Pacific Hagfish, *Eptatretus stouti*, and Black Hagfish, *E. deani*: The Oregon Fishery and Port Sampling Observations, 1988–92

WILLIAM H. BARSS

Introduction

Hagfish, *Eptatretus* spp., of the class Agnatha, family Myxinidae, are among the most primitive and unique of fishes. They have cylindrical eel-shaped bodies, a cartilaginous skeleton, four hearts, 10–14 pairs of gill pores, and lack scales, jaws, and paired fins. Their eyes are rudimentary, appearing as small lightly shaded areas of skin (Hart, 1973). These fish compensate for their lack of vision with keenly developed senses of smell and touch (Jensen, 1966).

The head has a single large terminal nostril, eight barbels surrounding the nostril and mouth, two parallel rows of strong, horny teeth on each side of the tongue-like dental plate, and one longer median tooth situated dorsally at the mouth opening (Dawson, 1963). Sexes are separate, and both male and female hagfish have a single gonad. During each spawning cycle, females produce a small number of large eggs, which are fertilized after extrusion (Jensen, 1966).

Hagfish have numerous glands along both sides of their body which produce copious quantities of tenacious slime when agitated or for self defense. Presence of this slime on fishing gear, such as traps and hooks, reduces the catch of other species. The slime is difficult to remove from vessels and gear. Thus, fishermen in the northeastern Pacific call hagfish "slime eels."

Hagfish behavior is also unique. They swim in a snake-like motion (Jensen, 1966). They attack hook-caught or trap-caught fish by burrowing into the fish's body to quickly devour the flesh and viscera.

Two species of hagfish are commonly found off Oregon: Pacific hagfish, *Eptatretus stouti*, and black hagfish, *E. deani*. The Pacific hagfish's body is usually gray to light brown and has a white ring around each gill pore and white along the ventral finfold. Black hagfish are usually a uniform black or dark brown and do not have a white ring around their gill pores.

Logbook records from Oregon hagfish fishermen indicate that Pacific hagfish are commonly caught at depths of 91–219 m, while black hagfish are commonly caught at depths >219 m. Cailliet (1991) reported that in Monterey Bay there was little overlap between species, but catches from 500–750 m infrequently included both species. He also stated that black hagfish were found out to depths of 1,000 m. Both species are strictly marine.

Hagfish have been observed during submersible dives off Oregon from 1987 through 1990 (Pearcy et al., 1989; Hixon et al., 1991). Hagfish were common on the muddy sea floor or in burrows. They appeared to prefer soft mud in contrast to sand. Pacific hagfish have also been observed near Vancouver Island, Can., on mud or silt substrate (McInerney and Evans, 1970). Adam and Strahan (1963) report that most species of hagfish require a bottom into which they can burrow, and that they are only found in large numbers where the bottom is covered by mud or soft sediment. Foss (1963) also reported that hagfish, *Myxine glutinosa*, have been observed entering holes on mud bottoms near Norway. Recent trap surveys and remotely operated vehicle (ROV) dives in Monterey Bay, Calif., have shown wider habitat use than previously reported, because while a majority of animals were found in sand or mud areas, a high percentage (30%) were in mixed substrate, and some occupied areas consisting only of massive substrate, (Cailliet, 1991).

Hagfish flesh is eaten in the Orient, and in recent years hagfish skins have

Wiliam H. Barss is with the Marine Region, Oregon Department of Fish and Wildlife, Marine Science Drive, Bldg. #3, Newport, OR 97365. This work was conducted with matching state and Federal P.L. 99–659 and P.L. 88–309 funds. Views or opinions expressed or implied are those of the author and do not necessarily reflect the position of the National Marine Fisheries Service, NOAA.

