Biology and Potential Use of Pacific Grenadier,
Coryphaenoides acrolepis, off California

TETSUO MATSUI, SUSUMU KATO and SUSAN E. SMITH

Introduction

Grenadiers (also known as rattails) belong to the family Macrouridae, and are related to the codfishes (family Gadidae). They are among the most abundant fishes in continental slope and abyssal waters worldwide. The majority of macrourid species appear to spend a good part of the time swimming near the ocean bottom, feeding on benthic and midwater organisms (Marshall and Merrett, 1977). About 300 species are known, of which 11 inhabit the deep waters off California.

Although abundant, grenadiers are not utilized to a great extent. The remoteness of their habitat and the small size, soft flesh, and low meat yield of many species have discouraged their commercial use. A few species with good flesh characteristics are presently sold as food fish, while others are used as fish meal and fertilizer. In the northeast and northwest Atlantic

ABSTRACT—Grenadiers (family Macrouridae) are the most abundant fish on most continental slope areas worldwide. Off California the Pacific grenadier, Coryphaenoides acrolepis, occurs in relatively large numbers and may have marketing potential. This report provides information on the biology of the species and catch results from a number of scientific cruises. Catch data on several other species found together with Pacific grenadier, particularly sablefish, Anoplopoma fimbria, are also given. The fish were caught with a bottom trawl (15 trawls), and with free-vehicle longline gear (117 sets). The latter was a hook and line system in which the gear was dropped to the sea flooruntethered to the fishing vessel, and floated to the surface, with the catch, when detachable weights were automatically released. Sablefish dominated longline catches in depths of 200-600 fm (334-1,098 m), while Pacific grenadier was most abundant between 600 and 1,000 fm (1,098-1,830 m). Best trawl catches of Pacific grenadier were made at depths between 635 and 675 fm (1,125 and 1,225 m) and at 760 fm (1,391 m).

Ripe females were absent from our samples, but spent females were found during the entire year with highest numbers in the spring and early summer. Only one larva was found despite extensive sampling with plankton nets. Pacific grenadier was found to have good edible qualities by a taste-test panel, although the protein content (15 percent) and flesh yield (24 percent) were significantly lower than those of other fishes. A second species, the giant grenadier, Albatrossia pectoralis, was found to have exceptionally poor eating qualities and even lower protein content.

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1Tomo Iwamoto, California Academy of Sciences, Golden Gate Park, San Francisco, CA 94118. Personal commun.
Figure 1.—Pacific grenadier, *Coryphaenoides acrolepis*.

Figure 2.—Giant grenadier, *Albatrossia pectoralis*.

Figure 3.—Abyssal grenadier, *Coryphaenoides armatus*.
its flesh is extremely soft and watery. This species is frequently taken together with the Pacific grenadier in bottom trawl nets and is reported to have a wide depth range of 110-1,185 ft (200-2,170 m) (Novikov, 1970). Skin color of the giant grenadier is much lighter than that of the other two species, and individuals are usually pale when caught because most of their scales are sloughed off during capture.

The abyssal grenadier (Fig. 3) is dark brown to blackish in color with scales that are much smoother than those of the Pacific grenadier, and has 10-12 pelvic finrays (in Pacific samples) (Iwamoto and Stein, 1974), compared with (mostly) 8 for the Pacific grenadier. It is considered one of the largest grenadiers, with a largest record of 87 cm or 34 inches (Iwamoto and Stein, 1974). C. armatus ranges to much greater depths than the other two species. Although the known depth range for the species is between 154 and 2,570 ft (46-780 m) (Grey, 1956) only three records came from less than 547 ft or 100 m (Marshall, 1973). In the eastern North Pacific they are taken in abundance between 2,000 and 4,000 ft (Iwamoto and Stein, 1974). Based on morphological differences, Wilson and Waples (1984) suggested recognition of the North Pacific population as a distinct
subspecies, C. armatus variabilis.

This report deals primarily with aspects that pertain to the harvest and utilization of the Pacific grenadier, providing information on fishing methods, catch rates, distribution, and qualities of its flesh. Information on its biology is also included as well as data on giant grenadier and sablefish, Anoplopoma fimbria, which are often caught together with Pacific grenadier.

Materials and Methods

Data Sources

Fishing data provided in this report were obtained from several sources. A large part came from free-vehicle longline (hook and line) fishing conducted by Scripps Institution of Oceanography (SIO), mainly by Carl Hubbs in 1965, 1967, and 1971 and from cruises sponsored by the SIO Marine Life Research Group (MLRG) primarily during 1971 and 1972 (Table 1). Plankton samples from the surface to near bottom depths were also collected on the MLRG cruises. More recent data were gathered during two National Marine Fisheries Service (NMFS) research cruises in September and December 1985 on the NOAA research vessel David Starr Jordan. On these NOAA cruises, both bottom trawl and longline gear were used to catch grenadiers and other species in deep water (Tables 2, 3).

