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

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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[1].

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 over 65,000 metric tons (t) of one species, the roundnose grenadier, *Coryphaenoides rupestris*, were caught in 1975 (FAO, 1979). Although the catch of this species has declined substantially, other species are starting to be utilized, and the total grenadier catch in 1986 was around 60,000 t, 54 percent of which was roundnose grenadier (FAO, 1988). Commercial landings in the northeast Pacific have been minimal, even though macrourids are the most abundant fishes found in trawl catches in deep waters off Oregon and Washington (Alton, 1972; Pearcy and Ambler, 1974).

Off California, at least three species of grenadier appear to be of sufficient size and abundance to warrant marketing consideration. These are the Pacific grenadier, *Coryphaenoides acrolepis*; abyssal grenadier, *C. armatus*; and giant grenadier, *Albatrossia pectoralis*. The Pacific grenadier (Fig. 1) appears to have the best potential, as the quality of its flesh is good and it is abundant off California. The largest specimen of *C. acrolepis* we have measured was over 95 cm (37 inches) in total length. It weighed 4 kg (8.8 pounds) and was taken at lat. 29°31.3′N, long. 117°12.0′W at a depth of 1,050 fm (1,920 m). This may have been an unusually large individual, as the prior known record length for the species is smaller at 87 cm or 34 inches (Rass, 1963, in Iwamoto and Stein, 1974). Pacific grenadier is a smaller species than the other two grenadiers. Its skin is dark and covered with adherent, rough scales. The long tapering tail, characteristic of all grenadiers, contributes to a low percentage yield of flesh compared with other fishes.

The giant grenadier (Fig. 2) is the largest of all of the grenadiers, reaching a length of around 150 cm (5 feet) (Iwamoto and Stein, 1974). Despite the large size and relatively high availability, its commercial potential is limited because

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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 floor untethered 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 615 and 675 fm (1,125 and 1,235 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.*

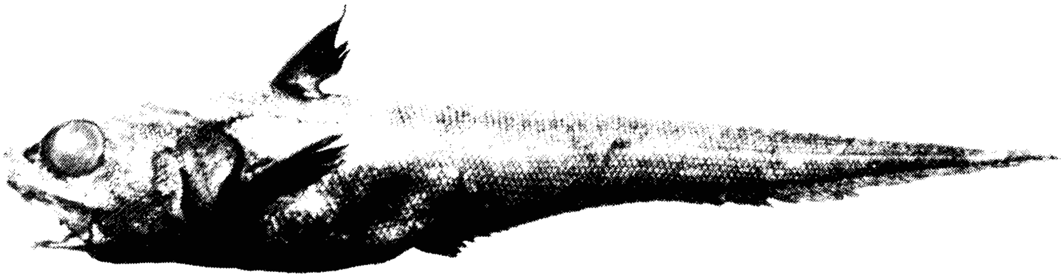

Figure 1.—Pacific grenadier, *Coryphaenoides acrolepis*.

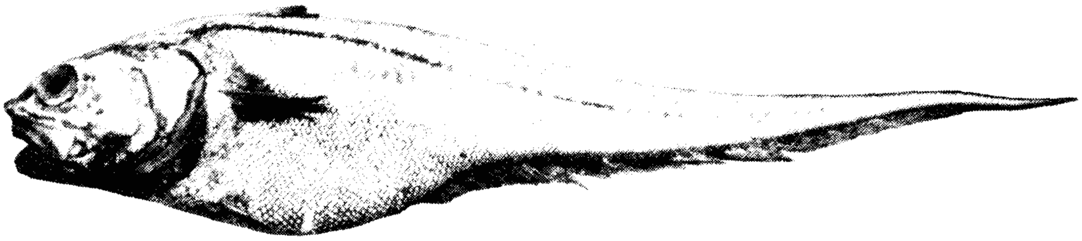

Figure 2.—Giant grenadier, *Albatrossia pectoralis*.

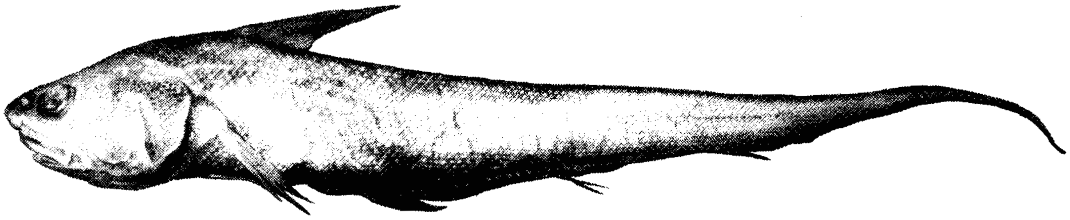

Figure 3.—Abyssal grenadier, *Coryphaenoides armatus*.

Table 1.—Station data (listed by depth) for free-vehicle longline fishing conducted by SIO from 1965 to 1979.