ABSTRACT—In 1988, the Oregon Department of Fish and Wildlife began sampling and monitoring the development of a new fishery for Pacific hagfish, Eptatretus stouti, *and black hagfish,* E. deani. *Hagfish landings by Oregon trap vessels have ranged from 11,695 kg in 1988 to 340,774 kg in 1992. Whole frozen fish were shipped to South Korea for the "eel skin" leather market. From 1988 through 1989, I sampled 924 Pacific hagfish and 897 black hagfish from commercial and research catches. Mean length of fish sampled from commercial landings was 39.6 cm for Pacific hagfish and 34.5 cm for black hagfish. Weight-length relationships ($W=aL^b$) were calculated for males and females of both species. Fifty percent maturity for male and female Pacific hagfish was 35 cm and 42 cm, respectively, while 50% maturity for male and female black hagfish was 34 cm and 38 cm, respectively. Examination of gonads for both species indicated that spawning either occurs throughout the year or the spawning period is protracted. Mature females of both species had from one to three distinct sizes of eggs, but they usually carried only one group of eggs over 5 mm in length. Mature Pacific hagfish females averaged 28 eggs over 5 mm in length, and black hagfish females averaged 14 eggs over 5 mm in length. Hermaphroditism was found in 0.2% of the Pacific hagfish examined.*

been eagerly sought by buyers from the Republic of Korea. The skin is processed into leather "eel skin," which is used to make wallets, purses, shoes, and other articles. Demand for this leather exceeds the Asian supply. In recent years, Asian hagfish landings have declined, and Korean buyers have sought quality hagfish skins worldwide (Gorbman et al., 1990). Information on the Asian hagfish fishery, research, and management practices has been very difficult to obtain.

The U.S. west coast fishery began in 1987 following a 1986 shipment of Pacific hagfish samples from California to the Republic of Korea (Kato[1]; Hardwick[2]). In 1988, at least seven boats landed about 313,400 kg of, primarily, Pacific hagfish at Monterey, Calif. In 1989, at least 37 vessels landed about 539,000 kg in California, and fishing extended to additional California ports. Fishermen initially used small, cylindrical, plastic, baited traps manufactured in Korea, which became known as "Korean traps." Fishermen now usually use larger traps, such as 5-gallon buckets and 50-gallon drums (Barsky[3]). California fishermen use the chemical MS–222 to anesthetize the fish as soon as the traps are pulled at sea, because live fish often bite each other, damaging the skins. Some buyers set a minimum acceptable fish size of 12–14 inches (30.5–35.6 cm). Fishermen received from $0.25 to $0.50/ pound ($0.11 - 0.23/ kg) for whole hagfish. California required hagfish fishermen to obtain a $25 trap permit until 1992, when, following a brief period of limited entry into the fishery, the trap permit was raised to $250 per season. Hagfish traps must include a biodegradable mechanism to prevent "ghost fishing" by lost traps. Vessels are limited to using either 1,200 cylindrical traps with a maximum size of 6 inches in diameter and 24 inches long or 300 traps of any other type. Fishermen must also keep a logbook on their fishing activities.

In 1992, California briefly established a limited entry on hagfishing. Limited entry qualifications were based on landing history, and a minimum landing of 500 pounds was required during the years 1988–90. Limited entry was repealed in August 1992 owing to the lack of markets for California hagfish.

Hagfish fishing off British Columbia started in 1988 (Neville[4]). Some vessels land frozen fish while others land fresh iced fish. Buyers do not purchase fish under 12 inches (30.5 cm). Fishermen use MS–222 to anesthetize or kill their hagfish at sea. Fishermen must maintain a logbook on their fishing activities and provide Canadian biologists with data and fish samples from their catches.

Canadian hagfish permits are required for hagfish fishing, and fishing is limited to standard traps (Harbo[5]). A standard trap is a cylinder 12 cm in diameter and 60 cm long. Separate permits are issued for inshore and offshore areas . The inshore area is inside the surf line, and 8 permits are available for this area. Vessels permitted inshore are limited to a maximum of 2,000 standard traps. Eleven permits are available for offshore, and each vessel is limited to 4,500 standard traps.