Our study area included offshore waters north of Cedros Island to Cape Mendocino but mainly near San Diego to Monterey, Calif. (Fig. 4). Fish taken south of Pt. Conception were predominantly caught on free-vehicle longlines. Longline sets included here (Tables 1, 2) were conducted at depths of 153-1,624 fm (280-2,970 m). Trawl tows are from the Jordan cruises in depths of 500 to 760 fm (915-1,391 m; Table 3). Maximum trawling depth was limited by the length of cable available on the Jordan.

Hook and Line Methods: Free-Vehicle Longline

In free-vehicle sampling, the gear or instrument package is allowed to free-fall to the sampling depth untethered to the ship. The package, which includes floats, returns to the surface after expendable weights are disengaged. The principal components of a free-vehicle longline are: 1) A main line with hooks attached and sufficient flotation to maintain positive buoyancy after the weight is released; 2) a locating float outfitted with a mast bearing a prominent flag, and as needed, other aids for locating the gear such as a radio transmitter or a strobe light; and 3) a chemical, electrical, mechanical, or sonic device which separates the disposable weight from the rest of the gear to allow the longline to return to the surface (Phleger and Soutar, 1971; Shutts, 1975). Size of gear, sampling depth, required precision of release time, and monetary costs are important considerations in choice of free-vehicle equipment.

Table 2.—Longline fishing conducted on R/V David Starr Jordan, September and December 1985.

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<tr>
<th>Cruise and sta.</th>
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<th>Long. (W)</th>
<th>Start fishing time</th>
<th>Fish- ing time</th>
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<td>0032</td>
<td>8.0</td>
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Table 3.—Trawl fishing conducted on R/V David Starr Jordan, September and December 1985.

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<th>Start fishing time</th>
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<td>122°22.9'</td>
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</table>

quid. The bottom hook was usually situated about 1.8 m (6 feet) off the bottom. Long-shank Mustad-Best Kirby hooks, size 8/0, were used on most SIO longline sets. On a few early SIO, as well as on most NMFS longline sets, equal numbers of these hooks were used together with size 6 or 9 Mustad tuna circle hooks. As catch results of the long-shank hooks appeared to be somewhat higher, the use of tuna circle hooks was discontinued in later SIO longline sets.

Most SIO longlines and all of those used on NMFS cruises were equipped with magnesium link release devices. Magnesium undergoes electrochemical corrosion in sea water when in contact with electron acceptors such as iron or zinc (Van Dorn, 1953; Isaacs and Schick, 1960). When the magnesium link deintegrates, the weight is detached and the rest of the gear rises to the surface. Soak time of the fishing gear was varied by using magnesium rods that were machined to specific diameters or by using "off-the-shelf" magnesium welding rods of various diameters. For precise release time, an electronically timed magnetic release mechanism was also used on some of the SIO longline cruises. Two of the simpler release mechanisms made with magnesium welding rods are

2Isopar M, a solvent with a relatively high flash point, is manufactured by Humbol Oil Refining Co. Mention of trade names or commercial firms does not imply endorsement by Scripps Institution of Oceanography or the National Marine Fisheries Service, NOAA.

3Daniel Brown, c/o MLRG, Scripps Institution of Oceanography, La Jolla, CA 92039. Unpubl. manuscr.
Figure 4.—Sites of fishing conducted on SIO and NMFS cruises.
Figure 5.—Free-vehicle longline gear used to catch grenadiers in deep water. The type A release mechanism was developed by D. Brown (personal commun.) and type B by A. Soutar (Phleger and Soutar, 1974).

The research vessel was usually deployed near the setting site about 1-2 hours before the estimated time of resurfacing of the gear. The free-vehicle longline invariably resurfaced close to the drop site, but drifted away with the wind and currents at the surface. When the catch was not recovered promptly we experienced problems of predation by birds, sharks, and sea lions.

Soak time is the period of time from the disappearance below the surface of the mast when setting the longline to when the gear was again detected on the surface, through visual sighting or audible signal. We estimate that the time the gear was on the bottom, in fishing position, was about an hour less than total soak time when fishing at 500-700 ft (914-1,280 m). In a single test with a time-depth recorder, the gear took 30 minutes to sink to the bottom at 680 ft (1,244 m). Using a magnetic-release device with precise timing we obtained a rise time of 32-39 minutes from depths of 500-710 ft (915-1,299 m). The surprisingly constant rise times may have resulted from the relatively faster rise rate of the deeper sets which caught more grenadiers, which have gas bladders which expand to provide more buoyancy as the gear rises, than sablefish, which do not possess gas bladders. In shallower sets the reverse was true as more sablefish than grenadiers were caught.

