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*Improved handling and development of new uses will be the key to the red crab fishery.*

# Development of the Pelagic Red Crab (Galatheidae, *Pleuroncodes planipes*) Fishery in the Eastern Pacific Ocean

SUSUMU KATO

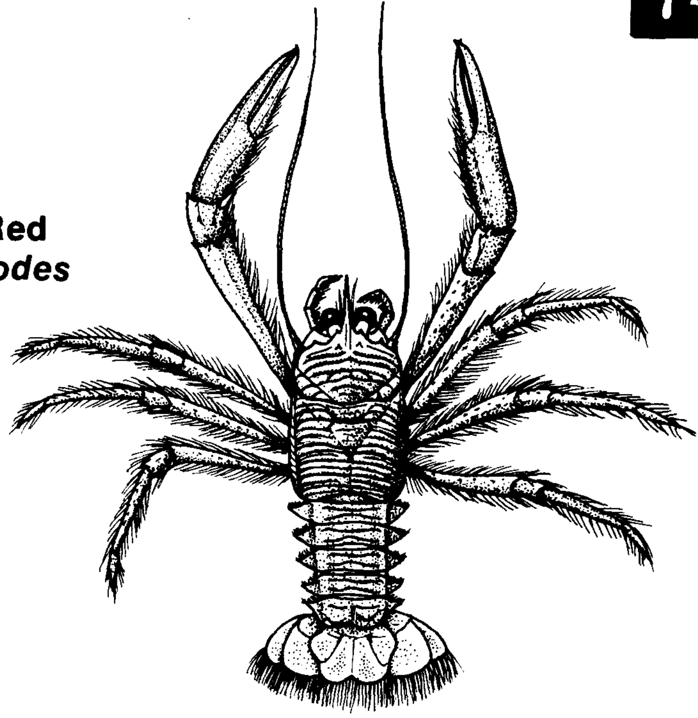

**Figure 1.—The pelagic red crab, *Pleuroncodes planipes*. Overall length is about 3.5 inches. (From Boyd, 1962.)**

## INTRODUCTION

Recent fishing trends demonstrate that the oceans may not contain an inexhaustible supply of fishes. Many of the major fisheries of the world have reached their peaks and several have declined because of decreasing populations. Thus, more and more the fishing nations have turned to previously unutilized resources, and to aquaculture, to satisfy an ever increasing demand for marine products.

Many species of fish and other marine organisms remain unutilized because knowledge is lacking about their distribution and abundance, or owing to a lack of technological capability to harvest and process them economically. As new harvesting and processing methods develop, concurrent with accumulation of knowledge about new resources it becomes possible to utilize previously unused species. Thus, for example, the Japanese and Russians have started fisheries for the small shrimp-like euphausiid ("krill") which is abundant in Antarctic waters (Lyubimova, Naumov, and Lagunov, 1973).

Another large crustacean resource is the pelagic red crab (*Pleuroncodes planipes*) found off the western coast of Mexico, especially near Baja California. (This species should not be confused with the deep-sea red crab, *Geryon quinquedens*, of the Atlantic coast.) Recently American fishermen, with the aid of the National Marine Fisheries Service (NMFS) and the Mexican Government, have started commercial utilization of the pelagic red crab. This paper summarizes the biological information on red crabs and the evolution of the fishery.

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## DESCRIPTION

The pelagic red crab, *Pleuroncodes planipes* Stimpson (Fig. 1), is a member of the crustacean family Galatheidae, a group of small, lobster-like crabs. Boyd (1962) points out Stimpson's humorous intent in deriving the name *Pleuroncodes planipes*, which translates to "bulgy-sided crab with flat feet." Galatheids typically have abdomens and tail fans well-adapted for swimming, and their long first pair of legs is armed with pincers (chelipeds) (Schmitt, 1921). Rows of hair-like setae are located on the front and hind margins of the walking legs. Their probable function is discussed later.

Adult red crabs are about 3.5 to 5 inches long, with the tail and chelipeds extended (Fig. 2). A pound of red crabs includes about 100-150 adult individuals. Their color ranges from pale orange to bright red; brilliance of their color may depend in part on ambient light conditions.

## LIFE HISTORY

Each female may have two and sometimes three broods of eggs in one season. Females may carry up to 3,650 eggs which hatch after about 2 weeks (Boyd, 1962).

In the laboratory, crabs have passed through five larval stages in from 2 to 4 months (Boyd, 1960), the length of time depending primarily on the temperature of the culture medium. The young crabs lead a planktonic life for about a year (Boyd, 1962). Sometime during their second year, crabs become reproductively mature and spend time on the bottom as well as in the plankton. By this time the crabs are about 0.6 inch long[1] (Boyd and Johnson, 1963). By the end of the second year the crabs become strictly benthic at a size of about 1.02 inches (Boyd, 1962).

Principal spawning grounds for red crabs probably are inshore near

[1] The 0.6-inch carapace length, measured from the base of the large spine at the front of the head to the posterior margin of the carapace, is used as the standard measurement throughout this paper.


Figure 2.—Adult red crabs.