In 1992, only one vessel fished for hagfish off Canada, and there was only one buyer. The vessel was allowed to fish some experimental 5-gallon traps but was also required to fish standard traps.

Washington requires a permit for hagfish fishing within the Puget Sound, and the first one was issued in 1989 (Wildermuth[6]; Culver[7]). This permit specifies the species, type of trap, number of traps, fishing area, when fishing is allowed, and reporting requirements. No landings have been made under the permit and commercial quantities of hagfish in that area are doubtful.

Hagfishing began off the Washington coast in 1991 (Culver[7]). Beginning in 1992, an experimental fishing gear permit was required for the hagfish trap fishery in Washington's ocean waters. This permit was designed after a similar permit used by Oregon. It authorizes that only hagfish can be retained from hagfish traps, and it requires biodegradable escape exits, buoys marked with permittee's buoy identification number, and logbook records on fishing activities.

Since about 1989, some hagfish fishing has also occurred off Alaska with minor landings (Paust[8]). A sustained fishery has not developed, and while black hagfish were plentiful, few Pacific hagfish were caught.

A hagfish trap fishery began off the Oregon coast in 1988. At that time, Oregon regulation for fish traps (OAR 635–04–035) required biodegradable escape panels. These panels had to provide an opening of at least 8 inches (20.3 cm) in diameter when the panel deteriorated. It was difficult for hagfish fishermen to comply with this rule, and in May 1990, the Oregon Department of Fish and Wildlife (ODFW) began issuing experimental fishing gear permits for the hagfish trap fishery. The permit authorized the use of hagfish traps approved by ODFW. An approved trap contained an escape exit of at least 3 inches (7.6 cm) diameter of qualifying biodegradable materials. All species of finfish and shellfish except hagfish caught in these traps had to be released immediately. By October 1990, 52 permits were issued. On that date, Oregon Administrative Rules were amended to authorize the use of approved hagfish traps, and permits were no longer required

Following the first Oregon hagfish landing in 1988, because of the commercial interest in hagfish and the lack of literature about basic hagfish life history, abundance, or even distribution,

[1]S. Kato. 1990. Report of the biology of Pacific hagfish, *Eptatretus stoutii*, and the development of its fishery in California. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Tiburon Lab., Tiburon, Calif. Unpubl. manuscr., 39 p.

[2]J. Hardwick. 1988. Calif. Dep. Fish Game, 2201 Garden Road, Monterey, CA 93940. Personal commun.

[3]K. Barsky. 1990, 1993. Calif. Dep. of Fish Game, P.O. Box 821, Santa Barbara, CA 93102. Personal commun.

[4]C. Neville. 1989. Dep. Fish. Oceans, Pac. Biol. Sta., Hammond Bay Road, Nanaimo, B.C. V9R 5K6. Personal commun.

[5]R. Harbo. 1993. Dep. Fish. Oceans, Fish. Branch, 3225 Stephenson Point Road, Nanaimo, B.C. V9T 1K3. Personal commun.

[6]D. Wildermuth. 1989. Wash. Dep. Fish., 7600 Sand Point Way NE, Bin C15700, Bldg. 4, Seattle, WA 98115. Personal commun.

[7]B. Culver. 1993. Wash. Dep. Fish., Coastal Lab., 331 State Hwy. 12, Montesano, WA 98563. Personal commun.

[8] B. Paust. 1989, 1993. Mar. Ext. Serv., Univ. Alaska, P.O. Box 1329, Petersburg, AK 99833. Personal commun.

ODFW began to monitor its hagfish fishery and collect the necessary data to manage its hagfish stocks and develop a sustainable commercial hagfish fishery. From October 1988 through 1991, hagfish sampling was conducted on a continuing basis to obtain an information base for sound management of the fishery and optimum use of the hagfish resource. This paper describes Oregon's hagfish fishery and summarizes the biological data that we obtained during our first 2 years of sampling hagfish.