Bottom Trawling

The trawl used in 1985 aboard the David Starr Jordan was a standard high-rise bottom trawl, designed to catch rockfish, Sebastes spp. The webbing was made of polypropylene twine through-out, with a stretched mesh of 114 mm (4.5 inches). The cod end had an inner liner of 12.7 mm (0.5-inch) mesh webbing. The headrope, 23 m (75 feet) long, and the footrope, 34 m (110 feet) long, were constructed of rope-wrapped wire cable and 76 mm (3 inches) rubber discs. Trawl doors were standard V-doors, 1.5 x 2.1 m (5 x 7 feet) constructed of metal frames.
and wood sidings. Trawl cable diameter on the *Jordan* was 16 mm (5/8 inches), and each of two winches held 1,100 fm (2,000 m) of cable. The cable-to-depth ratio varied from 1.2:1 for deep tows, to 2:1 for shallower tows. All available cable was used for tows deeper than 650 fm (1,200 m).

All trawl tows were made in daylight hours. Tow sites were selected primarily on the basis of depth and no attempt was made to sample the study area systematically. Tow duration was 1.5 hours, starting from the time the trawl cable had been completely payed out. Towing speed was about 2 knots.

**Plankton Sampling for Eggs and Larvae**

Plankton was sampled during SIO-MLRG cruises using modified 1 m CalCOFI nets (Brinton, 1967), 2 m Stramin net (Wimpenny, 1966), and 3 m Isaacs-Kidd midwater trawl (IKMT) (Isaacs and Kidd, 1953). The nets were towed obliquely to sample the entire water column, with the ship underway at speeds of 1-2 knots for the CalCOFI net and IKMT, and 2-3 knots for the Stramin net. The CalCOFI nets were used in series of four nets that were opened and closed by messengers to collect discrete samples from different depths. The nets had wide collars to accommodate pursing lines to close the nets, and were towed from modified Leavitt (1938) release mechanisms. The system was essentially the same as that used by Brinton (1967). The nets, which were made with synthetic Nytex webbing with 0.3 or 0.5 mm mesh, were towed open for about an hour. Two or three series of these nets were spaced to cover the entire water column, but the coverage was uneven due to malfunction of some of the nets. Flowmeters attached to each net recorded the amount of water sampled by the net, and some of these meters were also capable of recording the depth sampled as well. A 408 kg (900 lb) lead weight was attached to the end of the cable to minimize the wire angle. These tows were taken at depths of about 400-1000 fm (732-1,829 m) on 9 cruises made in February, April, August, September, and December of 1971, February and April 1972, and March and May 1973. Open-net tows with the Stramin net and IKMT were also taken on these cruises in the same area. Stramin net tows were made on cruises of June, August, September, November, and December of 1971, and February and April 1972; and IKMT tows (in the same area but only at 600-680 fm depths) in February 1972, and March and May 1973. The Stramin net was lowered until it was near bottom, then hauled to the surface in tows that lasted 1.5-4 hours. Each IKMT station consisted of three tows using different towing wire lengths, designed to cover the entire area from near bottom to the surface. Each tow lasted 2-3 hours. The net used on the IKMT was entirely of 0.5 mm mesh Nytex netting. The Stramin net was made of 1 mm mesh Stramin netting.

An acoustical pinging device monitored the approximate depth of the nets, and a Benthos time-depth recorder (model 1170) was attached to the net frame near the distal end of the cable to record depth and time data for all plankton tows.

**Data Collection and Analysis**

All Pacific grenadiers caught on hook and line, and subsamples of those caught in trawls were measured, and some were weighed and sexed as well. Length measurements taken were: 1) Total length (TL; snout to tip of intact tail); 2) anal length (SVL; snout to vent); and 3) head length (HL; snout to posterior edge of gill cover). The tips of the tail of many individuals showed evidence of undergoing regenerative growth after having been severed, or were missing owing to injury during capture. These fish were excluded from length statistics reported in this paper.

Sacular otoliths were obtained from Pacific grenadiers for age determination. To better differentiate the calcified bands, the otoliths were studied by the "break and burn" method (Chilton and Beamish, 1982), being split and exposed to a flame before being examined with the aid of a microscope. A FISHPARM subroutine (Saila et al., 1988) was used to generate a growth curve from estimated ages (otolith band counts) and anal lengths of 60 *C. acrolepis* of both sexes. We combined these data because of the lack of age-at-length data by sex. The subroutine fits the von Bertalanffy (1938) equation:

\[ L_t = L_\infty \left\{1 - \exp \left(-K(t - t_0)\right)\right\}\]

where \( L_t \) is anal length at time \( t \), \( L_\infty \) is the asymptotic length, \( K \) is the growth coefficient, and \( t_0 \) is the time when length would theoretically be zero.