Figure 3.—Dead crabs strewn on the beach at Bahia Magdalena.

southern Baja California, especially in the region of Bahia Magdalena (Boyd, 1960). Katsuo Nishikawa, Escuela de Ciencias Marinas, Ensenada (pers. comm.), reported finding dense concentrations of megalop larvae, presumably of red crabs, while skin diving in Bahia Magdalena. Breeding also occurs far offshore (Longhurst and Seibert, 1971), and during certain years as far north as southern California. Probably these crabs have difficulty returning to the inshore environment, although subsurface currents could possibly aid their migration (Longhurst, 1968a).

The primary breeding season for red crabs appears to be from January through March (Boyd and Johnson, 1963), but I have seen berried females in late October, and young larvae have been found during other months. In the laboratory, the egg-bearing season was November through April, with a peak in February (Boyd, 1962).

Larvae of most Galatheids are planktonic (carried passively by currents), and adults are usually benthic (live on the bottom). Adults of *Munida gregaria*, an Antarctic species, however, occasionally swarm in midwater or at the surface (Matthews, 1932). Red crabs are unique in that they spend a considerable part of their adult life both on and off the bottom and may well interchange these different life styles as conditions dictate (Boyd, 1967). The term "pelagic," usually referring to strong swimmers, has been applied to red crabs found off the bottom, but with the understanding that currents play a major role in their distribution and movements. Crabs larger than about 1 inch in carapace length, probably 2 years old, appear to be strictly benthic and live in deeper waters of the continental shelf (ibid).

Boyd (1967) found significantly higher catch rates of red crabs in plankton hauls at night than during the day. He attributed the difference to upward migration from deeper water at night and the reverse during the day. Crabs caught at night were generally larger, as were those caught at higher latitudes.

The habit of swarming at the surface makes red crabs conspicuous to ocean travelers. These swarms are apparently not associated with seasonal (winter) breeding cycles (Boyd, 1967). Windrows of crabs at the surface sometimes stretch for miles like a blood-red river. Such concentrations occur more commonly at night, but are also evident during the day (Boyd, 1962). Mass mortalities occur when the pelagic red crabs are carried to shore by winds, waves, and currents (Fig. 3).

## FEEDING AND PREDATORS

Red crabs are omnivorous and quite versatile in their food habits. When kept in aquaria they feed readily on fish, using their chelipeds to break off small pieces of flesh. They also use the chelipeds to capture small prey like copepods (Longhurst, Lovenzen, and Thomas, 1967). They are unusual in that they can also feed directly on microscopic plants and animals (plankton) by filtration. Analyses of stomach contents of red crabs reveal that the pelagic phase feeds primarily on small phyto- and zooplankton (Longhurst, et al., 1967; Beklemishev, 1960).

In the wild, red crabs can be observed swimming backward and upward by rapidly flexing their abdomens. At or near the surface they stop swimming, stretch out all their legs—thus creating a parachute effect because of the numerous fine hairs on the legs—and float slowly downward while using their filtering mechanism to feed (Fig. 4). Benthic red crabs probably feed primarily on detritus by raking up sediments with their feet and mouth parts (Boyd, 1962).

Beklemishev (1960) described a peculiar behavioral pattern of red crabs which may be related to feeding. About one-third of the red crabs he observed swam upside down, and the majority of these crabs appeared to maintain themselves at the surface by hanging on the surface film with their legs, presumably feeding on surface plankton.

Predators of red crabs are many and varied. Wherever they are found, red crabs are eaten by skipjack tuna, yellowfin tuna, and albacore (Alverson, 1963; McHugh, 1952), many other species of fishes, several species of birds, sea lions (Boyd, 1967), and some whales (Matthews, 1932). Because of their ability to feed on phytoplankton, red crabs form an important and rather direct intermediate link in the food chain from primary productivity to terminal predators (Longhurst, et al., 1967).

**Figure 4.—Red crabs swimming and feeding near the surface. Crabs with outstretched legs are slowly drifting downward, while those with chelipeds extended in front and abdomens flexed are swimming upward.**

## DISTRIBUTION

The distribution of the pelagic or planktonic phase of red crabs has been well-documented (Boyd, 1967; Longhurst, 1967, 1968a; Blackburn, 1968, 1969). Generally, the center of distribution is near the west coast of central and southern Baja California. The dominant California Current carries some crabs far out to sea as it swings offshore from southern Baja California. Red crabs have been found over 1,000 miles from the Baja California coast and in two instances were also reported from Central America and Peru (Longhurst and Seibert, 1971). Although the pelagic distribution is widespread, dense concentrations are few; the region of greatest abundance is over the continental shelf off southern Baja California (Fig. 5A). Distribution and abundance of red crabs along the coast appears to correspond to the plankton-rich waters derived from coastal upwellings (Longhurst, 1967; Blackburn, 1969).

Large concentrations of red crabs have also been reported from the northern part of the Gulf of California, and mass strandings have occurred on beaches there (Boyd, 1967; Cadieux, 1973). Whether these crabs form a population separate from those off the west coast of Baja California is unknown.