Methods

Most data were collected from commercial trap landings at Newport and Astoria, Oreg., during the fall of 1988 and from July through December 1989. These landings represented catches off Oregon except for a single trip in November 1988 that included fish from off Crescent City and Eureka, Calif. (Fig. 1). In 1989, additional samples were obtained from the National Marine Fisheries Service through research trawl catches off Oregon made by the F/V *Golden Fleece* and by Oregon State University on the F/V *Olympic*, from incidental catches in Dungeness crab, *Cancer magister*, and sablefish, *Anoplopoma fimbria*, traps, and from experimental hagfish traps. The incidental catches and experimental trap catches came from off Oregon and off Washington immediately north of the mouth of the Columbia River.

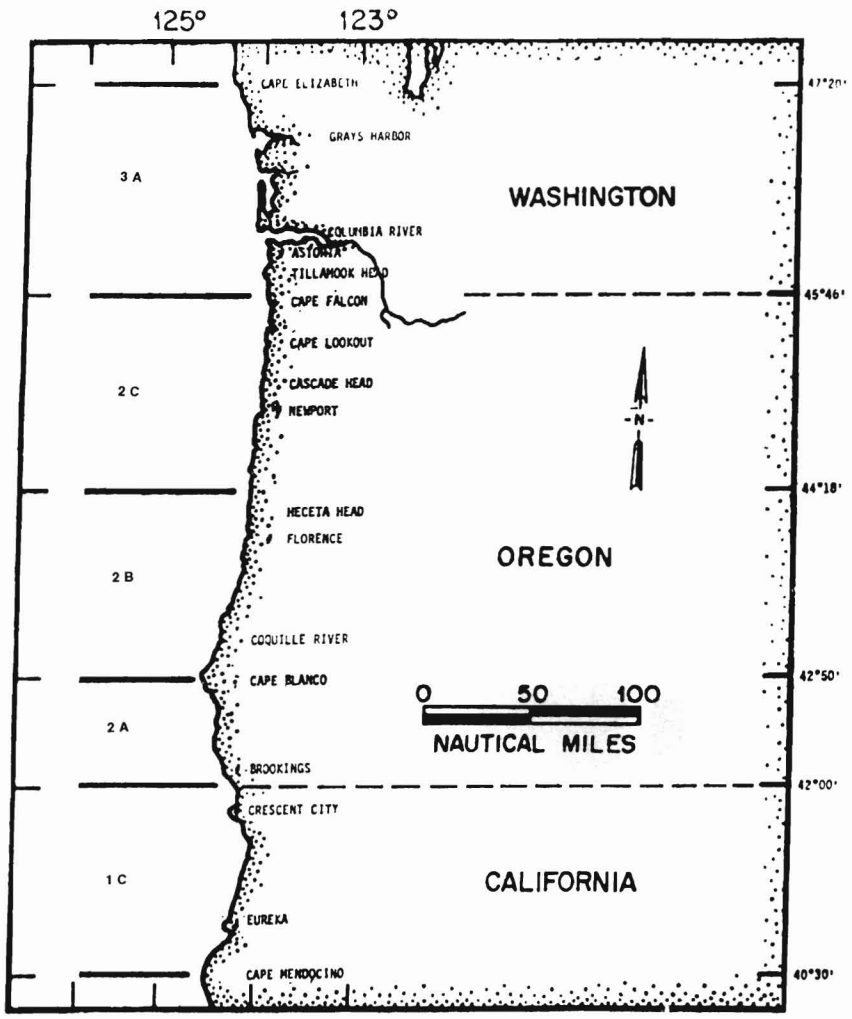

Figure 1.—Pacific coast from Cape Elizabeth, Wash., to Cape Mendocino, Calif., and Pacific Marine Fisheries Commission International Statistical Areas 3A to 1C.