Gonads were removed and preserved in 10 percent Formalin, and sexes were recorded for most fish caught on MLRG-SIO cruises. The material was examined later in the laboratory, and all female fish were classified as to state of maturity (immature, ripening, or spent). Ovaries collected from 28 fish caught during February, March, April, November, and December 1974 were examined to get egg counts during different stages of development. Subsamples weighing between 0.003 and 0.035 g each were taken from the anterior and posterior parts of each ovary. The ovarian tissue was treated with several drops of methylene blue solution, then flushed with water. Eggs were counted and measured and classified into the following groups:

- **Stage 0**: Eggs nearly completely stained and measuring 0.05-0.20 mm diameter.
- **Stage 1**: Eggs only stained on the outer half and measuring 0.20-0.28 mm.
- **Stage 2**: Eggs unstained or only lightly stained on the outer surface and measuring 0.28-0.80 mm.
- **Stage 3**: Eggs unstained or only lightly stained on the outer surface and measuring 0.80-1.6 mm.

Our stages 2 and 3 correspond to those used by Stein and Pearcy (1982). We found no ripe eggs that they classified as stage 4. The outer membrane of the ovaries was removed and excluded from the weight of the ovaries in our calculations.

The relationship of various body measurements to total length was calculated to allow comparison with the work of others because the long, slender, and fragile tail of *C. acrolepis* was often damaged. The relationships of anal length to weight and total length to weight...
Table 4.—Catch data (listed by depth) from SIO free-vehicle longline stations recorded in Table 1. Total catch includes fish other than Pacific grenadier and sablefish.

<table>
<thead>
<tr>
<th>Cruise and station</th>
<th>Depth (ft)</th>
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<th>Sablefish</th>
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<td>0.10</td>
</tr>
<tr>
<td>M12-2</td>
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<td>50</td>
<td>5</td>
<td>0.10</td>
<td>0.74</td>
</tr>
<tr>
<td>MV65-III-34</td>
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<td>1</td>
<td>0.03</td>
<td>0.18</td>
</tr>
<tr>
<td>M9-3</td>
<td>550</td>
<td>7</td>
<td>1</td>
<td>0.14</td>
<td>0.39</td>
</tr>
<tr>
<td>MV71-15-68</td>
<td>563</td>
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<td>9</td>
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</tr>
<tr>
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<tr>
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</tr>
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</tr>
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<td>0.06</td>
</tr>
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</tr>
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</tr>
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<td>0.44</td>
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</tr>
<tr>
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</tr>
<tr>
<td>M6-2</td>
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<td>57</td>
<td>26</td>
<td>0.43</td>
<td>0.23</td>
</tr>
</tbody>
</table>

were computed using the allometric growth equation subroutine of FISH-PARM (Saila et al., 1988), which fits the equation:

\[ W = a L^b \]

where \( W \) is weight (kg) and \( L \) is total or anal length (mm), and \( a \) and \( b \) are constants. The relationship of anal length to total length was determined by using a least square fit of the single linear equation:

\[ Y = bx + a \]

where \( Y \) is total length and \( x \) is anal length.

To investigate the market potential of grenadier flesh, samples of fillet kept on ice were sent to the Utilization Research Division (URD) of the NMFS Northwest Fisheries Science Center (NWFSC), Seattle, Wash., for chemical and taste tests. A "sensory analysis panel" composed of trained URD personnel conducted tests to classify general characteristics of the cooked flesh of both Pacific and giant grenadiers.

**Fishing Results**

**Free-vehicle Longline**

Vertically set longline gear deployed...
at depths of 100–1,600 fm (183–2,926 m) in the sampling area (Fig. 4) caught mostly two species, Pacific grenadier and sablefish. Other species, which together made up less than 5 percent of the catch, were giant grenadier, abyssal grenadier, California slickhead, Alepocephalus tenebrosus, and finescale codling, Antimora microlepis. Longlines rarely failed to catch either sablefish or Pacific grenadier at these depths, confirming the ubiquity of these species over these waters.

Catch data from 117 free-vehicle longlines made on R/V David Starr Jordan, September and December 1985. Listed are catches of Pacific grenadier and sablefish, whose depth distributions overlap considerably. Sablefish were taken from 153 to 916 fm (280–1,675 m) and Pacific grenadier from 490 to 1,624 fm (897–2,972 m). Sablefish dominated the catches from 200 to 600 fm (366–1,098 m), while Pacific grenadier was most abundant at the deeper stations, especially between 600 and 1,000 fm (1,098 and 1,830 m) (Fig. 6, Table 4). Depth readings given above refer to depths to the sea floor, but both Pacific grenadier and sablefish were caught along the entire length of the vertical longline, from the lowest to the highest hooks (about 55 fm or 100 m above the sea floor). Two longline sets with baited hooks placed well off the bottom (lowest hook at 50 m or 27 fm above the bottom at station M2A2, and 25 m or 14 fm at station M4-2) produced catch rates of 0.66 and 0.30 Pacific grenadiers per hook, respectively. This shows that the fish can find bait quite high in the water column even when there is no bait near the bottom to guide the fish.