Seasonal variation in distribution apparently is slight, but annual variations may be great (Longhurst, 1967). During certain years, strong north-

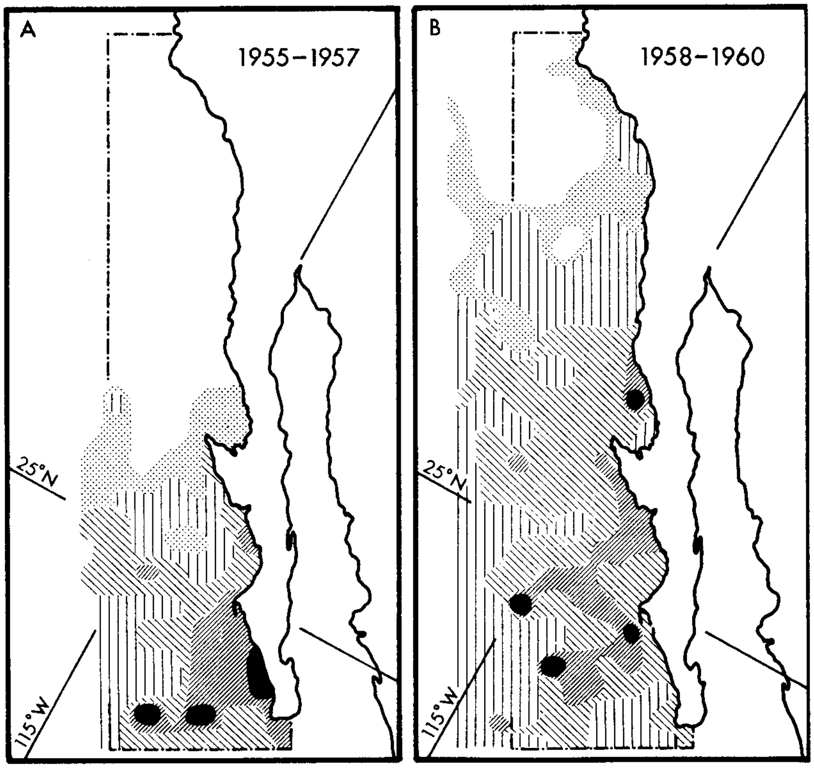


**Figure 5.—General distribution of pelagic red crabs along the Baja California and California coasts. Darker shading indicates heavier concentration. A: Normal year. B: Warm year. (From Longhurst, 1967.)**

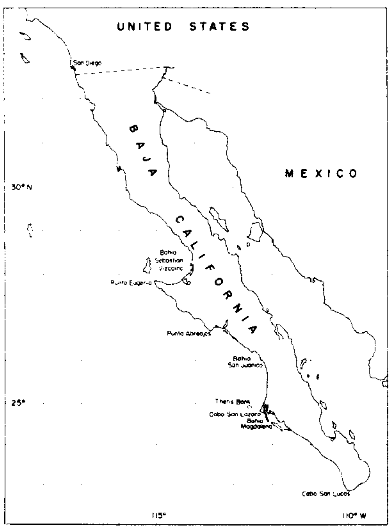


**Figure 6.—Map of Baja California, showing important landmarks on the west coast.**

ward transport of water along the west coast carries red crabs to southern California and occasionally as far north as central California (Fig. 5B). The period 1958-60 saw this happening, and most recently during the summer of 1972, red crabs were caught in large numbers with a midwater trawl at the Channel Islands near Los Angeles by the California Department of Fish and Game (Kenneth Mais, Dept. Fish and Game, 350 Golden Shore, Long Beach, Calif., pers. comm.). Red crabs were evident off southern California throughout the rest of the year and into the spring months of 1973. Several mass strandings of red crabs occurred on coastal beaches near Los Angeles and the Channel Islands. Commercial fishermen reported large numbers in the water and in the stomachs of fishes that they caught. Red crabs were also found near Monterey, Calif. during spring of 1973 (Jerome Spratt, California Dept. Fish and Game, 2201 Garden Rd., Monterey, Calif., pers. comm.).

Red crabs are found mostly in 59-70°F seas, but have also been found in temperatures of 48-82°F (Longhurst, 1967). Crabs found in offshore areas are generally smaller than those found close to shore. This suggests that they may have originated in inshore waters but were swept offshore as larvae. However, since egg-bearing females about 0.5 inch in carapace length have also been found offshore, it is likely that at least some red crabs are hatched in offshore waters (Longhurst, 1967). Examination of samples taken between 1958 and 1960 indicated that more male than female red crabs occur in the plankton (Boyd and Johnson, 1963). The sex ratio for the entire time period was about 54:46 in favor of males.

Larvae of all stages are found in the plankton from January to July, with the peak in February and March (Boyd, 1960). The greatest concentration was found within a radius of 50 miles of Bahia Magdalena (Fig. 6). In this area, up to 42,000 larvae per 1,300 cubic yards of water were caught in plankton nets, while outside the area during the same period (January through July) the average catch was only five larvae per 1,300 cubic yards.