Samples were obtained from two different types of commercial traps, and one of these types was modified with escape holes and used as an experimental trap. Traps were usually baited with fish frames or whole fish rejected from the trawl fishery. The most commonly used trap was the cylindrical, plastic trap known as the "Korean trap." This black-colored trap was about 53 cm in length, 11.5 cm in diameter, and contained a removable funnel-type entrance at one end. Its sides were perforated with a large number of holes of approximately 8 mm in diameter. The second type trap was used only in 1988 by one vessel. It was similar in design to the trap known as the Korean conical sablefish trap, and fishermen called it a prawn-style trap. This trap had a base diameter of about 60 cm, and was about 46 cm high. The experimental trap was the cylindrical, plastic "Korean trap" modified to contain one to two escape holes. Escape holes had diameters of 1.3 cm, 1.9 cm, or 2.5 cm. These traps were designed to test the hypothesis that traps could be made that would retain a desired size of hagfish, while also allowing small fish to escape.

I tried to sample at least one 13–18 kg box of hagfish per month from commercial landings. Hagfish from commercial landings were not usually available until they had been landed, randomly placed in shipping boxes, and frozen. A box of hagfish contained up to 300 fish, and all the fish in a box were usually sampled. I also sampled incidental hagfish catches from commercial sablefish traps, commercial crab traps, experimental traps, and research trawls.

Sorting of commercial catches was not common in 1988, but in 1989, most Oregon catches were sorted at sea by fishermen to remove unmarketable or small hagfish. Sorting did not occur on hagfish during incidental or research trawl catches.

Samples were examined at the ODFW laboratory in Newport. Data recorded for each fish examined included species, sex, and total length (cm). Most fish were also sampled for round weight (g) and stage of maturity. Data were also obtained on number of eggs, egg length (mm), and/or testis diameter (mm).

Criteria for determination of sex and maturity stage are given in Table 1. Photographs of selected maturity stages are shown in Figures 2 and 3. Gonads were not microscopically examined. Females containing eggs over 5 mm long were classified as mature. Males with round gonad follicles larger than 1 mm in diameter were classified as mature.

Two situations were used for discerning the time of spawning. First, anchor-like terminal hooks with each hook attached to the egg by a thin filament are formed at each end of a hagfish egg just before egg extrusion (Fig. 2 D). Second, a developing egg is held in a ovarian capsule, and a large empty capsule is found in the ovary for a short period of time following extrusion of the egg from that capsule (Fig. 2 E).

Sample data were summarized by species, sex, gear, and month with special emphasis on length at maturity and time of spawning.

Oregon's Commercial Hagfish Fishery

Oregon's hagfish fishery began in October 1988 when two trap vessels landed 11,695 kg at Newport. About 4,165 kg was black hagfish, and the rest was Pacific hagfish. About 60% of the catch was frozen at sea. An estimated

