[3]). IFDP and the Catholic University of Valparaiso are reported to have developed over 20 different krill products which include minced krill, dried krill, krill paste, and krill sticks. The krill sticks were reported by the State-owned fishing company Pesquera, Chile, to have achieved good success. In 1977, Chile distributed batter-dipped krill sticks at the annual trade fair in Cologne, Germany (FRG).

In 1978, it was reported that Chile was to construct a vessel to be used in the krill fishery. The vessel was to have a carrying capacity of 1,200 t and a catching rate of about 100 t/d. No further reports of the status of the ship construction project have been received. The original plans called for a krill-catching period of about 240 d for the vessel. This is an almost impossibly long krill fishing period because of the natural ice restrictions on krill fishing unless finfish are to be caught.

In 1978, reports of proposals for establishing joint ventures with Chile to catch and process krill have mentioned Spain, France, and Japan in particular. Nothing concrete had developed by the spring of 1980. This apparent lack of firm agreements may be due in part to the Chilean government's failure to adopt a proposed Krill Development Law. Chilean interest in krill exploration and utiliza-

[3]Trade source indicates that the peeling was accomplished by Laitram shrimp peelers made in the United States.

tion still seems high because Chile was an active member of the FIBEX conducted from about mid-January to the end of March 1981.

Federal Republic of Germany.—Trade reports appearing in the press (Anonymous 1977b) state that "in spite of West Germany's recent energetic research work in Antarctic waters, the Soviet Union already has a five-year lead but is declining to co-operate in sharing any scientific discoveries she may have made."

Unlike the U.S.S.R., Germany has not concentrated most of its experimental work on krill paste. Instead, in the relatively short time since operations began in 1975-76, it has tried the following product forms: 1) Comminuted krill meat from boiled krill, 2) fried krill portions made from frozen comminuted krill, 3) souplike preparation obtained through an enzymatic process using raw (nonboiled) krill, and 4) meat product analogues from krill, dried milk, and saltfish.

Trade sources hint that the 1978-79 German venture into the Antarctic may well be its last. This is because West German fishery industry people have expressed criticism of krill exploration. They definitely prefer "closer-to-home research with more immediate prospects of tangible results" (Anonymous 1977). In view of the alleged German industry attitude, it would appear that German Antarctic explorations may be curtailed except for multinational ventures such as the recently completed (1981) FIBEX.

Poland.—Polish investigators have had little experience with crustaceans other than three species of freshwater crayfish that are native to Poland and eastern Europe. Following the lead of the U.S.S.R., the Poles have made six annual trips to the Antarctic in the pursuit of krill and its manufacture into food. From all accounts, the Polish investigators have avoided the U.S.S.R.'s heavy emphasis upon krill paste and have chosen to explore other alternatives. In the short time Poland has been active in krill research and processing, its investigators have developed a method of peeling krill that is alleged to be in the process of being patented. The krill are first boiled, then individually quick-frozen, and peeled in a machine resembling a potato peeler. The principle of continuous centrifugal abrasion appears to be central to the method. The meats and shell fragments are then separated by air. The yield of meats is reportedly between 16 and 20%. The resultant tail meats are said to be of attractive appearance.

A slightly different peeling principle has been patented by Dalmor Deep Sea Fishery of Gdynia, Poland (Kryszewski and Jasniewicz 1977). While little detailed information is available, it is believed that the krill are cooked and then subjected to mechanical treatment that includes a high speed rotating drum and large quantities of water. The yield from the prototype model is about 10%, but it is believed that with further improvement, the yield could be raised to 15%. It is to be noted that with both Polish peeling machines the krill are cooked before peeling whereas with the American-made peelers by Laitram and Skrmetta the krill must be fresh raw or thawed raw. Yields with the American peelers are in excess of 15%.

Argentina.—Despite its proximity to abundant krill stocks, reports of active work on krill studies by Argentina are lacking except for the sending of a scientific observer on a German research vessel to the Antarctic. It would appear that Argentina's interest in the Antarctic lies more in oceanographic and other operations that come within the purview of the Argentine Navy. Plans of Centro De Investigaciones de Tecnologia Pesquera (CITEP) do not call for immediate krill studies. CITEP is fully aware, however, of the international interest in the potential of krill.