Unlike the pelagic environment, the benthic habitat of red crabs has not been extensively surveyed. For several years, scientists of Scripps Institution of Oceanography (SIO) have occasionally conducted cruises in inshore waters of central and southern Baja California using otter trawls to capture benthic fishes. At times the presence of red crabs made it impossible for SIO personnel to trawl for fishes (Don Dockins, SIO, La Jolla, Calif., pers. comm.). Red crabs were caught from Bahia Sebastian Vizcaino to Cabo San Lucas. Depths of the areas trawled were generally between 30 and 100 fathoms.

Parker (in Longhurst, 1968b) found benthic red crabs as far north as Bahia Sebastian Vizcaino (about lat 28°N), which appears to be the northern limit of the crabs, except during warm years when both benthic and pelagic phases are found off California. The greatest depth at which red crabs were found was 200 fathoms. Perkins (ibid) reported that the crabs were extremely abundant in waters deeper than 80 fathoms.

In November-December 1960, Boyd (1967) used a small otter trawl to sample the bottom from about lat 25° N to 31°N. No red crabs were found north of Punta San Eugenio (lat 27°

**Table 1.—Proximate composition of uncooked red crabs.**

| | |
|---|---|
| Moisture | 76.89% |
| Total Crude Protein | 10.61% |
| Total Lipid | 2.48% |
| Ash | 6.29% |
| Iodine No. of Fat | 175 |
| Crude Fiber (Chitin) | 5.00% |
| Salt (NaCl) | 1.25% |
| Volatine Acid Number | 16.8 |
| Volatile Base N | 0.03% |
| pH | 6.88 |
| Total Carbohydrate (as glucose) | 0.94% |

**Table 2.—Composition of cooked and uncooked red crabs.**

| Composition | Cooked | Uncooked |
|---|---|---|
| | Percent | |
| Total solids | 16.9 | 23.4 |
| Total lipids | 0.8 | 3.0 |
| Ash | 6.2 | 8.2 |

**Table 3.—Material balance of cooked and uncooked red crabs after passing through a meat/shell separating machine.**

| | Cooked | Uncooked |
|---|---|---|
| Wt of crabs | 26.6 lb | 29.5 lb |
| Wt of discarded shell | 8.4 lb | 13.2 lb |
| Wt of meats & viscera | 17.8 lb | 8.8 lb |
| Physical loss | 0.3 lb | 7.5 lb |
| Percentage yield | 67.0 | 30.0 |

**Table 4.—Composition of cooked and uncooked red crab meat and viscera fraction.**

| Composition | Cooked | Uncooked |
|---|---|---|
| | *Percent* | |
| Solids | 12.9 | 16.3 |
| Lipid | 1.0 | 3.8 |
| Ash | 3.7 | 3.3 |

**Table 5.—Composition of protein concentrate prepared from meat and viscera.**

| Composition | Cooked | Uncooked |
|---|---|---|
| | *Percent* | |
| Protein[1] (N × 6.25) | 61.4 | 59.3 |
| Lipid | 0.05 | 0.05 |
| Ash | 23.3 | 24.8 |

[1]Not corrected for chitin.

50'N). During a cruise in April 1961, he found crabs south of lat 24°N. In running a transect of trawling stations from near shore to the edge of the continental shelf, Boyd found red crabs between 41 and 164 fathoms. At the latter depth, the crabs measured an average of 1.10 inches carapace length, with a maximum of 1.26 inches. These crabs were presumed to be strictly benthic, because no crabs over 1.02 inches were found in the plankton or in bottom samples from shallower areas. Boyd also suggests that in shallow waters, crabs which are planktonic at night may settle on the bottom during the day when suitable bottom is available.

A cruise in April 1973 by SIO discovered that red crabs are abundant as far south as Costa Rica (Don Dockins, SIO, La Jolla, California, pers. comm.). Between about lat 11-12°N, at depths of about 60-100 fathoms, the crabs were numerous enough to cause problems in retrieval of the bottom trawl used, and subsequent separation of desired fish specimens from the crabs.

## ABUNDANCE

Because very few quantitative data are available, no estimate of the total abundance of red crabs can be made. The catch with a small (10-foot headrope) otter trawl towed for 25 minutes at 2 knots was about 400-500 pounds (Boyd, 1967). Thus a conventional shrimp trawl (55-foot headrope) would be expected to catch about 2,500 pounds under similar conditions.

Beklemishev (1960) calculated that there were more than 300,000 tons of red crabs in an area of about 77,000 square miles off Baja California which was surveyed by the Russian research vessel *Vityaz* in January 1960. Based on catch rates aboard the NMFS research vessel *David Starr Jordan* catches up to 20 tons an hour could be expected with a 50-foot midwater trawl (National Fisherman, 1970). It is clear that in areas where red crabs are concentrated, the catch rate is limited only by the size of the gear that a vessel can handle. It should be pointed out, however, that concentrations yielding such high catch rates are not found throughout the range of the species.

