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Zooplankton Fisheries of the World: A Review

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Abstract

About 20 species of zooplankters (copepods, mysids, euphausiids, sergestids, and Scyphomedusae) are commercially fished and utilised as food or feed today. The annual world catch of crustacean zooplankton is probably a little less than 210,000 tons and accounts for 11% of the total crustacean catch in the world. The present status of plankton harvesting in various parts of the world is described. Problems in development of plankton fisheries are discussed.

Introduction

The possibility of utilizing plankton as a food source for mankind has been discussed since the late 19th century (Herdman, 1891; Clarke, 1939; Hardy, 1941; Jackson, 1954; Parsons, 1972). With regard to the problem of feeding the world's increasing population, the planktologist is sometimes asked by the outside public whether zooplankton can be of commercial interest to mankind or whether plankton can save starving people. Recently, much interest has focused on the practicality of fishing Antarctic krill. However, few seem aware that plankton fisheries utilizing crustaceans and jellyfish have existed for many years in various parts of the world. Information gained from these plankton fisheries may not only aid in understanding the problems of the plankton harvest, but also be useful for developing future plankton fisheries. This paper briefly reviews the present status of plankton fisheries of the world.

Current Plankton Fisheries

Table 1 lists the species of zooplankton which are being harvested in the world. At present, about 20 species are commercially fished and utilized as food, feed or bait. They are mainly marine crustaceans having body lengths greater than 10 mm. Some species are illustrated in Fig. 1.

Copepods

Calanus finmarchicus and *C. plumchrus* are the most abundant copepods in the northern part of the North Atlantic and North Pacific Oceans, respectively. They live 1 year or less, and occur in patches on the surface of the sea in spring and early summer.

In some fjords in western Norway, from Bergen to Trondheim and in the Lofoten area, *Calanus finmarchicus* has been fished commercially on a small scale for nearly 15 years (Wiborg, 1976). The fishing season is from the end of April to June, and *C. finmarchicus* is collected mainly with large stationary nets set in sounds where tidal currents are of moderate strength. The catches are usually best during late evening and night when the plankton rises to the surface. At present, the annual catch is 20 to 50 tons. The copepods are deep-frozen and used to feed pet fish and cultured salmonids. *C. plumchrus* has been taken in the vicinity of the Fraser River estuary, on the west coast of Canada (Parsons, 1972). The same species has also been fished for many years off Kinkazan, on the Pacific coast of Honshu, Japan, when the surface swarming of *C. plumchrus* occurs in spring. Like *C. finmarchicus*, *C. plumchrus* is marketed as pet food or ground bait.

Mysids

Appreciable quantities of mysids have been taken in the estuarine waters and

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Table 1. Species of zooplankton of economic value. +: Less than 100 tons per year; ++: 100 to 1000 tons per year; +++: 1000 to 10,000 tons per year; ++++: more than 10,000 tons per year

Species	Body length (mm)	Locality	Commercial exploitation
Copepoda			
Calanus finmarchicus Gunnerus[a]	3-5	Norway	+
Calanus plumchrus Marukawa[a]	4-7	Canada, Japan	+
Mysidacea			
Neomysis intermedia (Czerniavsky)	9-11	Japan	+++
Neomysis japonica Nakazawa	10-12	Japan	+++
Acanthomysis mitsukurii (Nakazawa)	8-9	Japan	+++
Various species		China, Korea, SE-Asia	++(?)
Euphausiacea			
Euphausia pacifica Hansen[a]	15-20	Canada, Japan, Korea	+++
Euphausia superba Dana	50-55	Antarctica	++++
Meganyctiphanes norvegica (Sars)[a]	25-48	France, Monaco, Norway	+
Decapoda			
Acetes americanus americanus Ortmann	7-20	Brazil, Surinam	+
Acetes chinensis Hansen	30-40	China, Korea, Taiwan	++++
Acetes erythraeus Nobili	16-30	China, SE-Asia, E-Africa, India	+++
Acetes indicus H. Milne-Edwards	16-31	SE-Asia, India	++++
Acetes intermedius Omori	20-24	Philippines, Taiwan	+
Acetes japonicus Kishinouye	12-29	China, Korea, Japan	++
Acetes serrulatus (Kröyer)	14-20	China	+
Acetes sibogae sibogae Hansen	18-32	SE-Asia	++
Acetes vulgaris Hansen	20-34	SE-Asia	++
Sergia lucens (Hansen)	35-45	Japan	+++
Scyphomedusae			
Rhopilema esculenta Kishinouye	250-500[b]	China, Japan, Korea	++(?)
Stomolophus nomurai (Kishinouye)	700-1000[b]	China, Japan, Korea SE-Asia	+++(?)