Cruise and station	Date	Lat. (N)	Long. (W)	Depth (fm)	Time started	Hours fished	Cruise and station	Date	Lat. (N)	Long. (W)	Depth (fm)	Time started	Hours fished
MV71-I-49	5/30/71	32°22.5′	118°28.1′	153	2316	11.23	M7-1	9/13/71	32°25.2′	117°28.9′	680	2337	8.97
MF71-2	7/22/71	32°38.2′	117°57.3′	240	0919	3.37	M9-1	12/20/71	32°24.8′	117°29.0′	680	2258	13.43
MV71-I-46	5/30/71	32°06.6′	118°15.6′	293	2046	10.98	M9-2	12/20/71	32°25.1′	117°29.1′	680	2340	12.75
MV71-I-50	5/30/71	32°22.2′	118°26.4′	304	2334	10.65	M10-2	2/07/72	32°25.8′	117°28.0′	680	2348	12.27
MV71-I-57	5/31/71	32°34.7′	118°00.4′	310	2042	9.68	M10-4	2/09/72	32°26.4′	117°33.5′	680	0005	14.50
MV71-I-40	5/28/71	30°16.5′	116°09.7′	320	2132	9.63	M11-3	4/08/72	32°24.8′	117°28.6′	680	2345	7.00
MV71-2	7/22/71	32°38.2′	117°57.3′	330	0928	3.28	M12-1	9/27/72	32°24.9′	117°29.0′	680	0019	9.17
MV65-III-18	9/24/65	32°44.0′	118°20.8′	337	2130	10.28	M13-1	2/28/73	32°25.5′	117°28.9′	680	2325	9.00
MV71-I-52	5/13/71	32°22.4′	118°21.3′	346	0012	11.63	MV67-IA-3	4/20/67	31°29.0′	118°01.0′	690	2025	12.58
M6-3	8/12/71	32°50.0′	117°31.4′	400	2254	8.68	SC75	—	32°34.9′	117°26.7′	700	1343	3.53
MV67-II-26	6/16/67	38°00.0′	123°31.0′	400	1915	18.92	MV71-I-47	5/30/71	32°08.8′	118°17.0′	702	2102	11.13
SC2-74	11/23/74	32°36.8′	117°28.5′	420	1044	4.40	MV71-I-11	5/20/71	28°52.7′	118°12.2′	710	1937	11.88
MV65-II-33	9/26/65	32°40.0′	118°37.5′	426	2144	10.02	S2-1-1	5/06/75	32°28.2′	118°48.5′	710	0725	5.92
M1-2	2/02/71	32°50.0′	117°31.2′	445	2204	9.93	MV65-III-37	9/22/65	32°42.6′	118°46.0′	712	0013	10.10
M5-3	7/16/71	32°50.0′	117°31.0′	445	0950	3.75	MV71-I-10	5/20/71	28°55.0′	118°11.4′	715	2006	10.63
M3-3	5/13/71	32°50.0′	117°31.0′	445	0735	4.58	M2A1	4/13/71	31°51.0′	117°11.7′	730	2153	10.32
MV71-I-24	5/25/71	28°21.8′	115°44.3′	453	2114	11.27	M2A2	4/13/71	31°51.0′	117°11.7′	730	2110	11.95
MV67-IA-22	4/26/67	28°09.0′	118°16.2′	455	0218	15.70	71RI-2	1/19/71	32°45.2′	119°26.5′	735	2110	11.58
MV71-I-16	5/23/71	29°27.5′	117°19.2′	490	2204	12.65	MV65-III-19	9/24/65	32°42.0′	118°16.0′	738	2317	9.30
M10-5	2/09/72	32°34.7′	117°26.0′	530	2140	10.33	MV65-III-26	9/25/65	32°47.6′	118°47.0′	748	1936	13.07
MV67-IA-28	4/27/67	29°26.5′	117°15.6′	536	1953	11.88	MV71-I-3	5/18/71	28°52.2′	118°12.0′	750	2106	10.04
MV65-III-24	9/25/65	32°44.5′	118°43.5′	537	1830	13.00	MV71-I-59	5/31/71	32°31.8′	117°58.7′	765	2124	10.43
S2-2	5/08/75	32°50.4′	117°47.9′	550	1635	4.18	MV67-II-16	6/12/67	36°42.8′	122°03.5′	790	1947	16.43
M10-6	2/09/72	32°34.5′	117°25.4′	550	2156	9.15	MV65-III-3	9/21/65	30°52.0′	118°07.6′	790	1746	17.40
MV65-III-34	9/26/65	32°41.3′	118°39.0′	555	2221	9.90	MV65-III-38	9/27/65	32°43.0′	118°48.5′	798	0050	9.83
M9-3	12/21/71	32°26.0′	117°33.7′	555	1935	13.58	MV67-II-28	—	37°59.0′	123°34.0′	800	2007	19.75
MV71-I-58	5/31/71	32°32.8′	117°59.5′	560	2104	10.25	MV65-I-5	6/10/65	28°51.0′	115°46.7′	814	1851	15.05
MV67-II-15	6/12/67	36°43.3′	122°03.7′	560	1925	20.38	M8-7	11/02/71	32°35.0′	118°03.1′	850	2340	10.00
M8-2	11/01/71	32°26.8′	117°34.0′	561	2212	9.05	MV67-1A-9	4/22/67	30°47.2′	117°12.7′	873	1913	12.35
MV71-I-51	5/30/71	32°22.2′	118°23.7′	563	2351	11.35	MV71-I-25	5/25/71	28°23.6′	115°47.5′	875	2149	11.02
M12-2	9/28/72	32°26.5′	117°33.8′	568	0047	7.52	MV67-IA-7	4/22/67	30°53.3′	117°13.0′	890	0215	6.00
M9-4	12/21/71	32°26.5′	117°33.5′	595	1945	14.00	MV65-III-28	9/25/65	32°50.6′	118°52.0′	896	2055	14.07
M15-5	3/31/74	35°25.0′	121°42.2′	600	0554	3.27	MV67-IA-18	4/24/67	29°35.3′	117°18.1′	900	2301	14.40
M8-3	11/01/71	32°26.2′	117°33.1′	605	2231	8.90	MV65-III-29	9/25/65	32°51.2′	118°54.8′	916	2207	12.05
MV65-III-35	9/26/65	32°41.6′	118°41.0′	610	2253	11.02	M1-3	2/01/71	32°30.1′	118°11.4′	925	2142	11.05
M12-3	9/28/72	32°26.7′	117°33.6′	610	0109	6.82	M3-2	5/12/71	32°30.5′	118°11.5′	925	2130	4.13
SC74	11/17/74	32°25.8′	117°22.1′	610	1105	4.22	M5-2	7/15/71	32°30.0′	118°11.5′	925	1956	9.00
M11-2	4/07/72	32°34.1′	117°26.9′	620	1908	9.12	M8-5	11/02/71	32°30.0′	118°11.4′	930	2158	9.53
SC79	11/03/79	32°36.0′	117°28.1′	620	1055	2.00	M6-2	8/11/71	32°30.1′	118°11.7′	937	0903	8.18
SC3-74	11/23/74	32°38.2′	117°30.0′	630	1101	7.23	MV71-I-42	5/28/71	30°11.5′	116°12.5′	938	2229	10.23
M8-4	11/01/71	32°25.6′	117°32.5′	630	2255	9.92	MV65-III-21	9/25/65	32°40.3′	118°11.8′	952	0015	9.88
MV65-III-36	9/26/65	32°42.2′	118°43.8′	631	2324	10.02	M7-3	9/14/71	32°30.0′	118°11.0′	980	2351	9.02
M11-4	4/09/72	32°26.4′	117°33.6′	647	0046	6.82	MV71-I-48	5/30/71	32°12.4′	118°14.1′	998	2138	10.88
70RI-7	10/29/70	32°34.8′	117°30.0′	655	1810	9.88	MV65-III-4	9/21/65	30°50.4′	118°08.7′	1017	1842	16.55
MV71-I-17	5/23/71	29°28.9′	117°17.1′	655	2225	13.70	MV67-IA-20	4/26/67	28°08.2′	118°13.3′	1024	0117	16.30
70RI-8	10/29/70	32°35.0′	117°30.0′	656	1820	10.00	MV71-I-60	6/01/71	32°30.0′	117°57.9′	1026	2149	10.27
SC17	7/22/75	32°34.4′	117°28.5′	660	1045	3.12	MV71-I-4	5/18/71	28°52.8′	118°10.8′	1026	2147	10.82
MV71-I-4	5/28/71	30°15.5′	116°10.7′	663	2149	10.46	MV71-I-12	5/21/71	28°52.9′	118°10.9′	1039	2001	11.90
M15-3	3/27/74	32°32.7′	117°34.3′	668	0705	4.77	MV71-I-19	5/23/71	29°31.3′	117°12.0′	1050	2133	14.73
M15-1	3/26/74	32°28.8′	117°32.1′	670	1203	4.57	MV67-IA-10	4/22/67	30°47.0′	117°03.2′	1075	2022	13.53
M8-6	11/02/71	32°35.0′	118°03.1′	670	2312	9.30	MV71-I-26	5/25/71	28°25.2′	115°49.7′	1095	2214	11.08
70RI-2	10/26/70	32°25.2′	117°28.9′	680	2230	10.92	MV67-II-18	6/12/67	36°37.1′	122°09.2′	1200	2118	17.12
70RI-3	10/26/70	32°25.2′	117°28.9′	680	2250	11.50	MV67-IA-11	4/22/67	30°53.6′	117°04.0′	1208	2103	13.53
70RI-4	10/26/70	32°25.2′	117°28.9′	680	2304	15.43	MV67-II-29	6/16/67	37°58.0′	123°38.0′	1233	2039	19.68
71RI-1	1/18/71	32°27.0′	117°29.1′	680	2110	5.33	MV67-IA-16	4/24/67	29°36.6′	117°20.4′	1382	2225	13.72
M4-1	6/22/71	32°29.6′	117°28.6′	680	1832	13.70	MV65-III-6	9/21/65	30°36.3′	118°13.4′	1391	2121	16.95
M4-2	6/22/71	32°29.8′	117°28.6′	680	1832	15.70	MV67-II-30	6/16/67	37°57.4′	123°40.5′	1480	2103	20.78
M5-1	7/05/71	32°25.2′	117°29.0′	680	1058	4.03	SIO66-50	5/21/66	40°34.6′	125°51.4′	1624	1907	13.38
M6-1	8/10/71	32°24.8′	117°28.8′	680	1110	8.92							