Longhurst (1968b) suggested that the four million yellowfin tuna caught by the United States and Mexican fishery off Baja California in 1960 consumed 2,000 tons of red crabs each day. It is evident, however, that a decimal point was misplaced in his

**Figure 7.—Salmon-rearing pens located at Squaxin Island, Washington. (Photo by J. Frazer, STOWW.)**

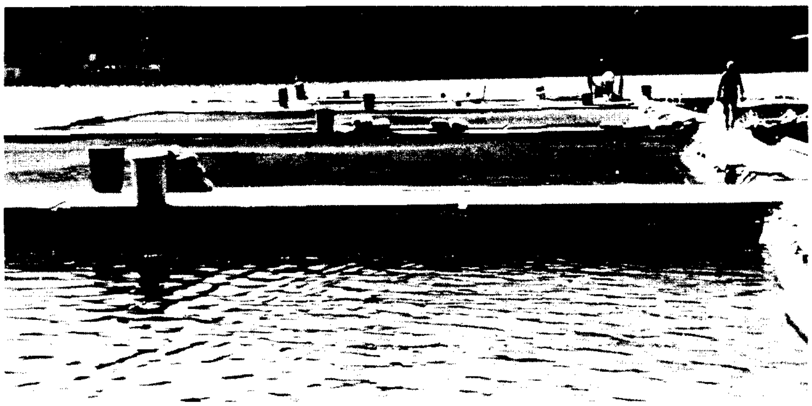

**Figure 8.—Pan-sized salmon ready for market. (Photo by J. Frazer, STOWW.)**

calculation because the data on which that estimate was based showed that the 567 yellowfin stomachs sampled contained a total of 30.9 quarts of red crabs (Alverson, 1963), which amounts to 0.05 quarts per fish rather than 0.5 quarts as indicated by Longhurst. Thus his estimate is too high by a factor of 10. However, when one considers the consumption by the entire population of yellowfin, as well as skipjack and scores of other predators which feed on the crabs, it is evident that the stock of red crabs is huge.

## UTILIZATION

The abundance of the red crab resource has been common knowledge to the fishing industry for years. However, no attempts were made to develop uses for the crabs, principally because of the small amount of meat in the tail. To explore possible uses, NMFS ran a series of analyses on red crabs to provide potential users with basic data. Tables 1-5, reported previously in National Fisherman (1970), give results of these analyses by NMFS and by a private firm.

The results attracted the attention of a pet food manufacturing firm which decided to explore the possibility of including the crabs in a special pack. Accordingly, it ordered a sample shipment from Matt May, then owner of the vessel *American Eagle*, and the commercial fishery was born. Fifteen hundred pounds of red crabs—enough for studies on consumer (cats) acceptance—were caught during the first trip in July 1970. NMFS provided the gear for catching the crabs, and the author went along to study the crabs and fishing operations.

Meanwhile, the NMFS's Northwest Fisheries Center in Seattle discovered that when red crabs were included in the diet of pen-reared Pacific salmon (*Oncorhynchus* sp.), the flesh gained its natural reddish tint (Anthony Novotny, NMFS, Northwest Fisheries Center, pers. comm.). Without the crabs, the flesh remained white. Carotenoid pigments, which red crabs contain in quantity (Wilkie, 1972), caused this effect. Earlier efforts to induce red-colored flesh included feeding the salmon with various sources of carotenoid pigments, and even paprika. The salmon-rearing industry has grown dramatically recently (Fig. 7 and 8) and the production from three private firms was projected to reach 4-5 million pounds by 1974 (Wagner, 1972).

Red crabs were sorely needed for further research, and the California Department of Fish and Game's research vessel *Alaska* provided two one-ton loads. The crabs were used primarily by the NMFS's Pacific Fishery Products Technology Center in Seattle to study characteristics of red crabs pertaining to handling and storage aboard fishing vessels. Studies of the effects of the crabs in the diet of rainbow trout brood stock were also begun at the University of Washington.

Late in 1972 the Small Tribes Organization of Western Washington (STOWW) requested aid from NMFS in getting a supply of red crabs for feeding pen-reared salmon. STOWW is a service organization providing economic, social, and administrative services to the membership of 18 Indian tribes. Red crabs had been present in southern California waters since summer, and in early 1973 they were still being stranded on beaches while fishermen reported large numbers near the Channel Islands. Brent Bixler, owner and captain of the fishing vessel *Lady Olga*, agreed to try fishing for red crabs for STOWW after learning of the potential growth of the fishery. In February, equipped with both large and small midwater trawls loaned by NMFS, *Lady Olga* fished for 4 days at the Channel Islands. Total catch was a disappointing 500 pounds of crabs, but valuable experience was gained.

Since red crabs are distributed primarily near Baja California, the Mexican Government was petitioned to allow *Lady Olga* to fish for crabs in Mexican waters. Owing to the experimental nature of the fishery, Mexican officials granted the *Lady Olga* their permission in exchange for data on all aspects of the fishery. Thus on 11 April 1973, the vessel left San Diego to launch the fishery in earnest. Besides Bixler, crewman Dave Johnson, and the author, Mario Yoshida, a student from the Escuela Superior de Ciencias Marinas in Ensenada, Mexico, went along as official observer for the Mexican Government.