United Kingdom.—Despite the years of exploratory work done by the British in the years between the two World Wars recorded in the Discovery Reports, the British have never sent an expedition aimed solely at utilizing krill for human food. Germany invited British fishery investigators as observers in the German expeditions of 1975-76 and 1977-78.

The Torry Research Station Annual Report of 1976 stated among other things "Euphausia when cooked has a mild shrimp-like flavor and the texture of the meat is slightly sloppy. It has potential as a raw material for food, but no product of wide appeal has yet been made from it."

In the 1977 annual report from Torry, it was stated "The economic viability of an Antarctic fishery done by the UK fishing industry would depend critically on the existence of a profitable market for the products; suitable products still remain to be developed. Whilst limited research is prudent, any major effort does not seem justified at this stage."

A British fisheries trade journal (Anonymous 1976) stated that the Fisheries Research and Development Board has gone on record to the effect that the disadvantages of a krill operation exceed the advantages. It has stated that it would prefer to investigate the possibility of exploiting deep-water blue whiting stocks that exist close to its shores.

Norway.—Norway has given the world the word "krill" (kril) to identify the luminescent euphausids which form the chief food of baleen whales. Norway is one of the seven nations that claims sovereignty over certain parts of Antarctica itself; yet, it has not engaged in extensive efforts to explore the possibilities latent in krill. The reason for Norway's apparent lack of interest is not known, but since Norway is one of the top protein exporters in the form of fishery products, it would appear that the supply of fish in home waters is more inviting than in the Antarctic.

Taiwan.—This country first became involved in krill exploration in 1975 with the catching of 136 t of krill. Products made from the catch include krill vegetable stew, fried krill rolls, krill soup, bean curd stuffed with krill, and other Chinese foods. The investigators have emphasized the problem of enzymatic degradation of krill, drip loss, and discoloration of the krill. No further explorations have been made expressly for krill although an Antarctic trip was made in 1977-78 for finfish.

Byproducts

The exoskeleton of krill, like that of many crustaceans, is rich in two byproducts of potential interest. These are chitin, a polysaccharide similar to cellulose of plant cells, and astaxanthin, a natural pigment associated with many Crustacea.

Chitin and its deacetylated derivative chitosan are presently being produced commerically for use in a number of applications, particularly wastewater treatment. Both chitin and chitosan are at least equal to, if not superior to, bovine cartilage in accelerating the healing of wounds. They can serve as replacements for arteries, veins, bones, and cartilage in human protheses. Chitin and chitosan are nontoxic and biodegradable, and research has shown that applications are valuable in the food industry, as coatings and for wet-strength paper, for encapsulating drugs, and as chelating and flocculating agents for water treatment.

The main deterrent to the commercial development of chitin from shellfish waste in this country has been the lack of a constant supply of shellfish waste in a given locale. Since the theoretical yield of chitin is <1.4% of whole krill, a well-developed krill fishery might be an ideal source of raw material. At reported catch rates of 100 t daily, the production of chitin/chitosan could well represent a significant aspect of the krill fishery.

Reports reaching us indicate that Polish investigators have pretty well solved the problems associated with the manufacture of chitin and chitosan aboard ship and are now reported to be nearly ready to supply markets for these high grade finished products.

The pigment astaxanthin can be extracted from a number of crustacea, such as pelagic red crab, *Pleuroncodes planipes*, deep sea red crab, *Geryon quinquedens*, and several species of shrimp. In recent years, this pigment has been shown to be of value in feeding hatchery-bred trout and salmon because the pigment enhances the red color of the fish flesh. Krill contains about 3,600 μg/100g of astaxanthin (range 600-9,700) which can be extracted as part of the derivation of chitin.

A more prosaic byproduct is krill meal which presents no particular problems of manufacture. Krill meal, according to Grantham (1977), has a protein content of about 55% which is generally lower than most fish meals. The fat content, however, ranges from 12 to 20%. The high fat content gives the krill meal a higher calorific value so that despite its apparent lower composition value based upon protein content alone, feeding trials indicate that it is of higher feed quality than expected.

MARKETING

National Accomplishments

Study of the literature, in addition to personal examination of various krill products made by Polish and West German investigators, lead us to conclude that krill manufacture has a long way to go. Neither country is satisfied that it has produced a krill product sufficiently appealing to satisfy international tastes and cultural differences.