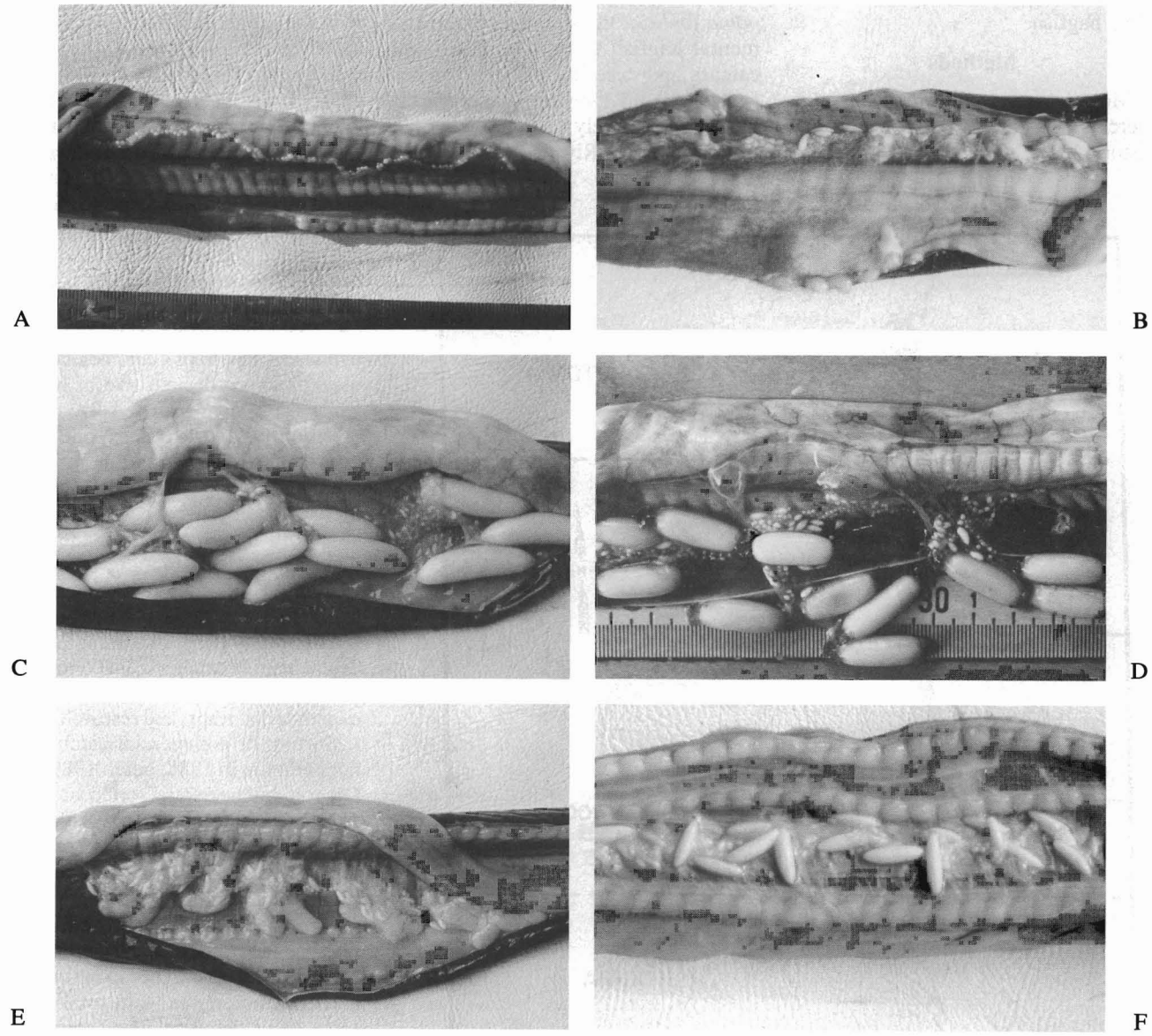

Figure 2.—Female black hagfish gonads. A) Gonad stage 1, immature female. All eggs are small (≤1 mm in length), round, and located all along the length of the gonad. B) Gonad stage 2, maturing female. There are a few oblong eggs >1 mm but <5 mm in length. C) Gonad stage 3, mature ova, developing female. Here, some eggs are >5 mm in length. D) Gonad stage 4, mature ova, developed female. Hooks are present at both ends of each large egg. E) Gonad stage 5, mature, spent female. Large empty ovarian capsules are present (as well as some small oblong eggs). F) This gonad contains three different size groups of eggs.