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 fm (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 fm (282-4,700 m) (Grey, 1956) only three records came from less than 547 fm or 1,000 m (Marshall, 1973). In the eastern North Pacific they are taken in abundance between 2,000 and 4,000 m (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*.

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

Cruise and sta.	Date (1985)	Lat. (N)	Long. (W)	Start fishing	Fishing time
Cruise DS85-10(193)					
1	9-19	32°56.3′	118°19.2′	0551h	8.0h
2	9-19	33°13.6′	118°59.1′	2318	6.4
3	9-20	33°05.8′	119°17.3′	2328	6.8
4	9-23	35°02.6′	121°41.5′	2343	6.2
5	9-26	32°28.7′	118°48.0′	0832	5.8
Cruise DS85-121(195)					
6	12-5	34°57.8′	121°35.1′	0032	8.0
7	12-6	35°09.4′	121°48.2′	0000	8.0
8	12-6	35°42.9′	122°11.8′	2306	7.2
9	12-9	36°55.2′	122°34.7′	1105	6.8
10	12-10	36°26.9′	122°06.3′	1106	8.0
11	12-11	37°01.7′	122°54.1′	1149	8.0

Table 3.—Trawl fishing conducted on R/V *David Starr Jordan*, September and December 1985.

Cruise and sta.	Date (1985)	Lat. (N)	Long. (W)	Start fishing	Fishing time	Depth (fm)
Cruise DS85-10(193)						
1	9-20	33°14.0′	118°58.7′	1034h	1.5h	610
2	9-21	33°02.6′	119°21.7′	0812	2.5	600
3	9-22	33°50.7′	119°26.6′	0806	1.5	690
4	9-23	35°06.3′	121°38.9′	0820	2.5	675
5	9-23	35°07.6′	121°42.1′	1256	1.5	725
6	9-24	35°06.1′	121°37.9′	0856	1.5	615
7	9-24	35°10.0′	121°38.1′	1301	1.5	550
8	9-25	34°33.4′	121°08.2′	1320	1.5	500
Cruise DS85-12(195)						
9	12-5	34°53.4′	121°34.5′	1138	1.5	600
10	12-5	34°58.5′	121°35.9′	1623	1.5	650
11	12-6	35°10.7′	121°42.3′	1115	1.5	685
12	12-7	35°44.6′	122°03.8′	1008	1.5	635
13	12-7	35°53.1′	121°56.3′	1520	1.5	700
14	12-8	36°13.2′	122°13.4′	0811	1.5	570
15	12-8	36°15.3′	122°22.9′	1410	1.5	760

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.

Figure 5 illustrates a free-vehicle longline used on the *Jordan* and some of the SIO cruises. Each 19 l (5-gallon) plastic carboy, used for floatation and filled with Isopar M, an industrial solvent[2], provides about 4.5 kg (10 pounds) of flotation (Shutts, 1975). Both SIO and NMFS longlines were designed to fish vertically with a weight on the bottom of the longline and floats at the top. On each longline, from 25 to 100 hooks were spaced 1 m (39 inches) apart and baited with cut squid. 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 disintegrates, 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[3] was also used on some of the SIO longline cruises. Two of the simpler release mechanisms made with magnesium welding rods are

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[2] Isopar M, a solvent with a relatively high flash point, is manufactured by Humble 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.

[3] Daniel Brown, c/o MLRG, Scripps Institution of Oceanography, La Jolla, CA 92093. Unpubl. manuscr.