The catch rate of 97 longline sets made in depths greater than 500 fm (915 m) (Table 6) averaged 0.30 Pacific grenadiers per hook. Differences were relatively small between 25-hook (0.30 per hook average), 50-hook (0.32), and 100-hook (0.27) longlines. From these results, expectations were for hourly catch rates to increase on average nearly in proportion to the number of hooks deployed. The somewhat lower catch of 0.65 grenadiers per hour for the 25-hook sets, compared with 1.6 per hour for 50-hook sets and 3.8 per hour for 100-hook sets (Table 6), was probably due to the disproportionate number of these sets being made in depths (Table 4) near the deep end of the species’ range. Averages of 97 longline catches plotted in Figure 7 show a trend of increasing fishing time and
fewer hooks with increasing fishing depth. The decline in average catch per hook for longlines fished longer than 13 hours was probably also the result of fishing at deeper, less favorable depths. Catch per hook generally increased with lengths of fishing time, reaching a maximum around 8-13 hours, then declining. However, some of the highest catches were made in sets fished longer than 13 hours. For example, a catch of 0.60 fish per hook (Station M4-2 in Table 4), the second highest for Pacific grenadier, was made after 15.7 hours, and the highest catch of sablefish listed in Table 4, 0.83 per hook, (MV67-II-26) occurred when the line fished for nearly 19 hours. These results indicate that catch rates can be high with longer fishing times in productive areas. They also suggest low predation on, as well as low escapement of, hooked fish. Because sets made for longer periods were generally in very deep water, often beyond the optimum habitat of Pacific grenadier, our data probably do not reveal true catch rates after 13 hours.

Catch rates for fishing stations deeper than 500 fm (915 m) on the (Table 5) averaged 0.21 per hook for Pacific grenadier and 0.05 for sablefish, less than the averages of 0.31 and 0.11 for the SIO cruises. The shorter average fishing time of 8.1 hours used during the Jordan cruises, compared with the 10.8 hours of SIO samples, may have caused the difference, but the small number of fishing stations (11) for the Jordan cruises also was a factor.

Figure 8, which represents the catch rate of Pacific grenadier by month, shows no clear trends in seasonal availability of Pacific grenadier off southern California. The species was available most months, though catch rates were low in several fishing trials.

Results of Trawl Fishing on R/V David Starr Jordan

Catches of Pacific grenadier by trawl fishing conducted on the Jordan are shown in Table 7. Catches of giant grenadier are included, as well as those of sablefish, Dover sole, Microstomus pacificus; and shortspine and longspine thornyheads, Sebastolobus alascanus and S. altivelis, respectively. The last four species are commercially valuable fishes frequently found together with Pacific grenadier. Best trawl catches of both Pacific and giant grenadiers were made in depths of 615-675 fm (1,125-1,235 m), and at the deepest trawl station, 760 fm (1,391 m). The other species were more prevalent in the shallower trawl tows, but thornyheads were also commonly caught down to 700 fm (1,281 m).

The most productive trawling locality for larger individuals of Pacific grenadier was at Santa Lucia Bank, about 50 miles northwest of Pt. Conception (Fig. 4). The area is characterized by wide expanses of flat bottom in deep water.

Plankton Sampling Results

A single 9 mm TL larval Pacific grenadier was caught in one of the CalCOFI net samples at lat. 32°31.2'N, and long. 118°05'W on 2 February 1971. The net was estimated to have sampled depths between 2.7 and 120 fm (5-220 m) from the surface over water 680 fm (1,244 m) deep. No larvae were found in the remaining 121 CalCOFI net tows made during 9 MLRG cruises, nor in twelve Stramin net samples, nor nine IKMT samples from those cruises.

Life History of the Pacific Grenadier

Coryphaenoides acrolepis ranges from Japan and the Okhotsk and Bering Seas on the western Pacific, eastward along the Aleutian Islands to the west coast of North America (Iwamoto and Stein, 1974), as far south as Cedros Island (ca. lat. 28°N, station MV65-5, Table 1) off Baja California, Mex. It generally occurs along continental slope waters and is mainly caught with bottom sampling gear (otter trawls, bottom set hook and line). Our free-vehicle longline catches of C. acrolepis were made at depths ranging from 490 to 1,640 fm (896-3,000 m), the deepest capture being made at station SIO66-50. It may inhabit shallower depths at higher latitudes, as Okamura

Table 7.—Catch (in pounds) of the most common species of fish caught per 1.5-hour tow by trawl fishing on the R/V David Starr Jordan. Station numbers correspond to those given in Table 3.

<table>
<thead>
<tr>
<th>Station</th>
<th>Depth (fm)</th>
<th>Pacific grenadier</th>
<th>Giant grenadier</th>
<th>Sablefish</th>
<th>Dover sole</th>
<th>Channel rockfish</th>
<th>Total</th>
</tr>
</thead>
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<tr>
<td>8</td>
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<td>257</td>
<td>769</td>
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</tr>
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<td>65</td>
<td>0</td>
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</table>

1 Excluding giant grenadier, the only species presently without commercial value.
(1970) gives a depth range for the species of 339-1,202 fm (620-2,200 m).