Japan has tried to make more products than Russia, and with the high rate of seafood consumption in Japan, it is likely that Japan will produce krill products that will establish some sort of home market but not necessarily an international market. In 1976, Japan introduced whole, boiled, frozen krill for about $700/t at the wholesale level. At retail, ton lots of krill packed in 300 g containers are sold at prices ranging from $1,000 to as much as $1,600. All products were sold within Japan.

Trade sources state that Chileans have marketed canned roller-peeled meats at about $1.50/lb ($3.20/kg). Chile has also introduced block-frozen meats at $1.00 to $1.10 for packs weighing 80-90 g (2.8-3.2 oz). In paste form, the Russian block-frozen and canned product has been sold at retail levels for $2.00-$2.80/kg. It is reported that for a while block-frozen krill paste was available at about $1,600/t.

Frozen blocks of minced krill made from both raw and cooked krill have been made by both Polish and West German investigators. Minced krill made from raw material has a shelf life of only 2 to 3 mo at −25 °C (Grantham 1977). A minced product made from cooked krill is much more stable in the frozen state than the minced product made from raw krill. Frozen, cooked krill tail meats are considered of greater value than cooked minced krill. Other product forms such as concentrates, hydrolysates, meal, and protein isolates have been made but, again, none can command a market price, much less create a market demand.

Market Research and Economic Analyses

It would appear that each nation that has tried to utilize krill has done so through government scientists or, in some cases, through government-supported contractors. No mention is made of conducting market research to determine the suitability of various forms of krill products. It would appear that those who make the products are those who would presume to pass upon the acceptability or usefulness. The fact that there are no market-ready forms of krill that have much national potential, much less international appeal, may indicate a weakness in the approach so far.

The energy requirements to sail a vessel many thousands of miles to and from Antarctica in addition to heat-processing krill aboard ship and also to freeze and maintain proper freezing storage temperatures are tremendously high. Yet, seldom in the literature reviewed have any considerations been given to making complete economic analyses. It is not likely that any combination of private interests would dare to tackle a task of as great a magnitude without first running even an abbreviated economic analysis.

POSSIBLE PROBLEM AREAS

Krill Resource

At present, there seems to be no immediate problem with the maintenance of the krill stocks in Antarctic waters. No concerted fishery for krill is likely to be mounted until more efficient peeling machines are devised to produce attractive tail meats at an acceptable yield and high rate of speed. The limited fishery season (November to April) in addition to the sailing distance to Antarctic krill stocks serve as effective constraints to immediate overexploitation. If baleen whales were to increase due to reduced whaling activity, they would be natural competitors during the same season.

Harvesting Krill

Problems could arise when competing vessels have different end-use applications in krill harvesting. Most notably would be the presence of vessels geared to harvest large amounts of krill for manufacture into meal if krill meal manufacture is of itself economically feasible. Such vessels would be designed and equipped to capture and process larger amounts of krill than vessels engaged in krill utilization for human use. Physical damage to newly caught krill is of far less importance for krill meal or byproduct use than krill destined for human use. Conflicts might eventually develop because both types would hunt the same prolific area but not at the same catch rate, thus leading to potential problems of resentment of one type of fishery against the other.

Problems may yet occur when the present Antarctic Treaty expires in 1990. Failure on the part of some signatories to ratify an extension of the treaty might signal an intention to extend the jurisdiction of those nations. Some of the very richest krill areas lie within a 200-mi limit of important islands in the Antarctic area. This is particularly true of the dependencies of the Falkland Islands which include the South Sandwich and South Orkney Islands as well as South Georgia. These areas are administered by the United Kingdom but are still claimed by Argentina.

Extension of jurisdiction from the southern tip of the South American continent by both Chile and Argentina could also include rich krill areas. Territorial claims in Antarctica have been made by Argentina, Australia, Chile, France, Great Britain, New Zealand, and Norway. It is of interest that each of these nations now subscribes to the 200-mi extended jurisdiction philosophy. Whether or not any of these nations would make such claims is, at the present time, a matter of speculation. Conditions after 1990 may be appreciably different.

Processing Technology

Although no vessels have been expressly designed and built for the harvesting and processing of krill, in late 1979 a Finnish shipyard, Wartsila Turku, announced that it had designed, but not built, a powerful stern trawler for harvesting krill. The proposed factory trawler is designed to lower its warps under the ice to fish in ice fields up to 60 cm thick. It would have a fully covered deck and would be equipped with the Wartsila air bubbling system to reduce ice resistance. Included in its design is a processing capacity of about 200 t of krill a day. End products would be peeled krill, krill meal, and krill oil. No details were released about krill processing equipment.