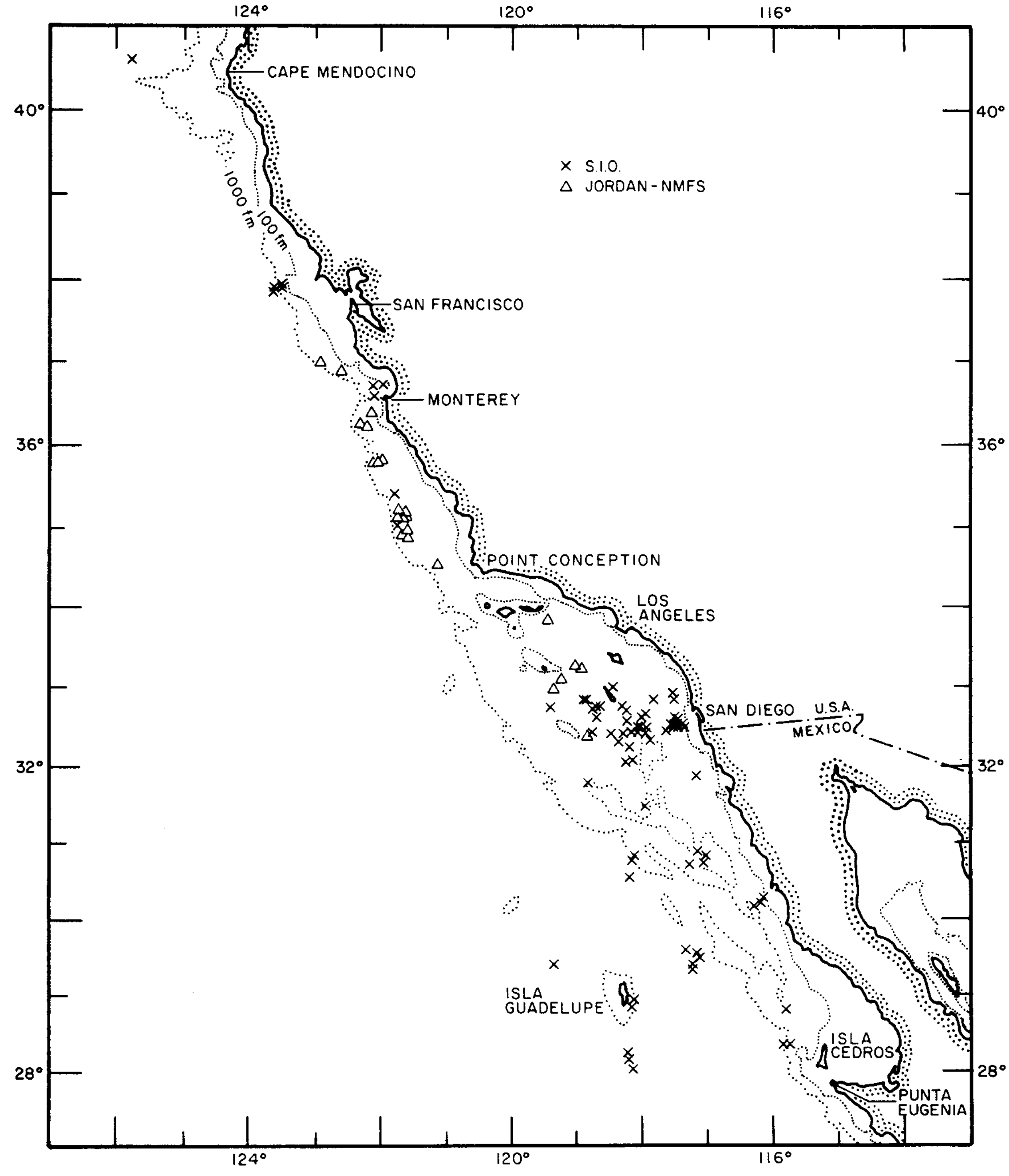

Figure 4.—Sites of fishing conducted on SIO and NMFS cruises.

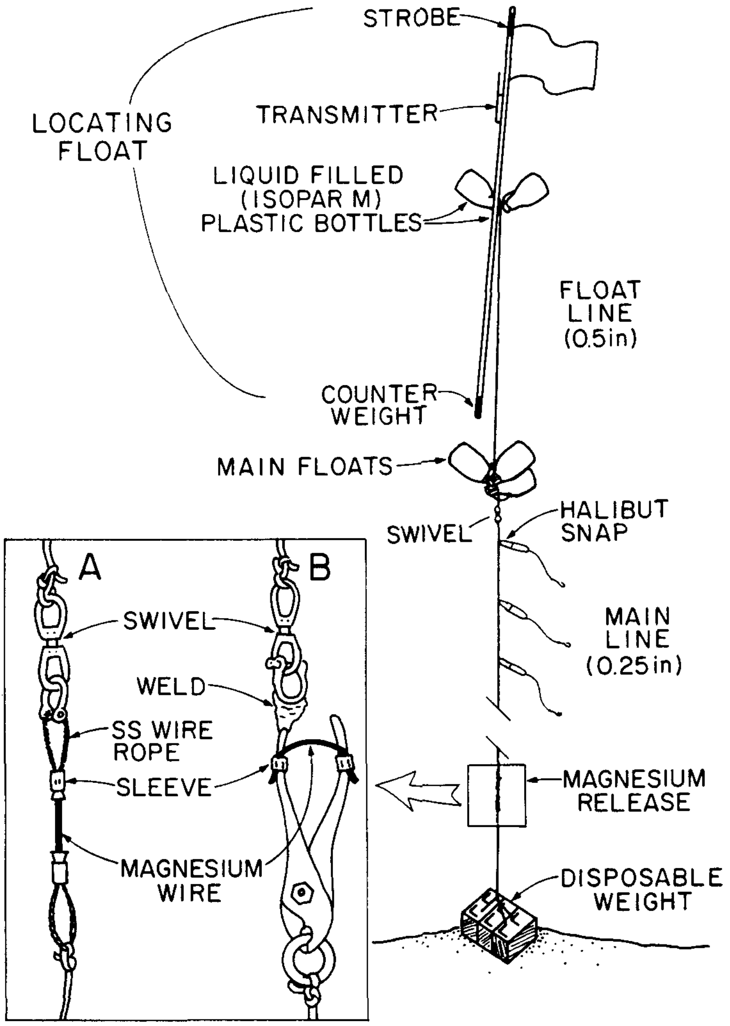

Figure 5.—Free-vehicle longline gear used to catch grenadiers in deep water. The type A release mechanism was developed by D. Brown (personal commun.) and type B by A. Soutar (Phleger and Soutar, 1974).

illustrated in the Figure 5 inset. The type shown in Figure 5A was constructed by simply crimping wire loops on a magnesium welding rod. Unlike other release devices used during SIO cruises, this type of linkage causes the magnesium rod to receive direct strain from the floats and the weight, resulting in shorter and more unpredictable release times than if no strain were present. Although unsophisticated, it gave good results on the NMFS cruises. Longlines using this device with a 2.3 mm (0.09 inch) diameter magnesium wire resurfaced after 6.1-8.2 hours in 5 trials in September 1985 and 7.6-9.0 hours in 6 trials in December 1985. On most SIO-MLRG cruises we used a modified version of the plier-release magnesium link gear described by Phleger and Souter (1971) (Fig. 5B). The strain between the weight and floats is taken up by the plier, resulting in a more predictable and consistent release time.

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 fm (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 fm (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 fm (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 throughout, 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 × 2.1 m (5 × 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 or 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 gillcover). 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 grenadier 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 small sample size and because of the lack of age-at-length data by sex. The subroutine fits the von Bertalanffy (1938) equation:

$$l_t = L_\infty \{1 - \exp(-K[t - t_o])\}$$

where l_t is anal length at time t, L_∞ is the asymptotic length, K is the growth coefficient, and t_o 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.