[a]Used primarily for feed and bait.

[b]Diameter (mm).

brackish lakes in Japan. *Neomysis intermedia* is a typical marine relict and the most commercially important mysid. It lives 2 to 7 months. The annual catch of this species from Lake Kasumigaura and other lakes in Japan attains 2000 to 3000 tons (Murano, 1963). The catches are boiled, dried in the sun, and often made into the preserved, cooked food known as "Tsukudani".

Various species of mysids are fished locally in China, Korea and some Southeast Asian countries, and are mainly used to make shrimp paste and sauce. Unfortunately, very little is known about the taxonomy of the mysids in these areas; no catch statistics are available.

Euphausiids

In Japan, *Euphausia pacifica* has been commercially fished for many years (Komaki, 1967). The principal fishing ground is off the northern coast of the Yamaguchi Prefecture (the Sea of Japan) and off the Pacific coast of Honshu around Kinkazan. The life-span of this euphausiid is 1 to 2 years. The species swarms at the surface during daytime from February to April, and is caught by a one-boat purse seine or scoop net. The annual catch fluctuates greatly from year to year, but it has recently been 2000 to 8000 tons in the Kinkazan area. The catches are dried and used mostly as bait and feed, but recently frozen euphausiids have often been marketed as bait for sport fishing. This species has also been utilized along the east coast of Korea and off British Columbia, Canada. Other areas where euphausiids have been harvested include the Mediterranean Sea and off the Norwegian coast. *Meganyctiphanes norvegica* is fished off Monaco in winter; the catch is used primarily for bait (Parsons, 1972).

Antarctic krill, *Euphausia superba* (Fig. 2), is now being considered as a possible addition to the menus of mankind. With the decline of the Antarctic baleen whale stocks, investigation began of other ways to exploit krill, which may constitute one of the largest single and still latent sources of animal protein foodstuffs accessible to man. Recent Russian papers estimate the standing stock as being in the order of 800 million to 5 billion tons (Lyubimova *et al.*, 1973), and investigations by Russian and Japanese scientists suggest that a potential of 20 to 30 million tons per