We emphasize that harvesting technology far outstrips processing technology. Additional catching ability will avail little until krill peeling equipment is advanced to the point at which it will process an economically justifiable portion of the catch. One of the most critical deterrents to the successful production of intact krill tail meats is the lack of equipment that will produce such desirable meats at a high rate of yield and production.

Marketing

Krill products have been many and varied, although none are outstanding. The lack of a reasonably acceptable product could very well hamper further efforts at development. A critical analysis of the products made to date should be made to determine which type offers the greatest promise. Experimental work concentrated on one or a few end products having promise will probably result in a product(s) with favorable marketing appeal.

CONCLUSIONS

Owing to the many and long-standing uncertainties about krill stocks and the coming development of acceptable krill products for human consumption, we conclude that:

1) Necessary knowledge for judicious management of krill stocks will continue to lag behind technological development.

2) Technology of krill utilization will be accomplished by one or more nations before 1986.

3) There is a likelihood that intensive exploitation of krill stocks will be underway well before the expiration of the Antarctic Treaty in 1990.

4) There is little or no possibility that underdeveloped countries will tap krill stocks for human protein needs.

5) The nations that will be successful in exploiting krill stocks will be 1) those whose fisheries are fully government subsidized and vertically integrated, or 2) those that have great expertise in fishing enterprises in some form of cooperation of industry with government.

Property of
NOAA Miami Library
4301 Rickenbacker Causeway
Miami, Florida 33149

LITERATURE CITED

ALLEN, K. R.
1971. Relation between production and biomass. J. Fish. Res. Board Can. 28:1573-1581.
ALVERSON, D. L.
1979. Tug-of-war for the Antarctic krill. Ocean Dev. Int. Law 8:171-182.
ANONYMOUS.
1976. British stay on the fringe of research into krill. Fish. News Int. 15(8):21, 23
1977a. Germans research Antarctic krill. Mar. Fish. Rev. 39(1):29-30.
1977b. Germans try dishes from Antarctic krill. Fish. News Int. 16(1):77.
1977c. Soup firm in krill project with USSR. Fish. News Int. 16(3):70.
1979. Japanese scientists develop krill spotter plane. Aust. Fish. 38(1):31.
BAKUS, G. J., W. GARLING, and J. E. BUCHANAN.
1978. The Antarctic krill resource: Prospects for commercial exploitation, p. 149. NTIS PB280791. U.S. Dep. State, Wash., DC 20520.
BARDACH, J. E., and E. R. PARISER.
1978. Aquatic proteins. *In* M. Milner, N. S. Scrimshaw, and D. I. C. Wang (editors), Protein resources and technology: Status and research needs, p. 427-484. Avi Publ. Co., Westport, Conn.
BERTRAM, G. C. L., and J. D. M. BLYTH.
1956. The fisheries of Antarctica. FAO Fish. Bull. 9:79-84.
BYKOV, V.
1975. Biological value of Antarctic krill and possibility of their utilization for human consumption. Oceanology International 75. Conference papers. London BPS Exhibitions, p. 361-363.
CHEKUNOVA, V. I., and T. I. RYNKOVA.
1974. Energy requirements of the Antarctic crustacean *Euphasia superba* Dana. Oceanology 14:434-440.
EDDIE, G. O.
1977. The harvesting of krill. Southern Ocean Fisheries Survey Programme, 76 p. FAO, Rome.
EL-SAYED, S. Z.
1975. Biology of the Southern Ocean. Oceanus 18(4):40-49.
EL-SAYED, S. Z., and M. A. McWHINNIE.
1979. Antarctic krill: Protein of the last frontier. Oceanus 22(1):13-20.
FORD, A. B.
1981. Antarctica. *In* The new Encyclopedia Britannica. 15th ed. Vol. 1, p. 947-966. Encyclopedia Britannica, Inc., Publ., Chicago.
GRANTHAM, G. J.
1977. The utilization of krill. Southern Ocean Fisheries Programme, 61 p. FAO, Rome.
GULLAND, J. A.
1970. The development of the resources of the Antarctic seas. *In* M. W. Holdgate (editor), Antarctic ecology, p. 217-223. Acad. Press, N.Y.
HARDY, A.
1967. Great waters. Harper & Row Publ., N.Y., 542 p.
JOYNER, T., C. V. W. MAHNKEN, and R. C. CLARK, Jr.
1974. Salmon—Future harvest from the Antarctic Ocean? Mar. Fish. Rev. 36(5):20-28.
KRYSZEWSKI, J., and Z. JASNIEWICZ.
1977. Will krill become a nutrient? Pol. Marit. News 20(222):21-22.
LAGUNOV, L., M. KRYUCHOVA, N. ORDUKHANYAN, and L. SYSOEVA.
1973. Utilization of krill for human consumption. Food Agric. Organ. U.N. FP/73/E-34, p. 247-250.
MAKAROV, R.
1970. Separate existence of various age groups of Antarctic krill. Inf. Bull. Sov. Antarct. Exped. 7:547-550.
MARR, J.
1962. The natural history and geography of the Antarctic krill (*Euphausia superba* Dana). Discovery Rep. 32:33-463.
MAUCHLINE, J., and L. R. FISHER.
1969. Euphausiids in the marine environment. Adv. Mar. Biol. 7:374-391.
SIEBURTH, J. M.
1959. Gastrointestinal microflora of Antarctic birds. J. Bacteriol. 77:521-531.
1960. Acrylic acid, an "antibiotic" principle in *Phaeocystis* blooms in Antarctic waters. Science (Wash., D.C.) 132(3428):676-677.
1961. Antibiotic properties of acrylic acid, a factor in the gastrointestinal antibiosis of polar marine animals. J. Bacteriol. 82:72-79.
SOEVIK, T., and O. R. BRAEKKAN.
1979. Fluoride in Antarctic krill (*Euphausia superba*) and Atlantic krill (*Meganyctiphanes norvegica*). J. Fish. Res. Board Can. 36:1414-1416.
YANASE, M.
1975. Chemical composition of the exoskeleton of Antarctic krill. [In Jpn., Engl. abstr.] Bull. Tokai Reg. Fish. Res. Lab. 83:1-6.