Cruise and station	Depth (fm)	No. of hooks	Pacific grenadier		Sablefish		Total catch per hook
			Catch	No./hook	Catch	No./hook	
MV71-I-49	153	25	0	0	13	0.52	0.64
MV71-2	240	25	0	0	6	0.24	0.24
MV71-I-46	293	25	0	0	9	0.36	0.40
MV71-I-50	304	25	0	0	20	0.80	0.80
MV71-I-57	310	25	0	0	15	0.60	0.60
MV71-I-40	320	25	0	0	7	0.28	0.28
MV71-2	330	25	0	0	11	0.44	0.44
MV65-III-18	337	30	0	0	6	0.20	0.20
MV71-I-52	346	25	0	0	17	0.68	0.68
M6-3	400	50	0	0	23	0.46	0.46
MV67-II-26	400	30	0	0	25	0.83	0.83
SC2-74	420	100	0	0	35	0.35	0.35
MV65-II-33	426	30	0	0	10	0.33	0.33
M1-2	445	100	0	0	32	0.32	0.32
M5-3	445	50	0	0	14	0.28	0.28
M3-3	445	100	0	0	23	0.23	0.23
MV71-I-24	453	26	0	0	10	0.38	0.38
MV67-IA-22	455	30	0	0	0	0	0.03
MV71-I-16	490	26	3	0.12	0	0	0.12
M10-5	530	50	1	0.02	30	0.60	0.62
MV67-IA-28	536	30	4	0.13	0	0	0.17
MV65-III-24	537	30	2	0.07	10	0.33	0.40
S2-2	550	100	2	0.02	10	0.10	0.12
M10-6	550	50	5	0.10	17	0.34	0.44
MV65-III-34	555	30	1	0.03	18	0.60	0.63
M9-3	555	50	7	0.14	19	0.38	0.54
MV71-I-58	560	25	9	0.36	8	0.32	0.68
MV67-II-15	560	30	12	0.40	9	0.30	0.70
M8-2	561	50	12	0.24	13	0.26	0.50
MV71-I-51	563	25	12	0.48	2	0.08	0.56
M12-2	568	50	15	0.30	18	0.36	0.66
M9-4	595	50	5	0.10	12	0.24	0.34
M15-5	600	69	13	0.19	8	0.12	0.30
M8-3	605	50	15	0.30	11	0.22	0.52
MV65-III-35	610	30	6	0.20	5	0.17	0.37
M12-3	610	50	19	0.38	20	0.40	0.78
SC74	610	100	43	0.43	6	0.06	0.49
M11-2	620	50	11	0.22	10	0.20	0.44
SC79	620	50	6	0.12	1	0.02	0.14
SC3-74	630	50	15	0.30	16	0.32	0.62
M8-4	630	50	10	0.20	19	0.38	0.58
MV65-III-36	631	30	3	0.10	15	0.50	0.60
M11-4	647	93	7	0.08	3	0.03	0.11
70RI-7	655	25	11	0.44	6	0.24	0.68
MV71-I-17	655	26	13	0.50	0	0	0.50
70RI-8	656	25	7	0.28	5	0.20	0.48
SC17	660	99	5	0.05	0	0	0.05
MV71-I-4	663	25	8	0.32	3	0.12	0.44
M15-3	668	100	21	0.21	7	0.07	0.28
M15-1	670	100	22	0.22	4	0.04	0.26
M8-6	670	50	21	0.42	1	0.02	0.44
70RI-2	680	25	11	0.44	5	0.20	0.64
70RI-3	680	25	11	0.44	5	0.20	0.64
70RI-4	680	25	6	0.24	0	0	0.28
71RI-1	680	100	40	0.40	24	0.24	0.64
M4-1	680	100	54	0.54	8	0.08	0.62
M4-2	680	50	30	0.60	4	0.08	0.68
M5-1	680	100	14	0.14	1	0.01	0.15
M6-1	680	57	26	0.46	13	0.23	0.68
M7-1	680	50	19	0.38	9	0.18	0.56
M9-1	680	50	15	0.30	11	0.22	0.52
M9-2	680	50	19	0.38	13	0.26	0.64
M10-2	680	50	22	0.44	14	0.28	0.72
M10-4	680	50	7	0.14	15	0.30	0.44
M11-3	680	49	16	0.33	4	0.08	0.41
M12-1	680	100	36	0.36	18	0.18	0.54
M13-1	680	200	53	0.26	22	0.11	0.38
MV67-IA-3	690	30	17	0.57	4	0.13	0.70
SC75	700	50	14	0.28	1	0.02	0.30
MV71-I-47	702	25	11	0.44	2	0.08	0.52
MV71-I-11	710	40	12	0.30	0	0	0.30
S2-1-1	710	100	17	0.17	1	0.01	0.19
MV65-III-37	712	30	12	0.40	4	0.13	0.57
MV71-I-10	715	40	14	0.35	0	0	0.42
M2A1	730	100	54	0.54	2	0.02	0.56
M2A2	730	50	33	0.66	1	0.02	0.68
71RI-2	735	50	4	0.08	4	.08	0.20
MV65-III-19	738	30	11	0.37	0	0	0.40
MV65-III-26	748	30	10	0.33	5	0.17	0.57
MV71-I-3	750	41	18	0.44	0	0	0.56
MV71-I-59	765	25	18	0.72	0	0	0.72
MV67-III-16	790	30	17	0.57	1	0.03	0.60
MV65-III-3	790	30	3	0.10	0	0	0.10
MV65-III-38	798	30	8	0.27	1	0.03	0.33
MV67-II-28	800	30	9	0.30	1	0.03	0.40
MV65-I-5	814	100	18	0.18	0	0	0.19
M8-7	850	50	27	0.54	1	0.02	0.62
MV67-1A-9	873	30	17	0.57	0	0	0.57
MV71-I-25	875	26	14	0.54	1	0.04	0.62
MV67-IA-7	890	30	9	0.30	0	0	0.30
MV65-III-28	896	30	7	0.23	2	0.07	0.30
MV67-IA-18	900	30	9	0.30	0	0	0.30
MV65-III-29	916	30	6	0.20	7	0.23	0.43
M1-3	925	100	54	0.54	0	0	0.54
M3-2	925	100	15	0.15	0	0	0.15
M5-2	925	50	26	0.52	0	0	0.52
M8-5	930	50	27	0.54	0	0	0.54
M6-2	937	50	27	0.54	0	0	0.54
MV71-I-42	938	25	14	0.56	0	0	0.56
MV65-III-21	952	30	10	0.33	0	0	0.40
M7-3	980	50	37	0.74	0	0	0.74
MV71-I-48	998	25	11	0.44	0	0	0.44
MV65-III-4	1017	30	3	0.10	0	0	0.18
MV67-IA-20	1024	30	0	0	0	0	0
MV71-I-60	1026	25	14	0.31	0	0	0.38
MV71-I-4	1026	39	4	0.10	0	0	0.18
MV71-I-12	1039	39	7	0.18	0	0	0.36
MV71-I-19	1050	25	10	0.40	0	0	0.44
MV67-IA-10	1075	30	8	0.27	0	0	0.37
MV71-I-26	1095	26	8	0.31	0	0	0.38
MV67-II-18	1200	30	3	0.10	0	0	0.10
MV67-IA-11	1208	30	11	0.36	0	0	0.43
MV67-II-29	1233	30	5	0.17	0	0	0.20
MV67-IA-16	1382	30	0	0	0	0	0
MV65-III-6	1391	30	0	0	0	0	0.03
MV67-II-30	1480	30	2	0.07	0	0	0.07
SIO66-50	1624	30	1	0.03	0	0	0.10

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

$$W = aL^b$$

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

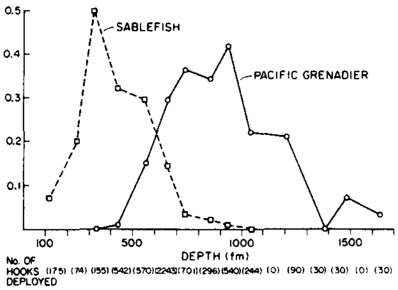

Figure 6.—SIO catch records of sablefish and Pacific grenadier by 117 free-vehicle longlines, 1965-79. Plotted points represent mean values at 100-fm depth intervals, with the number of deployed hooks representing each point in parentheses.