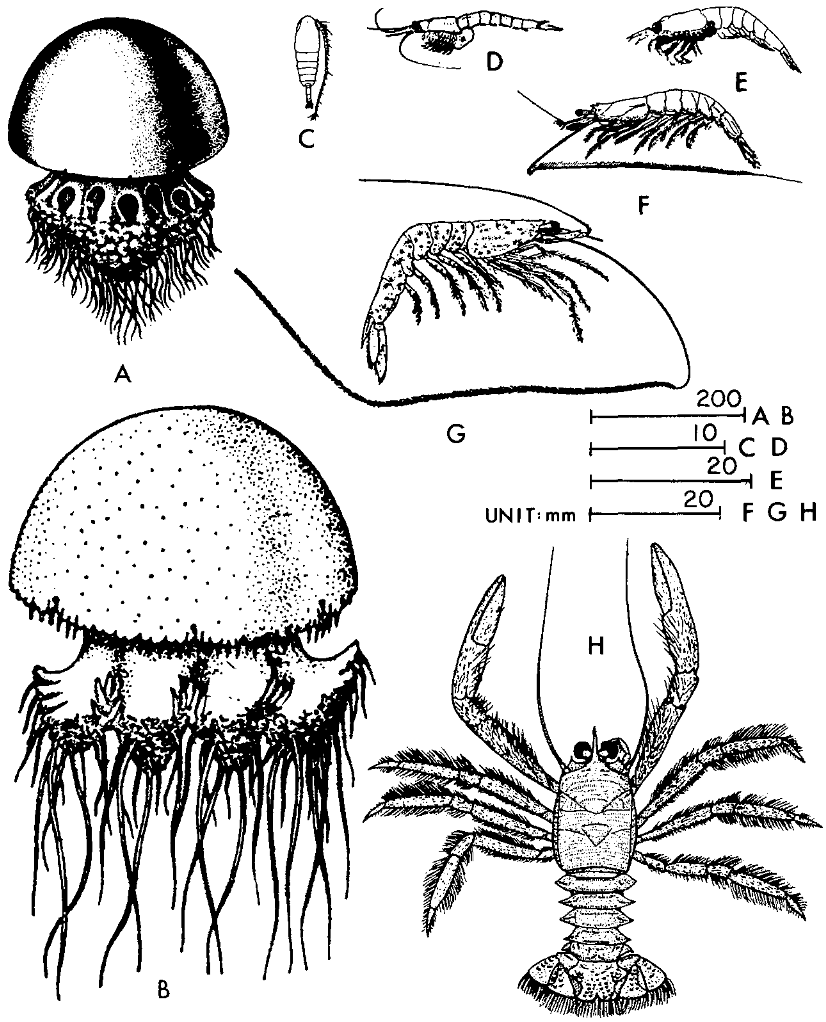

Fig. 1. Representative zooplankton of economic value. (A) *Rhopilema esculenta* Kishinouye; (B) *Stomolophus nomurai* (Kishinouye); (C) *Calanus plumchrus* Marukawa; (D) *Neomysis intermedia* (Czerniavsky); (E) *Euphausia pacifica* Hansen; (F) *Acetes japonicus* Kishinouye; (G) *Sergia lucens* (Hansen); (H) *Pleuroncodes planipes* Stimpson

year exist for the world fishery. The life-span of *E. superba* is thought to be 2 to 4 years. Generally, the species is found shallower than 250 m; swarming occurs mostly from the surface to a depth of 50 m. Dense swarms are frequently found in the Weddell Sea, Scotia Sea around the Trinity Peninsula, off Queen Maud Land, and off Wilkes Land (Fig. 3). According to Mackintosh (1972), there seems to exist at least 6 breeding stocks in the circumpolar seas.

Weather conditions permit the krill harvest in Antarctic waters for only 3 to 4 months in summer. The exploratory fishing of *Euphausia superba* was started by Russia in 1961, and later followed by Japan in 1972. Recently, several other nations have become active in the field or are contemplating activities in the near future (Chile from 1974, Poland and West Germany from 1975 and Taiwan from 1977). It is said that the Russian catch attained 7000 to 17,000 tons annually in recent years (Eddie, 1977). The krill fishery by countries other than Russia is still in an experimental stage. During the 1975-1976 season, two Japanese vessels took a combined catch of about 4700 tons; the total catch attained 11,900 tons in the 1976-1977 season by 5 trawling vessels (2200 to 4000 gross tonnage each) from Japan. The most effective method of capture is one-boat midwater trawling, in conjunction with sonar. For a number of years, Russia has been producing a protein-rich coagulate, called "Ocean paste" for human consumption, by heating mechanically-extracted euphausiid flesh (Lagunov *et al.*, 1974). In Japan, the krill has been boiled immediately after capture and marketed in