Fishing operations started at Punto Abreojos (lat 26°45'N; 113°40'W) where Fathometer[2] readings and visual sightings indicated the presence of red crabs. The first sign of large numbers of crabs near the surface was in waters discolored by a bloom of plankton, probably *Gonyaulax*, an organism which produces the widely known "red tide." Many crabs were seen repeatedly swimming to the surface and then sinking slowly, then swimming upwards again. Undoubtedly the crabs were feeding on the concentrated plankton. Boyd (1962) also reported red crabs associated with

[2] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

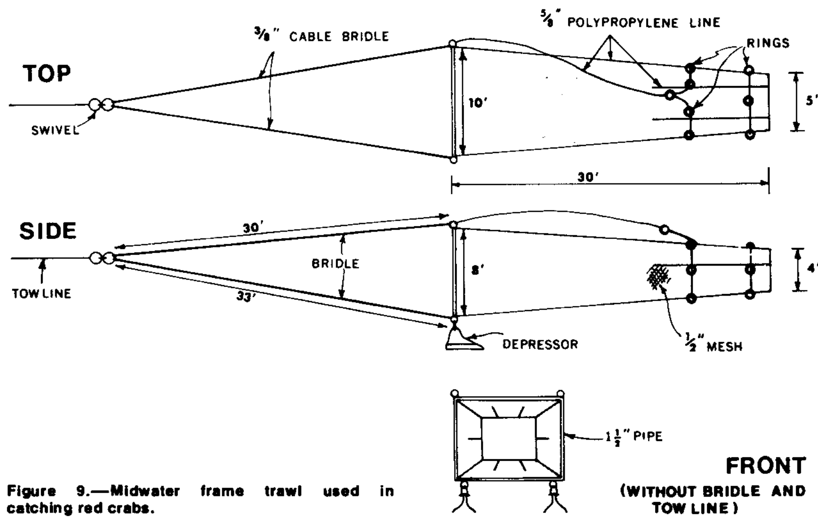


**Figure 9.—Midwater frame trawl used in catching red crabs.**

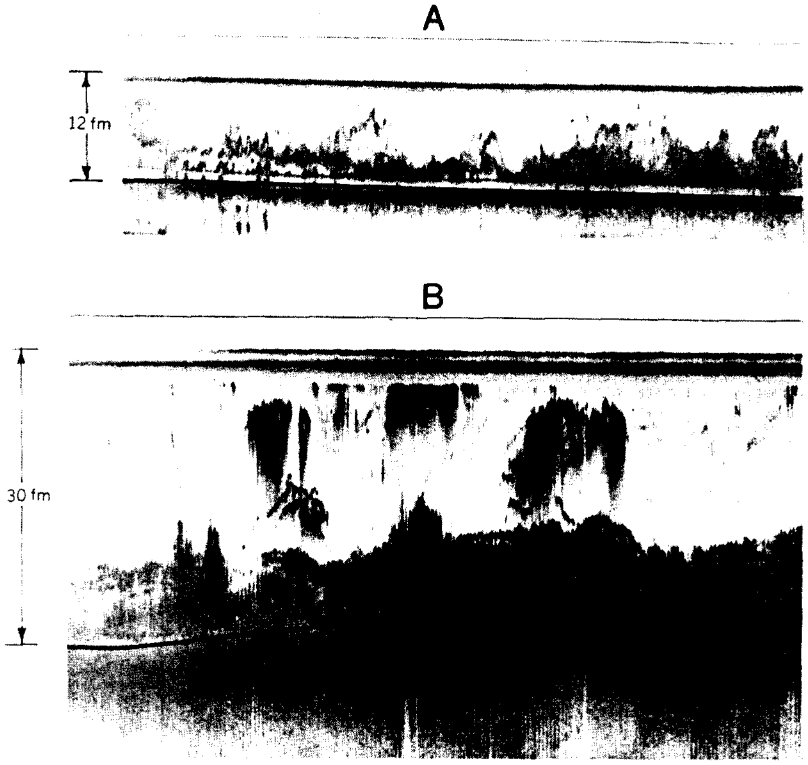


**Figure 10.—Daytime traces of pelagic red crabs on a "white line" Fathometer. A: Bahia Magdalena. Crabs on and near bottom. The inverted "V" traces were probably fish. B: Thetis Bank. Crabs on the bottom as well as near the surface. The "white line" is occluded because of the density of the crabs.**

*Gonyaulax*, which produces toxins fatal to many fishes and invertebrates. Apparently the crabs are immune to the toxins.

A few days of fishing near the area proved that commercial quantities were not present. For this trip a midwater frame trawl with an 8 × 10-foot opening was constructed (Fig. 9). The webbing was simply attached to the four sides of the frame and tapered to an end opening half the size of the mouth. A conventional cod end was not sewn into the end. A pair of 40-pound depressors kept the opening vertical during tows. The net worked satisfactorily in catching crabs, but bringing the crabs aboard proved difficult because the webbing was too light, and reinforcing riblines were insufficient to hold the weight of the crabs.