Numerous photographic observations have been made with remote cameras of Pacific grenadiers swimming near the bottom (Phleger, 1971). Although they are usually taken with bottom sampling gear, some adults (Iwamoto and Stein, 1974) as well as the youngest stages (Stein, 1980) have been caught in midwater. In Stein’s samples, the youngest larvae were collected at depths less than 110 fm (200 m) from the surface, with larger larvae and juveniles occurring deeper in the water column. Savvatimskii (1969) similarly reported that small C. acrolepis of 10-15 mm (0.39-0.59 inch) TL were found at 55-110 fm (100-200 m) and we collected a 9 mm (0.35 inch) TL larva in a net which sampled 2.7-120 fm (5-220 m) below the surface off San Diego. These records indicate that the youngest Pacific grenadiers occur near surface layers. The largest juvenile reported taken in a midwater trawl by Stein and Pearcy (1982) measured 83 mm (3.3 inches) TL (Stein and Pearcy, 1982). In the SIO-MLRG sampling program conducted off southern California, no females were found with a preponderance of ripe (2 mm) eggs. Oocytes of females with enlarged ovaries were in the ripening stage (0.8-1.6 mm). The number of females with ovaries at this stage was also relatively low throughout the year, but females with empty, flaccid ovaries that indicated a spent condition were common (Fig. 9). The number of spent females was especially high in spring and early summer. During this period the number of ripe males was also greater. However, spend females and those with ripening stage 3 (0.8-1.6 mm) oocytes were found throughout the year.

Occurrence of these stages was lowest in August and September when many females carried dominant stage 2 (0.4-0.8 mm) oocytes.

Length at maturity appears to be around 650 mm (26 inches) TL for females, and about 500 mm (20 inches) TL for males. Most females with oocytes 0.8 mm and larger weighed 1.1 kg (2.4 pounds) or more and measured >650 mm (>25.6 inches) TL; the smallest was 585 mm (23 inches) TL and weighed 0.5 kg (1.1 pounds). Stein and Pearcy (1982) found 0.8-1.6 mm eggs in individuals as small as 460 mm (18.1 inches) TL in their trawl samples. The smallest ripe male in their catches measured 485 mm (19.1 inches) TL and weighed 0.5 kg (1.1 pounds). Ripe males in our SIO-MLRG samples were always larger, but only a few individuals caught on our longlines were smaller than 500 mm (19.7 inches) TL and the smallest measured 400 mm (15.7 inches) TL.

Like other macrourids, fecundity of C. acrolepis is relatively high. In seven females, Stein and Pearcy (1982) estimated counts of 22,657-118,612 (x = 70,025) eggs. Our counts for 28 females are given in Table 8. Only stage 0 (0.05-0.20 mm) oocytes were present in the single immature female examined. A slightly larger female of 0.7 kg (1.6 pounds), probably just attaining maturity, had an estimated 20,749 stage 3 eggs. Highest estimated number of stage 3 oocytes was 150,258 from a female weighing around 2.0 kg (4.5 pounds).
Figure 10.—A von Bertalanffy growth curve (sexes combined) and otolith ring count by size for 60 Pacific grenadiers.

The number of oocytes generally increased with fish size, but there were wide differences among individuals of similar sizes (Table 8). Stages 0 and 1 oocytes were always numerous and their numbers were independent of the developmental state of the ovaries, even in those that were spent. Nearly all oocytes found in spent females were in these stages. The presence of large numbers of stage 2 oocytes together with dominant stage 3 oocytes in some ovaries raise some questions as to the fate of the former. One can speculate a second spawning or perhaps these eggs are resorbed.

Despite the apparently high fecundity, the young of C. acrolepis have rarely been found. After sorting through 2,700 midwater trawls taken off Oregon, Stein (1980) found only 78 larvae and juveniles of C. acrolepis.

**Age and Growth**

Rings were found on sacular otoliths but the lines were obscure in large individuals, especially near the periphery of the otolith. We also had difficulty in reading the calcified bands in some of the otoliths from larger fish because of irregular patterns of band deposition. Even so, the data fitted the von Bertalanffy curve rather well (Fig. 10), with much of the variability about the mean explained by the least squares predictor ($R^2 = 0.82$).

The growth equation for estimated ages 6-62 for both sexes was found to be represented by

$$l_t = 24.24 \left[1 - \exp \left(-0.063 \left(t - 1.093\right)\right)\right]$$

The growth curve assumes that the otolith rings represent annual growth marks, but we emphasize that we have no confirmation that this is true. Kulikova (1957, in Gordon, 1979), using rings on scales, reported a rapid growth rate for
Pacific grenadier, but Brothers et al. (1976) using sacular otoliths suggested the opposite, estimating a 58 cm (22.8-inch) individual to be 10-11 years old. As in our study, the rings were presumed to represent annual growth rings, but this has yet to be confirmed (Wilson, 1982).