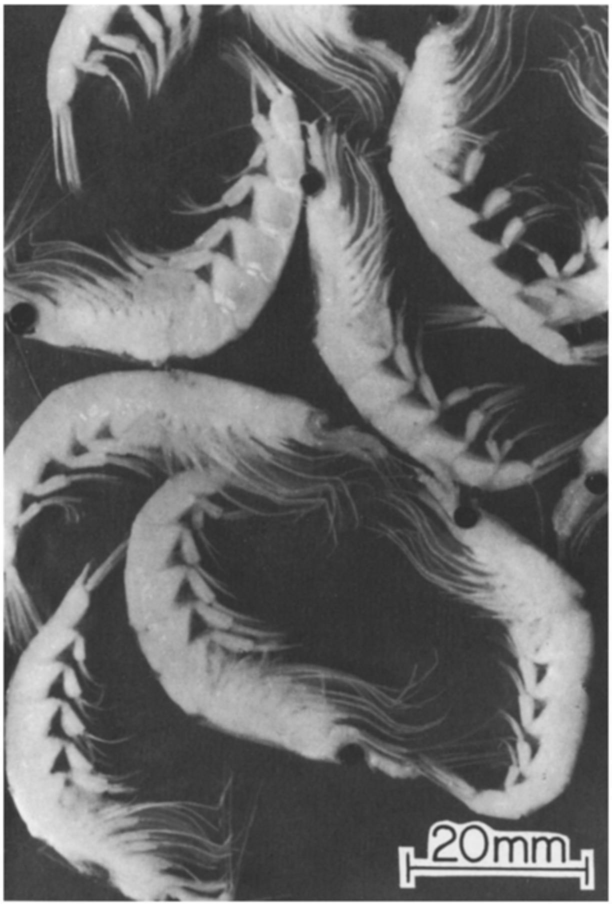

Fig. 2. *Euphausia superba,* Antarctic krill. (Photograph by Dr. A. Kawamura)

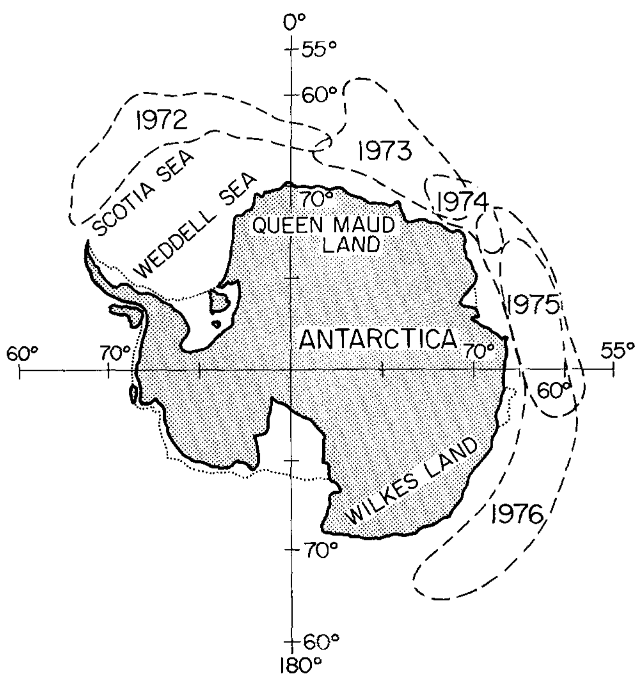

Fig. 3. *Euphausia superba*. Areas where exploratory fishing of Antarctic krill have been carried out by Japanese vessels from 1972 to 1976

frozen blocks or as dried food. Among many papers describing recent status of exploitation of Antarctic krill, reviews by Nemoto and Nasu (1975) and Eddie (1977) are informative.

Sergestids

Species of the genus *Acetes* live in the estuaries and coastal waters of the tropical and subtropical regions. During certain parts of the year they form conspicuous aggregations near the shore, and are fished mainly with push nets and fixed bag nets set near the shore against the flow of the tide. The fishing is generally done during the daytime. In Asian countries, only a small proportion of the catch is marketed as fresh shrimp; the greater proportion is dried, salted or fermented with salt in various ways for food. Shrimp paste and sauce are manufactured extensively throughout Southeast Asia and are esteemed for their taste and nourishment (Omori, 1975).

Acetes chinensis is one of the most important marine resources in China. The catch in the Gulf of Po Hai is tremendous, amounting to 60,000 to 70,000 tons a year for this species alone (Liu, 1956). The fishing season in Po Hai has two periods: from May to July and from September to October. Korea has utilized this species for many years along the coast of the Yellow Sea. In Japan, fishing on *A. japonicus* has been carried out in the Ariake Sea, the Seto Inland Sea and in the Toyama Bay. Utilization of *Acetes* spp. in Southeast Asia is vast, while in western North India, along the Maharashtra coast, *A. indicus* is fished from December to March. The annual catch of *A. indicus* in India attains up to 10,000 tons. According to Omori (1975), some species of *Acetes* have also been fished locally along the coast of East Africa, from Kenya to Mozambique, and in the northern part of South America. He estimated that the world catch of *Acetes* is at least 170,000 tons per year; it accounts for approximately 15% of the total shrimp catch in the world.