Following 4 days of unproductive searching and fishing, we entered Bahia Magdalena. Several Mexican shrimp vessels were anchored in the bay, and we learned from their crews that crabs were so abundant in the bay that at times it was impossible for them to trawl for shrimp. A couple of hours of scouting confirmed their reports. The Fathometer showed dense traces (Fig. 10) and hundreds of birds sat on the water feeding on red crabs, while others flew over the water and neatly picked up crabs at the surface.

Fishing began the next day, and by the end of 5 days the hold was filled with 42,600 pounds of red crabs (Table 6). Much time was lost owing to inadequacy of the net. The catch rate could easily be doubled with the proper net. Because the crabs had to be shoveled into plastic bags before being placed in the refrigerated fish hold, handling and storage was also time-consuming and laborious, and 6-8,000 pounds were about maximum for a 15-hour workday.

Several behavioral characteristics of red crabs and birds were learned which proved useful in finding the crabs. The crabs do not stay in the identical area from day to day. They may move both along the shore and slightly offshore or inshore. They often stayed very close to the bottom during the day (thus making it difficult to use a midwater trawl), and moved up somewhat during the late afternoon, although at times they hovered at mid-depths throughout the day. They evidently moved to the surface in large numbers at night, judging from the feeding activity of birds in the early morning hours. Pelicans do not appear to feed on red crabs, and when they are among a group of diving and working birds their feed would invariably be small baitfish rather than crabs. Boyd (1967), however, included pelicans among the predators of red crabs.

The cruise experience confirmed as well as contradicted published accounts regarding the crabs. The size of the crabs corresponded closely to that given by Boyd (1967). Samples taken from various localities showed remarkably little difference in size, ranging from 0.59 to 1.02 inches and averaging 0.85 inches in carapace length at all areas fished. Samples from Bahia Magdalena taken at 0900, 1500, and 1800 hours showed no difference in range or average size.

At Bahia Magdalena, some indications of diurnal migration were noted, but even during daylight hours the crabs did not settle directly on the bottom (Fig. 10A). Rather, they typically were distributed from the bottom

**Table 6.—Summary of fishing activity aboard *Lady Olga*, 16-24 April 1973.**

| Date | Locality | Bottom depth (fm) | Surface temp (F) | No of tows | Avg duration of tows (min) | Avg catch per tow (lb) | Total catch (lb) |
|---|---|---|---|---|---|---|---|
| 4/16 | Pta. Abreojos | 10-15 | 59 | 4 | 59 | 138 | 550 |
| 4/17 | Bahia San Juanico | 10-15 | 62 | 6 | 50 | 392 | 2,350 |
| 4/18 | Bahia San Juanico | 7-13 | 62 | 2 | 62 | 825 | 1,650 |
| 4/19 | Bahia San Juanico | 5-10 | 62 | 1 | 50 | 100 | 100 |
| 4/19 | Bahia Santa Maria | 20-22 | 62 | 1 | 32 | 100 | 100 |
| 4/20 | Bahia Magdalena | 5-15 | 64 | 4 | 13 | 1,500 | 6,000 |
| 4/21 | Bahia Magdalena | 5-15 | 64 | 9 | 37 | 833 | 7,500 |
| 4/22 | Bahia Magdalena | 5-15 | 64 | 6 | 31 | 1,350 | 8,100 |
| 4/23 | Bahia Magdalena | 10-15 | 64 | 4 | 38 | 3,150 | 12,600 |
| 4/24 | Bahia Magdalena | 12-15 | 64 | 2 | 30 | 1,825 | 3,650 |
| | | | | 39 | 40 | 1,092 | 42,600 |

**Figure 11.—Birds sitting on and flying low over the water, feeding on red crabs at the surface. Most of the birds are juveniles.**

to about midwater. Whether or not the crabs near bottom were sitting on each other is not known.

Boyd (1962) found that wave and wind action was responsible for strandings of red crabs on beaches. We found, however, that crabs were being stranded daily in a quiet cove where the wind and waves moved offshore rather than toward the beach. It seemed that the crabs were being stranded by the receding tide rather than by wave action. Cadieux (1973), on the other hand, observed many crabs actually walking out of the water to die on the beach. Hundreds of birds lined the beach where the crabs were washed ashore (Fig. 3), but they did not appear to feed on crabs on the beach. The birds occasionally took flight and picked up dead crabs that were awash in shallow water and returned to the beach to eat them. We noticed also that most, if not all, of these birds were adults, while most of the birds feeding on live crabs away from the shore (Fig. 11), had the mottled markings of juvenile birds.

Our fishing was confined to shallow, protected bays because of high seas. We found evidence of large concentrations of crabs in deeper offshore waters, however. About 15 miles north of Cabo San Lazaro (lat 24°48′N, long 110°18′W) during daylight, the Fathometer indicated large numbers of crabs in the top 10 fathoms. At the surface, narrow but long windrows of crabs were oriented in line with the strong northwest wind.

At Thetis Bank about 18 miles northwest of Cabo San Lazaro, we found crabs near the bottom in large numbers (Fig. 8). Fish caught there had stomachs full of red crabs, and many crabs were seen near the surface. Somewhat to the north of Thetis Bank in deep water at night, Fathometer traces of crabs were solid from the surface to a depth of 30 fathoms.