NOAA TECHNICAL REPORTS
NMFS Circular and Special Scientific Report—Fisheries

Guidelines for Contributors

CONTENTS OF MANUSCRIPT

First page. Give the title (as concise as possible) of the paper and the author's name, and footnote the author's affiliation, mailing address, and ZIP code.

Contents. Contains the text headings and abbreviated figure legends and table headings. Dots should follow each entry and page numbers should be omitted.

Abstract. Not to exceed one double-spaced page. Footnotes and literature citations do not belong in the abstract.

Text. See also Form of the Manuscript below. Follow the *U.S. Government Printing Office Style Manual,* 1973 edition. Fish names, follow the American Fisheries Society Special Publication No. 12, *A List of Common and Scientific Names of Fishes from the United States and Canada,* fourth edition, 1980. Use short, brief, informative headings in place of "Materials and Methods."

Text footnotes. Type on a separate sheet from the text. For unpublished or some processed material, give author, year, title of manuscript, number of pages, and where it is filed—agency and its location.

Personal communications. Cite name in text and footnote. Cite in footnote: John J. Jones, Fishery Biologist, Scripps Institution of Oceanography, La Jolla, CA 92037, pers. commun. 21 May 1977.

Figures. Should be self-explanatory, not requiring reference to the text. All figures should be cited consecutively in the text and their placement, where first mentioned, indicated in the left-hand margin of the manuscript page. Photographs and line drawings should be of "professional" quality—clear and balanced, and can be reduced to 42 picas for page width or to 20 picas for a single-column width, but no more than 57 picas high. Photographs and line drawings should be printed on glossy paper—sharply focused, good contrast. Label each figure. DO NOT SEND original figures to the Scientific Editor; NMFS Scientific Publications Office will request these if they are needed.

Tables. Each table should start on a separate page and should be self-explanatory, not requiring reference to the text. Headings should be short but amply descriptive. Use only horizontal rules. Number table footnotes consecutively across the page from left to right in Arabic numerals; and to avoid confusion with powers, place them to the *left* of the numerals. If the original tables are typed in our format and are clean and legible, these tables will be reproduced as they are. In the text all tables should be cited consecutively and their placement, where first mentioned, indicated in the left-hand margin of the manuscript page.