Sergia lucens is an upper mesopelagic shrimp which is found only in Suruga Bay and adjacent waters in Japan (Omori, 1969). A fishery for *S. lucens* has been conducted since 1894. Fishing is carried out by two-boat purse seine when the shrimp ascend to the upper layers (20 to 50 m depth) at night. The fishing season is from March to early June and from October to December. Fishing is prohibited during the summer, by regulation, to protect the spawning shrimp. The annual catch totals 3000 to 7500 tons (more than 8 million US $ in wholesale value), and is marketed mainly as dried shrimp for human consumption. The life-span of *S. lucens* is 1.2 to 1.5 years; it matures sexually at 1 year of age and spawns from June to August. According to Omori *et al.* (1973), the temperature conditions during the early breeding season have a great influence on the fluctuation in the abundance of *S. lucens*. Warm years bring good catches and cold years poor catches. Recently, the fishing effort has been controlled with a forecast of the stock size issued every year before commencement of the fishery.

Jellyfish (Scyphomedusae)

Little is known about the biology of edible giant Scyphomedusae. *Stomolophus nomurai* occurs in the Sea of Japan and the East and South China Seas; it is fished along the coast of China, Korea and sometimes off the Hokuriku coast of Japan. Occasionally, during the summer to early autumn, tremendous swarms of this species occur in the southern part of the Sea of Japan. Large individuals of *S. nomurai* attain 1 m in diameter and 150 kg; sometimes their swarms have caused difficulties for coastal fisheries because they break fishing nets. *Rhopilema esculenta* is caught between June and October along the southern coast of Korea and occasionally along the coasts of western Japan. Some species related to these two jellyfishes (or these species themselves) are abundant along the coast of Thailand, where a similar fishery exists. The fishery is located along the coastal area of the inner Gulf of Thailand from Rayong to Chumphon and around Ranong on the coast of the Andaman Sea. Fishing season seems to be related to the direction of the monsoon wind; it is from February to April at Chumphon, and from April to September at Chonburi. The gelatinous umbrella of this kind of jellyfish is stiff. It is preserved with a mixture of alum and table salt, and then sometimes dried. Jellyfish is an important foodstuff in Chinese cooking. To prepare the preserved jellyfish for the table, it is soaked in water, cut into small pieces, and flavored.

Discussion and Conclusions

Among many zooplankters, species of 5 groups, namely copepods, mysids, euphausiids, sergestids and Scyphomedusae, form the basis of real fisheries in the world today. Jellyfish are not likely to be of great interest as a protein source, because their chemical composition is deficient in substances of food value, whereas all crustacean zooplankton seem to have a nutritional value similar to prawns and crabs. Probably, the total world commercial catch of plankton excluding jellyfish is a little less than 210,000 tons per year. According to the fishery statistics by the Food and Agriculture Organization, UN (1976), the annual world catch of aquatic animals is about 70 million tons, the marine crustacean catch in the world was about 1.9 million tons in 1975. Thus, today, marine planktonic crustaceans contribute about 11% to the crustacean fishery in the world.

All plankton species now exploited occur in large swarms in shallow layers of water. Our ability to see or acoustically detect the location of swarms is essential for the present fisheries. In some areas, swarming has often been observed during daylight hours. Examples are *Euphausia pacifica*, *E. superba* and several species of *Acetes*. Fishing for jellyfish is also wholly dependent on visual sightings. These swarms often occur along water boundaries such as water-sinking immediately adjacent to zones of intensive upwelling or along the plume at the mouth of the river. Zooplankton also accumulate in certain restricted areas as a result of wind and tidal actions, which are functions of the local geography. In some locations they are concentrated by day near the sea floor between slopes of narrow, V-shaped canyons, where the depth is slightly shallower than their usual daytime residence depth. From a study of hydrographic and topographic factors, therefore, the seasonal occurrence and location of some planktonic swarms are to some extent predictable. As swarms of the exploitable plankton are very dense, usually the catch is composed entirely of one species of similar size. Concentrations up to about 15 kg wet weight per m^{-3} of *Calanus finmarchicus* have been measured off western Norway (Wiborg and Hansen, 1974). The maximum density of *Acetes japonicus* is about 3 kg wet weight m^{-3} (Omori, 1975); Moiseev (1970) estimated that the concentration of *E. superba* may attain 10 to 16 kg wet weight m^{-3}.