## FUTURE OF THE FISHERY

Development of a new fishery is always difficult. Even if the availability of a resource is known, studies are still necessary on all aspects from fishing to marketing. In the case of red crabs, the task is even more difficult because conventional uses for crustaceans do not apply, and new uses have to be developed. The future of the fishery lies in the success or failure of these new uses.

Certainly one of the more important areas of research is the value of red crabs as a coloring agent for pen-reared salmon. Current research being conducted by NMFS in Seattle on the optimum feeding rates and times will provide data necessary for evaluation and economic comparison with other sources of carotenoid pigments. Three of the five commercial firms in the United States now rearing salmon have enough supplies of red crabs to also undertake such feeding experiments. If results are favorable, red crabs may become an important component of the salmon's diet.

Along with this research other work related to use of red crabs as salmon feed is being done at NMFS Pacific Fishery Products Technology Center at Seattle. One aspect is to attempt to stabilize the carotenoid pigments of red crabs so that they can be included in dry pellets, which are cheaper to produce than other forms of salmon feed. Under normal heat-drying processes used in making dry pellets, the carotenoid pigments of red crabs may lose their effectiveness. Another aspect is directed toward separating the crabs into two fractions, one with high protein and carotenoid pigments (for salmon feed), and another with low protein and high chitin for other uses (Spinelli, Lehman, and Wieg, in press).

Even if red crabs become an integral part of the diet of pen-reared salmon, the total tonnage needed for this purpose will only be about a hundred tons per year. Other uses will have to be developed in order to sustain a fishery for crabs. The use of the flesh-coloring property can be carried over to other fishes and animals where external rather than internal coloration is desired, for example in aquarium fishes. Research is needed, however, to determine the effects of red crabs in the diets of various species of animals. In rainbow trout, at least, red crabs produce brilliant external coloration as well as pink flesh (Loren Donaldson, University of Washington, pers. comm.). If the same results can be achieved with aquarium fishes, and if the feed can be packaged in a convenient form this might become a major use for the crabs.

The chitin found in red crab shells could possibly form the basis of a major industry. Chitin is the structural material that holds together the shells of crustaceans. Presently a pilot plant near Seattle, Wash. is testing the feasibility of extracting chitin from shells of crustaceans. Chitin is similar in nature to cellulose and can be used in place of cellulose in some products. From chitin also, a material called chitosan can be derived, opening up a surprising variety of uses in papermaking, food, pharmaceuticals, sewage treatment, and many other applications (Pacific Northwest Sea, 1973).

Inclusion of red crab in pet food is still undergoing research. If results are favorable, the crab market could increase severalfold and the fishery would be assured a sound base. Of course, with the cost of fish meal rising dramatically, the possibility exists of using red crabs directly as fish meal despite their relatively low protein and high fiber content. Recent studies show that high-quality meal can be manufactured from crustaceans (Meyers and Rutledge, 1971).

Another possible use for the shell of red crabs is in horticulture. Dried and pulverized crab shells, when added to acid soil, would act to neutralize the soil and would also be useful as a slow releaser of nitrogen (Maynard Steinberg, NMFS, Pacific Fishery Products Technology Center, Seattle, pers. comm.).

Several possibilities exist for using the crabs as food. For example, the meat can be separated from the shell mechanically and used in soups or minced crab patties. The entire animal could also be used to prepare a concentrated protein paste (Minoru Okada, Tokai Fisheries Research Laboratory, Tokyo, Japan, pers. comm.). Alternately, red crabs can be ground and used as flavoring in fish cake products; experiments along this line have proved promising. Still another way of using red crabs as a flavoring agent is to dry and pulverize the whole crab.

Ultimately, the future of the pelagic red crab fishery will depend on the ex-vessel price of the crabs. Obviously, a lower price will attract more users and make feasible the use of all or parts of the crabs in a variety of products. In order for fishermen to operate at a low price, the efficiency of operations must be improved aboard the vessels. Our experience shows that improvements are needed mainly in the handling of the crabs once they are caught. Presently, catching the crabs is relatively efficient compared to handling and storing. Both midwater and bottom trawl are effective gear.

Probably the most efficient means of processing red crabs aboard a vessel would be to grind them. With the aid of suitable machinery, the ground crabs can be fed into bags and sealed automatically. Grinding would not only make handling easier, but would also decrease the volume of the crabs and hence increase the carrying capacity of a vessel. Further, refrigeration and ultimate freezing would be faster because air spaces would be eliminated. A disadvantage of grinding is that it may be impossible to make some contemplated products with ground crabs.

Prospects look good for the development of the red crab fishery. Ongoing studies are showing promising results, and it is likely that several experimental products will prove practicable. It should be pointed out, however, that although red crabs can be caught in international waters, the center of distribution lies well within Mexico's territorial limits. Thus, users here may have to depend on obtaining supplies from Mexico. For the present, Mexico is allowing some American fishing activity for the purpose of providing a supply of crabs to facilitate experimentation with various products and encourage development of fishing and handling methods. At the same time, Mexican scientists are studying the distribution and abundance of pelagic red crabs and are actively researching potential uses.

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