Our growth curve for Pacific grenadier shows a considerably slower growth rate than does Kulikova (1957), but somewhat faster than that found by Brothers et al. (1976). Known values for females in Figure 10 indicate a faster growth rate for females. Unfortunately six records of a number of individuals are lacking, and the growth curve in Figure 10 represents all otoliths examined.

The length-weight relationships computed for 141 males and 156 females, all with intact tails (Fig. 11), were as follows:

Females
\[ Wt = 8.879 \times 10^{-7} AL^{2.579} \quad R^2 = 0.92 \]
\[ Wt = 6.889 \times 10^{-9} TL^{2.922} \quad R^2 = 0.90 \]

Males
\[ Wt = 5.107 \times 10^{-6} AL^{2.251} \quad R^2 = 0.81 \]
\[ Wt = 2.225 \times 10^{-8} TL^{2.725} \quad R^2 = 0.87 \]

where \( Wt \) is weight (kg), \( AL \) is anal length (mm), and \( TL \) is total length (mm).

The relationship of total length to anal length is given in Figure 12. A least squares fit gave the following equations:

Males
\[ Y = 2.308x + 122.158 \quad R^2 = 0.864 \quad P<0.0001 \]

Females
\[ Y = 2.276x + 115.4 \quad R^2 = 0.925 \quad P<0.0001 \]

where \( Y \) is total length and \( x \) is anal length.

**Food and Feeding**

Because of expansion of their gas bladders, the stomachs of grenadiers are usually everted when they are captured near the bottom and hauled to the surface. Information on food habits of *C. acrolepis*, which has a large gas bladder, is thus scarce. Pearcy and Ambler (1974) found several species of cephalopods and crustaceans and remains of amphipods and fish in a few noneverted stomachs. Okamura (1970) lists as food items squid (37 percent), euphausiids (24 percent), fish (20 percent), and prawns (19 percent). Pacific grenadier has been collected thousands of meters above the sea floor and is considered by some to be bathypelagic rather than benthic. Savvatimskii (1969) found indications that it fed on nekton and macroplankton. Several squid beaks were found by one of us in an experimental fish trap (Brown, 1975) that had caught a Pacific grenadier near the sea floor. The beaks were presumed to have been regurgitated by the fish. In the SIO stomach samples we found remains of fish, euphausiids, other crustacea, squid beaks, and in the intestines, items such as polychaetes and sponge spicules, suggesting a generalized diet which included fish, plankton, and bottom organisms. The number of intact stomach samples we were able to obtain were too few for significant analysis, however.

**Flesh Characteristics**

Because its tail is thin and long, the amount of flesh obtainable from Pacific grenadier is less than that from other fish of comparable size. We obtained a fillet yield (weight of flesh compared with total weight) of only 22.26 percent (\( Y = 24.3 \) percent) from larger individuals. Kremsdorfer et al. (1979) were able to get a larger yield of 28 percent. Skin-on carcasses, with the head and intestines and most of the tail removed, averaged 50 percent of the total weight. Proximate analyses for Pacific and giant grenadiers obtained from NWSC Utilization Research Division and other data are given in Table 9. Protein content of giant grenadier was extremely low, and that of Pacific grenadier, 15.2 percent, was also considerably lower than the average of 19.5 percent found for 35 species of fishes, excluding sharks (Gooch et al., 1987).

Findings of the sensory analysis panel at NWSC, which tested and classified flesh characteristics of both Pacific and giant grenadier, are averaged and summarized in Table 10. Among the good attributes of Pacific grenadier flesh were firm texture, agreeable white color, and nonobjectionable taste. Flesh of the giant grenadier was unpalatable, according to the panelists, primarily because of its soft texture. This was reflected in the low scores for flakiness, hardness, chewiness, and fibrousness, and high score for moistness.

**Discussion**

Until quite recently a single species of

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*References omitted for brevity.*
Figure 11.—Length-weight relationships of Pacific grenadier. A shows weight (kg) to total length (mm) and B illustrates weight to anal length.
Figure 12.—Relationship of anal length to total length in the Pacific grenadier.

grenadier, *Coryphaenoides rupestris*, roundnose grenadier, made up the bulk of the world catch of the group. From 1975 to 1983 total annual catches from the northeast and northwest Atlantic, mostly by the Soviet Union, ranged from 15,000 to 65,000 t, averaging around 32,000 t (FAO, 1979, 1984). Between 1983 and 1986 however, the catches of roundnose grenadiers have averaged only 17,000 t. On the other hand catches of other species of grenadiers, again mostly by the Soviet Union, have increased rapidly. Between 1983 and 1986 the average catch of grenadiers in the southwest Atlantic (presumably *Macrourus holotrichus* and *M. carinatus*) was 18,000 t, while the catch in the northwest Pacific (presumably *Albatrossia pectoralis*, the giant grenadier) was around 17,750 t.