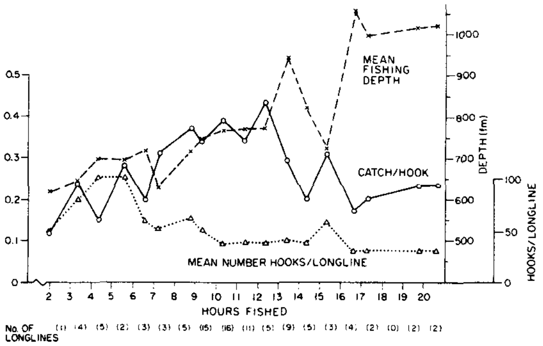

Figure 7.—Relationship of hours fished to average catch per hook, depth of fishing, and hooks per set. Data are from 97 SIO free-vehicle longlines from stations over 500 fm depth. Number of longlines are in parenthesis.

Table 5.—Catch data from longline fishing conducted on R/V *David Starr Jordan*, September and December 1985.

Cruise and station	Depth (fm)	No. of hooks	Pacific grenadier Total catch	Pacific grenadier Per hook	Sablefish Total catch	Sablefish Per hook	Total catch per hook
Cruise DS 85-10(193)							
1	695	48	0	0	1	0.02	0.02
2	626	48	5	0.10	5	0.10	0.21
3	888	48	3	0.06	3	0.06	0.12
4	835	47	12	0.26	0	0.0	0.26
5	725	48	25	0.52	0	0.0	0.52
Cruise DS 85-12(195)							
6	611	49	19	0.39	4	0.08	0.47
7	903	47	11	0.23	0	0.0	0.23
8	994	48	1	0.02	0	0.0	0.02
9	784	46	15	0.33	1	0.02	0.35
10	490	46	0	0	6	0.13	0.13
11	805	43	19	0.44	4	0.09	0.53
Total		518	110	0.21	24	0.05	0.26

Table 6.—Comparison of catch of Pacific grenadier on 25-, 50-, and 100-hook longlines listed in Table 4 from depths >500 fm. Actual number of hooks of the 25-hook group varied more than the others and averaged 28.4 hooks per longline.

Item	25-hook	50-hook	100-hook	Total
No. of longlines	47	35	15	97
No. of hooks deployed	1,328	1,724	1,492	4,544
Total catch	394	559	402	1,355
Hours fished	608.21	341.79	106.38	1,056.38
Avg. hours fished	12.94	9.76	7.09	10.89
Avg. catch per hook	0.297	0.324	0.269	0.298
Avg. catch per hour	0.648	1.64	3.78	1.28

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 ubiquitousness of these species over these waters.

Catch data from 117 free-vehicle longline sets made on SIO cruises are shown in Table 4. Longline catches made on the *Jordan* are given in Table 5. 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 1000 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 disporportionate 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

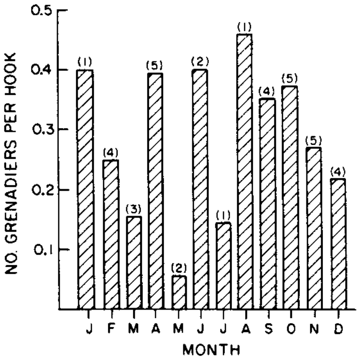

Figure 8.—Average catch rates of Pacific grenadier by free-vehicle longline, by month of fishing off southern California. Data are from SIO-MLRG fishing stations deeper than 550 fm. Number of fishing trials are in parentheses.

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.

Station	Depth (fm)	Pacific grenadier	Giant grenadier	Sablefish	Dover sole	Channel rockfish	Total[1]
8	500	1	10	257	769	241	1,268
7	550	153	29	328	193	135	809
14	570	14	12	58	0	40	112
2	600	0	9	13	31	23	67
9	600	23	12	26	51	10	110
1	610	3	30	28	1	56	88
6	615	204	80	36	5	305	550
12	635	162	59	351	1	116	630
10	650	237	117	50	309	100	696
4	675	352	183	5	1	125	483
11	685	74	41	5	0	39	204
3	690	0	18	5	11	151	169
13	700	14	12	58	0	40	112
5	725	68	30	0	0	9	77
15	760	289	160	65	0	25	379

[1] Excluding giant grenadier, the only species presently without commercial value.

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 *Jordan* cruises (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

Distribution

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

(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 inch) TL, and the smallest taken in bottom trawl, 73 mm (2.9 inches) TL. Thus the size at which the fish adopts a benthic habitat seems to be around 80 mm (3.1 inches) TL (Stein and Pearcy, 1982).

Reproduction

Ripe females of *C. acrolepis* have been reported off Kamchatka, eastern U.S.S.R., in September (Savvatimskii, 1969) and off Oregon in September, October, and April, with spent females also occurring in October (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.

Table 8.—Estimated egg counts of Pacific grenadiers listed by snout to vent measurements (SVL). Cruise and station data (e.g., M15-8) is given in Table 1.

Sample	SVL (mm)	Wt. (kg)	Stage 0	Stage 1	Stage 2	Stage 3
M15-8-1	162	0.45	427,662	0	0	0
M15-1-14	189	0.75	1,188,500	59,888	1,279	20,749
M16-1-18	234	1.10	1,355,458	139,772	0	0
M13-12	238		3,193,900	357,493	3,362	0
M15-6-17	239	1.30	2,218,260	124,264	18,508	68,742
SC3-74-19	241	1.10	2,772,477	243,467	6,087	0
M16-1-9	241	1.30	3,677,071	66,274	179,270	0
M16-1-8	244	1.30	2,443,828	210,883	13,730	77,434
M16-1-16	244	1.30	3,728,688	403,977	11,932	56,676
M15-1-13	244	1.25	1,466,740	110,730	63,028	0
M15-5-21	249	1.30	1,585,946	95,966	10,042	73,090
M15-7-5	249	1.30	1,666,046	92,237	52,819	61,228
M15-1-17	262	1.60	1,246,635	225,810	90,675	0
M15-7-3	262	1.65	3,513,178	537,420	166,384	70,647
M15-1-23	262	1.60	2,503,379	174,076	87,038	0
SC3-74-22	264	1.60	2,051,348	235,664	33,921	0
M16-1-12	265	1.50	1,590,299	256,262	40,073	0
SC74-4	270	1.80	3,412,846	114,168	196,225	0
M15-6-13	276	1.75	2,364,618	246,298	42,324	60,172
SC3-74-18	276	1.70	1,668,184	163,299	8,165	0
M15-1-8	286	2.10	4,212,138	612,496	156,546	107,750
M13-3	289		3,039,594	313,322	51,509	150,258
SC74-11	296	2.00	1,079,055	103,242	9,436	102,965
M15-1-12	301	2.10	5,927,000	435,821	117,645	0
M15-3-9	304	2.10	2,564,447	468,630	231,712	0
SC3-74	315	2.50	3,882,486	385,845	10,465	111,239
M15-1-18	318	2.65	7,991,482	681,650	358,280	0

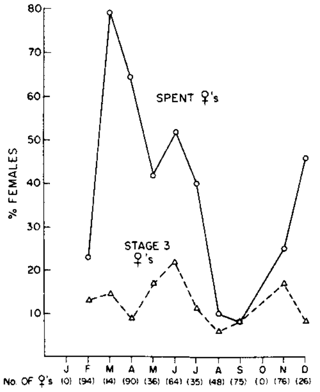

Figure 9.—Proportions of ripening and spent female Pacific grenadier making up some of the MLRG longline catches during different months of the year. Number of females are in parentheses.