Because of their swarming behavior, the copepod *Calanus cristatus*, the sergestid *Sergestes similis*, and two galatheids, *Munida gregaria* and *Pleuroncodes planipes*, may deserve to be explored as a potential resource. Dense accumulations of *C. cristatus* are found in shallow layers during the spring in most places across the entire subarctic Pacific (Barraclough *et al.*, 1969). Swarms of *S. similis* appear to be favorable food for some baleen whales in the southern Gulf of Alaska (Omori *et al.*, 1972). Recently, 3.8 tons of *S. similis* were collected off Japan by a commercial ground trawler and marketed (Mutoh and Omori, 1978). Post-larvae or adolescents of *M. gregaria* and *P. planipes* occur in vast pelagic swarms during the daytime in the Falkland-Patagonia area and off Baja California, respectively. Longhurst (1968) postulated that the unexploited population of *P. planipes* could provide 30,000 to 300,000 tons per year. The carotenoid content of *P. planipes* is 2 to 3 times greater than that of shrimp wastes, and feeding experiments using carotenoid extracts of *P. planipes* have proved useful in increasing the carotenoid level in cultured salmonids (Spinelli and Mahnken, 1978).

The life-span of most plankton of economic value is less than 2 years, and adults may represent an ephemeral stock with a rapid turnover. Due to their short generation time and small size, however, even though production rates may be very high, standing stocks of plankton animals are not always great in the sea. Therefore, we have to utilize the swarming of zooplankton in specific waters for a fishery, which is one of the limitations to economic feasibility.

In many areas the swarming of zooplankton is strongly seasonal, and the fishing season corresponds with the swarming season. Swarming is a complex form of behavior not readily explainable by any one mechanism or function. It varies in relation to maturation, predation, light intensity, temperature, wind, etc. Thus, the swarming season and location change slightly year by year; the size and density of swarms also vary considerably. Therefore, in most cases, a plankton fishery is characterized by a fishing season restricted to a few months and a catch fluctuating considerably. These facts lead to instability of the fishery.

It is difficult to foresee whether large-scale operation of the plankton harvest would be "economic" in the narrow sense. Lack of a satisfactory method for the large-scale fishing and processing of zooplankton for human consumption is also a great obstruction to the development of plankton fisheries. Even in small-scale operations, the fishery is often interrupted by high labor costs, low catch price, or limitation of local demand. Several species of *Calanus* and euphausiids are excellent food for red seabream and salmonids in culture and, like *Pleuroncodes planipes*, prevent discoloration of the flesh. At present, however, the fishing cost of these plankton is too high for large-scale marketing in Japan; only a small amount of plankton is profitably sold to sport fishermen who use plankton as bait. When animals of a lower trophic level are consumed by commercially important pelagic fish, less than 4% of the energy they contain is transformed into the new kind of living matter (Steele, 1965). The recovery of feed protein from domestic animals is usually only 10 to 30% (Byerly, 1967). Thus, in order to provide more protein for man from marine resources, plankton should be utilized directly by mankind as food. Apart from this question, the problem of local or ethnic food preference exists. This problem has to be resolved by processing the material to highly nutritious additives.

Harvesting Antarctic krill is technologically feasible. With present techniques, large fishing fleets can net up to 20 tons in an hour, and an average rate of catch of 300 tons per day might well be attained within a few years if the standing stock of krill is really enormous, as estimated by many scientists today. However, at the moment the demand for krill is not sufficient to meet the high cost of the fishery. Boiled krill is widely sold at markets in Japan at a price of $1 to $3 per kg, but according to the Japan Marine Fisheries Resource Research Center which sent a krill trawling vessel to the Antarctic waters, a balance sheet for the 1975-1976 season was as follows: expenses (chartering, fuel, etc.) about $827,000; income $310,000. Although various industrial and agricultural uses for Antarctic krill are also being tested, it will probably take a few more years to obtain conclusive results.

As long as dense swarms are the only object of a fishery, new individuals will recruit consistently from nearby waters and, therefore, the immediate problem of over-exploitation is unlikely. However, as exploitable zooplankton often occupy a key trophic level in marine communities, a commercial fishery should be carefully managed so that excessive fishing pressure does not disturb the food web. Our knowledge of the biology of zooplankton is not yet adequate to determine what is the fishable part of a resource. At the end of this review, the author would like to emphasize, in addition to the progress of food technology, the need for more biological and ecological studies of individual species. These studies contribute not only to the assessment of exploitable stocks, but also to the development of appropriate fishing gear and tactics.

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