A Soviet report indicated that not only was the flesh of the roundnose grenadier good, but that its liver was also valued because of high oil and vitamin content (Savvatimskii, 1971). Novikov (1970) likewise considered the giant grenadier a valuable food species in spite of its water-logged flesh, because its liver and eggs were rich in vitamins and fats, and because of the apparently large biomass.

In Japan, grenadiers were formerly used to make a minced fish product called “surimi,” which was in turn used to produce traditional jellied fish products known as “kamaboko.” Pacific grenadier was satisfactory for this purpose as well as for other fish products, but giant grenadier made a poor grade of surimi (Shibata, 1985). With the advent of long-distance trawlers and factory ships, other species, particularly walleye or Alaska pollock, *Theragra chalcogramma*, have taken over this market. Most grenadiers are now caught as a bycatch in trawl fisheries aimed at other species, and the small amount landed is usually used as fish meal or fertilizer. Some species, such as *Coelorinchus tokiensis* are still sought and caught by longline, as they command good prices as food fish.

Canadian researchers found that the roundnose as well as another Atlantic species, the roughhead grenadier, *Macrourus berglax*, have good eating qualities and withstand iced or frozen storage better than most fish (Botta and Shaw, 1975, 1976). A similar study of the flesh of Pacific grenadier was reported by Kremsdorf et al. (1979), and their results were almost identical to those of the Canadian researchers, i.e., flesh of Pacific grenadier kept on ice for around 2 weeks did not lose its fresh quality, and taste preference tests showed that it compared favorably with Icelandic cod, *Gadus* sp. Botta and Shaw (1976) also found that 2-day old fish were easier to

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Sustained catches of roundnose grenadier in the Atlantic have shown that the species can support a substantial fishery. It seems unlikely, based on our fishing experience, however, that Pacific grenadier is abundant enough to warrant a directed fishery off southern and central California. Furthermore, the high cost of fishing in deep water, as well as the low flesh yield and presently low price discourages development. But Pacific grenadier can be utilized when caught in deep-sea trawl fisheries directed at other species. The best depths for a mixed species trawl fishery may be around 650 fm where Dover sole, sablefish, and thornyheads are found together with Pacific grenadier (Table 6). Longline fishing may be a viable alternative to trawls for catching Pacific grenadier because the gear is relatively inexpensive. The method is also effective for catching sablefish, which is more valuable than grenadier. Traditional vertical or horizontal longlines as well as free-vehicle longlines could be used from small vessels. Compared to free vehicle gear, traditional longline gear would require larger winches or line haulers to pull the line. Since long soak times are effective for catching Pacific grenadier, it is possible to space the setting and hauling intervals of free-vehicle longlines to maximize catches.

Further Research

The high number of ripening and spent females caught between late winter and early summer by SIO longlines indicates that this is the period of greatest spawning of Pacific grenadier off southern California. The smallest number of ripe and spent Pacific grenadier was found in late summer to fall, but presence of a few ripening and spent individuals during this period suggests that some spawning occurs throughout the year. Heaviest spawning may occur earlier farther north, as many individuals taken by trawls off Pt. Conception on the Jordan in December were either running ripe males or females with spent or enlarged ovaries. In even more northern waters, Savvatimskii (1969) reported ripe females only in October, and Stein and Pearcy (1982) caught ripe females in the fall and in March.

We can only speculate as to our failure to catch ripe females of Pacific grenadier with our longlines. Possibly ripe females stop feeding. It is also possible that they migrate to other areas, or higher up in the water column as has been suggested in the case of roundnose grenadier, because two females and a male of that species in spawning condition were captured about midway between the surface and sea floor over depths of 770-980 fm (1,400-1,800 m) (Grigor'ev and Serebryakov, 1983).

The youngest stages have been found 110 fm (200 m) or less from the surface (Savvatimskii, 1969; Stein, 1980), while larger larvae and juveniles have been caught deeper in the water column. The rarity of the young, considering the high fecundity of the fish, is puzzling. During the SIO-MLRG cruises, only one larva was collected. These poor results are apparently the normal expectations, as demonstrated by Stein's (1980) collection of only 78 larvae and juveniles from 2,700 midwater trawls. Further, despite these sampling efforts, eggs of C. acrolepis, which have an outer cover with characteristic hexagonal patterns in ripe females (Boehlert, 1984) are not known to have been collected in the plankton. Neither has a larva with a yolk sac, and there is no evidence that would indicate C. acrolepis being viviparous or ovoviviparous. Future studies focused on locating spawning females would certainly be a profitable area of research.

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Literature Cited