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 0.75 kg (1.6 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 ($\bar{x}$ = 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).

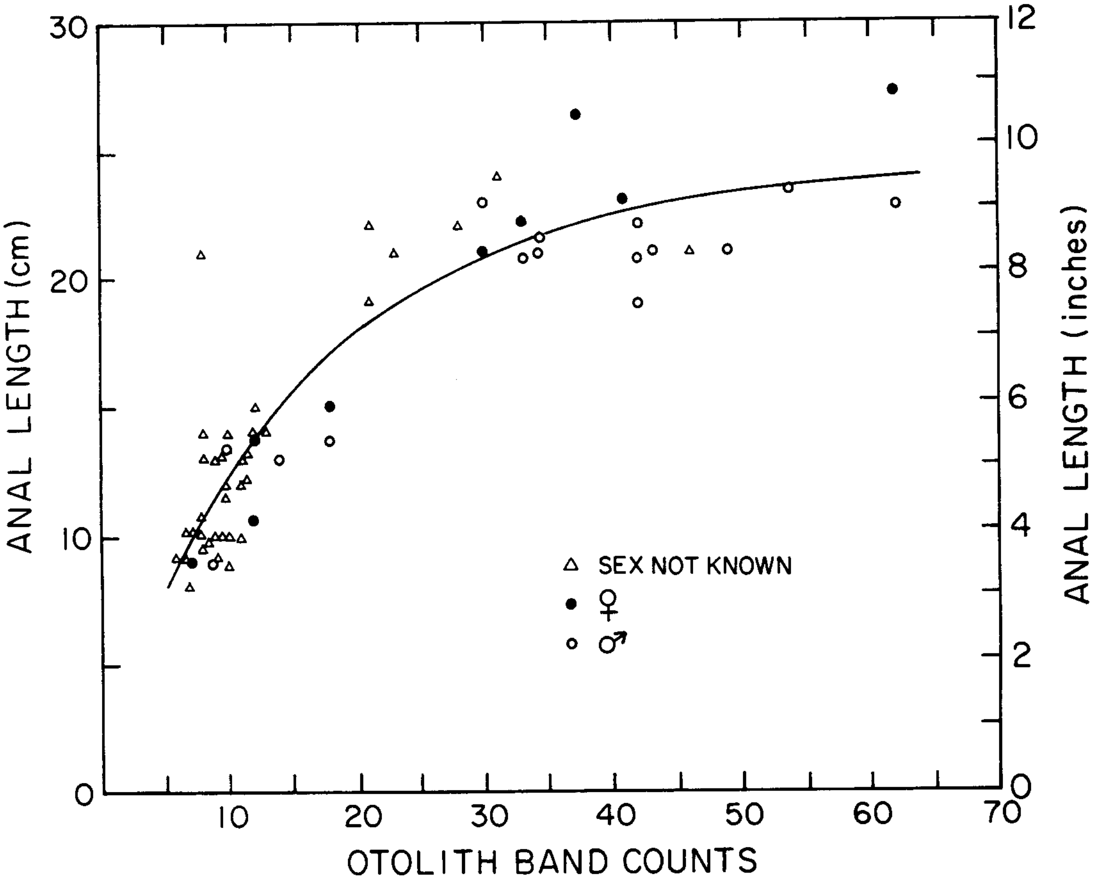

Figure 10.—A von Bertalanffy growth curve (sexes combined) and otolith ring count by size for 60 Pacific grenadiers.

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

$$l_t = 24.24\{1 - \exp(-0.063 [t - 1.093])\}$$

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 sex 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

$Y = 2.308x + 122.158$

$R^2 = 0.864 \quad P<0.0001$

Females

$Y = 2.276x + 115.4$

$R^2 = 0.925 \quad P<0.0001$

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 ($\bar{x} = 24.3$ percent) from larger individuals. Kremsdorf et al. (1979) were able to get a greater 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 NWFSC 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 NWFSC, 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[4]. 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.

Table 9.—Proximate composition (wet weight basis) for Pacific and giant grenadier.

	Pacific grenadier		Giant grenadier	
Item	Sample 1	Sample 2	Sample 1	Sample 2
Protein (%)	15.8	15.9	10.8	15.8
Fat (%)	0.1	0.2	0.2	0.2
Ash (%)	1.2	1.1	1.2	1.0
Moisture (%)	83.0	83.1	88.5	83.0
Energy (cal /100 g)	64.0	65.0	45.0	62.0
Minerals mg/g)				
Ca	148.000	111.700	180.900	175.200
Cu	0.424	0.896	0.147	0.441
Fe	3.820	4.650	3.330	3.310
K	2,748.000	3,144.000	1,368.000	3,065.000
Mg	432.000	332.000	313.000	348.000
Na	1,952.000	1,042.000	3,134.000	1,140.000
P	1,438.000	1,422.000	809.000	1,422.000
Sr	1.390	0.767	1.540	1.052
Zn	3.940	2.860	3.590	2.480

Table 10.—Characteristics of flesh and flavor profile of Pacific and giant grenadier. Scale is from 0 (none) to 7 (high). Data are from Alice Hall, NMFS, NWFSC, 2725 Montlake Blvd. E., Seattle, WA 98112.

	Pacific grenadier		Giant grenadier
Item	Sample 1	Sample 2	Sample 1
Flesh characteristics			
Darkness	1.73	0.44	0.45
Flakiness	5.09	5.44	3.36
Hardness	3.45	2.89	1.36
Chewiness	4.18	3.33	1.73
Fibrousness	4.36	3.33	2.45
Moistness	2.73	3.22	5.00
Oiliness	0.64	0.67	1.09
Flavor profile			
Flavor intensity	2.91	3.00	3.82
Sweet	1.45	2.11	0.91
Salty	2.00	1.00	3.27
Sour	0.36	0.33	0.36
Gamey	0.00	0.22	0.27
Fish oil	0.00	0.11	0.36
Shellfish	0.00	0.11	0.00
Earthy	0.53	0.51	0.30

Discussion

Until quite recently a single species of

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[4] Alice Hall, Northwest Fisheries Science Center, NMFS, NOAA, 2725 Montlake Blvd. N.W., Seattle, WA 98112. Personal commun.