Acknowledgments. Place at the end of text. Give credit only to those who gave exceptional contributions and *not* to those whose contributions are part of their normal duties.

Literature cited. In text as: Smith and Jones (1977) or (Smith and Jones 1977); if more than one author, list according to years (e.g., Smith 1936; Jones et al. 1975; Doe 1977). All papers referred to in the text should be listed alphabetically by the senior author's surname under the heading "Literature Cited"; only the author's surname and initials are required in the author line. The author is responsible for the accuracy of the literature citations. Abbreviations of names of periodicals and serials should conform to *Biological Abstracts List of Serials with Title Abbreviations.* Format, see recent SSRF or Circular.

Abbreviations and symbols. Common ones, such as mm, m, g, ml, mg, °C (for Celsius), %, ‰, etc., should be used. Abbreviate units of measures only when used with numerals; periods are rarely used in these abbreviations. But periods are used in et al., vs., e.g., i.e., Wash. (WA is used only with ZIP code), etc. Abbreviations are acceptable in tables and figures where there is lack of space.

Measurements. Should be given in metric units. Other equivalent units may be given in parentheses.

FORM OF THE MANUSCRIPT

Original of the manuscript should be typed double-spaced on white bond paper. Triple space above headings. Send good duplicated copies of manuscript rather than carbon copies. The sequence of the material should be:

FIRST PAGE
CONTENTS
ABSTRACT
TEXT
LITERATURE CITED
TEXT FOOTNOTES
APPENDIX
TABLES (provide headings, including "Table" and Arabic numeral, e.g., Table 1.--, Table 2.--, etc.)
LIST OF FIGURE LEGENDS (entire legend, including "Figure" and Arabic numeral, e.g., Figure 1.--, Figure 2.--, etc.)
FIGURES

ADDITIONAL INFORMATION

Send ribbon copy and two duplicated copies of the manuscript to:

Dr. Carl J. Sindermann, Scientific Editor
Northeast Fisheries Center Sandy Hook Laboratory
National Marine Fisheries Service, NOAA
Highlands, NJ 07732

Copies. Fifty copies will be supplied to the senior author and 100 to his organization free of charge.

UNITED STATES
DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL MARINE FISHERIES SERVICE
SCIENTIFIC PUBLICATIONS OFFICE
7600 SAND POINT WAY N.E.
BIN C15700
SEATTLE, WA 98115

OFFICIAL BUSINESS

POSTAGE AND FEES PAID
U.S. DEPARTMENT OF COMMERCE
COM-210

THIRD CLASS
BULK RATE

U.S.MAIL

NOAA, MIAMI LIBRARY S
4301 RICKENBACKER CAUSEWAY
MIAMI, FL 33149

NOAA SCIENTIFIC AND TECHNICAL PUBLICATIONS

The National Oceanic and Atmospheric Administration was established as part of the Department of Commerce on October 3, 1970. The mission responsibilities of NOAA are to assess the socioeconomic impact of natural and technological changes in the environment and to monitor and predict the state of the solid Earth, the oceans and their living resources, the atmosphere, and the space environment of the Earth.

The major components of NOAA regularly produce various types of scientific and technical information in the following kinds of publications:

PROFESSIONAL PAPERS — Important definitive research results, major techniques, and special investigations.

CONTRACT AND GRANT REPORTS — Reports prepared by contractors or grantees under NOAA sponsorship.

ATLAS — Presentation of analyzed data generally in the form of maps showing distribution of rainfall, chemical and physical conditions of oceans and atmosphere, distribution of fishes and marine mammals, ionospheric conditions, etc.

TECHNICAL SERVICE PUBLICATIONS — Reports containing data, observations, instructions, etc. A partial listing includes data serials; prediction and outlook periodicals; technical manuals, training papers, planning reports, and information serials; and miscellaneous technical publications.

TECHNICAL REPORTS — Journal quality with extensive details, mathematical developments, or data listings.

TECHNICAL MEMORANDUMS — Reports of preliminary, partial, or negative research or technology results, interim instructions, and the like.

Information on availability of NOAA publications can be obtained from:

PUBLICATIONS SERVICES BRANCH (E/AI 13)
NATIONAL ENVIRONMENTAL SATELLITE, DATA, AND INFORMATION SERVICE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

11400 Rockville Pike
Rockville, MD 20852