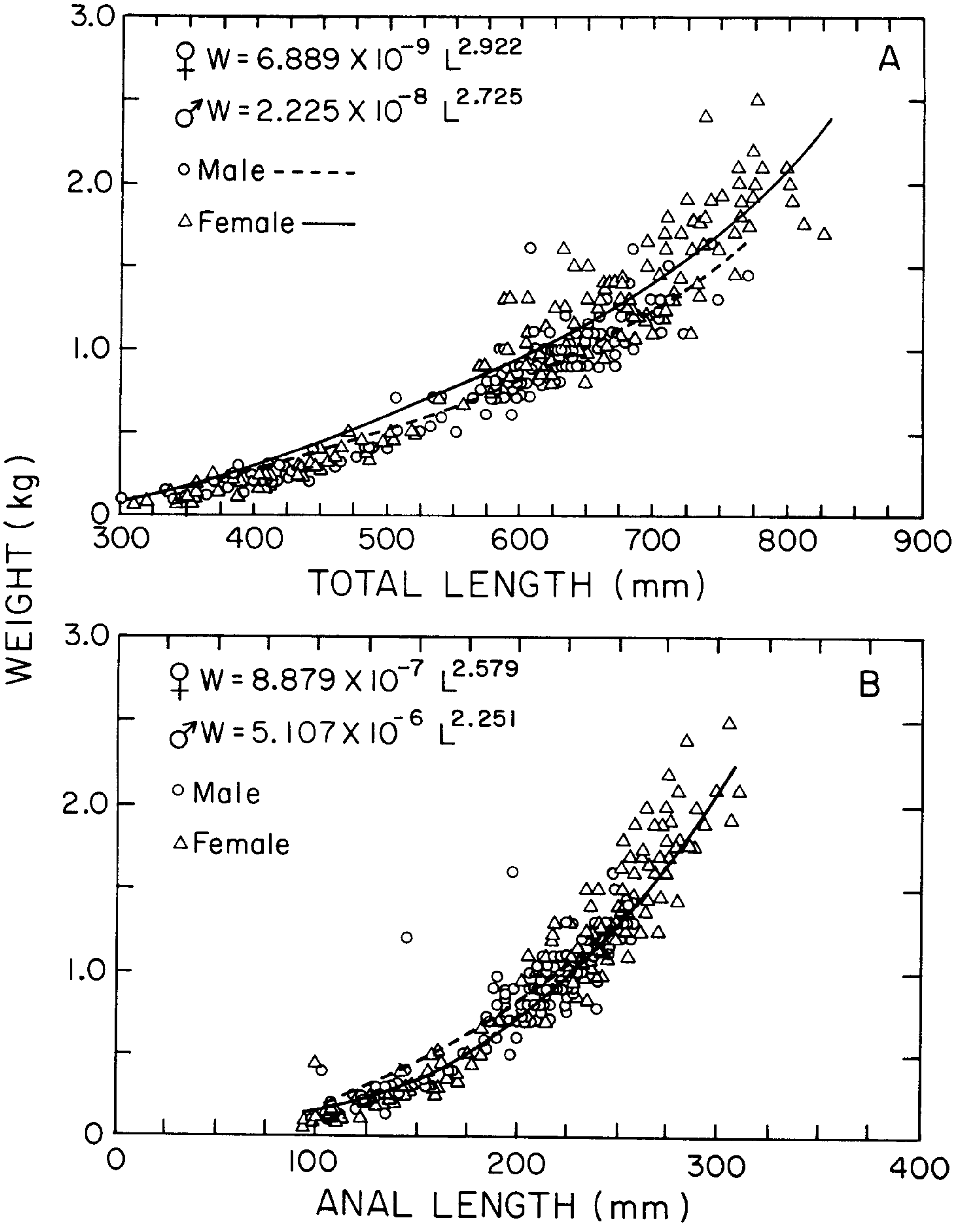

Figure 11.—Length-weight relationships of Pacific grenadier. A shows weight (kg) to total length (mm) and B illustrates weight to anal length.

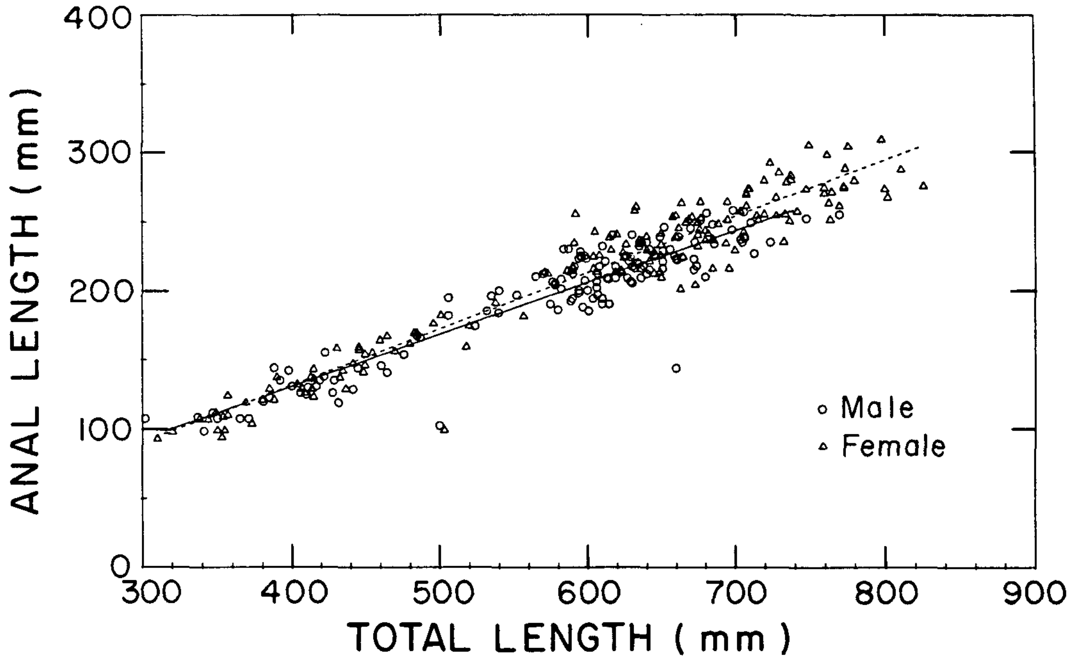

Figure 12.—Relationship of anal length to total length in the Pacific grenadier.

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 holotrachys* 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[5].

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[6].

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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[5] Tomio Iwamoto, California Academy of Sciences, Golden Gate Park, San Francisco, CA 94118. Personal commun.

[6] Osamu Okamura, Department of Biology, Kochi University, Kochi 780, Japan. Personal commun.

fillet, and yielded fillets which had better appearance and texture than fresher fish.

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.

Acknowledgments

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