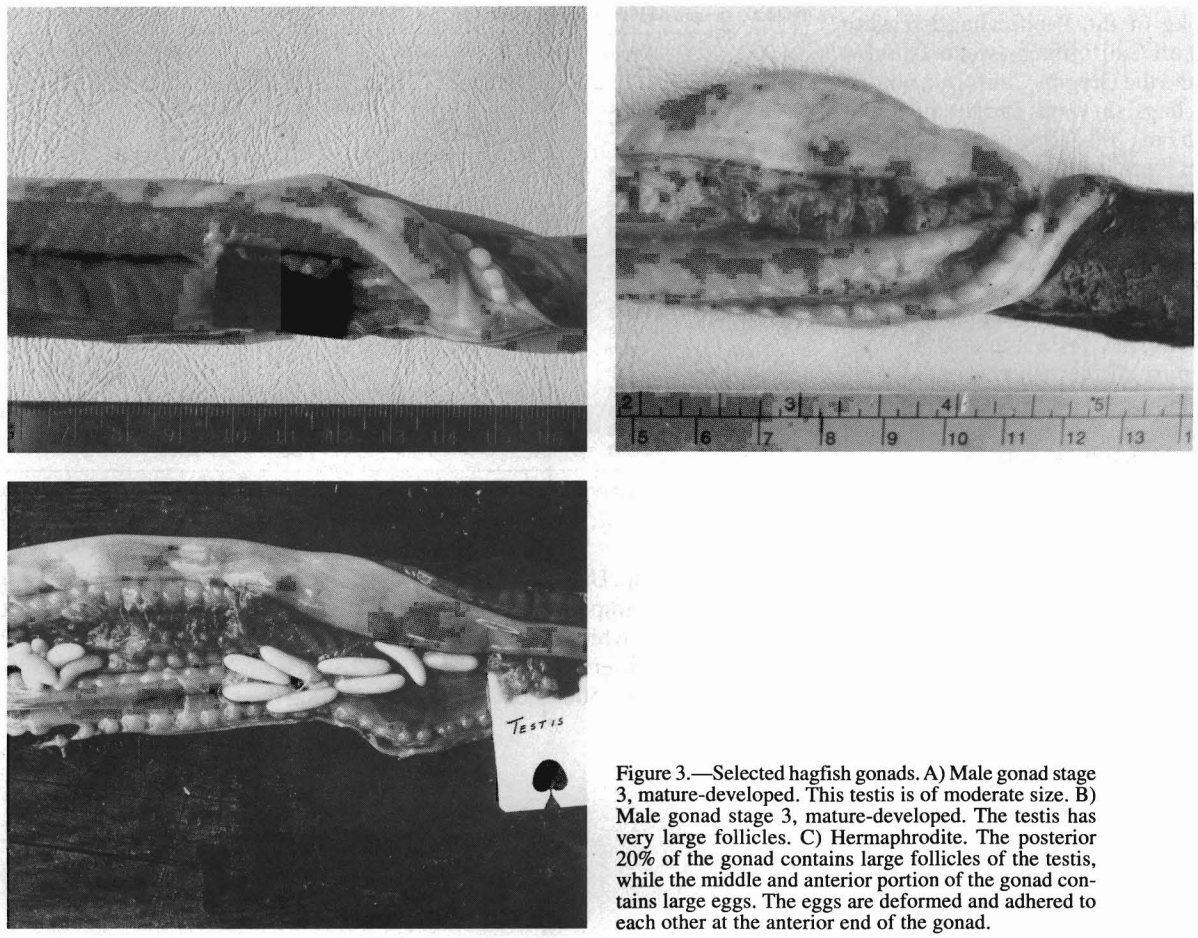

Figure 3.—Selected hagfish gonads. A) Male gonad stage 3, mature-developed. This testis is of moderate size. B) Male gonad stage 3, mature-developed. The testis has very large follicles. C) Hermaphrodite. The posterior 20% of the gonad contains large follicles of the testis, while the middle and anterior portion of the gonad contains large eggs. The eggs are deformed and adhered to each other at the anterior end of the gonad.

Table 1.—Gonad condition criteria applied to the genus *Eptratretus* from samples collected in Oregon, 1988–89[1].

Sex and stage	Condition	Criteria
Females		
1	Immature	All round eggs, ≤1 mm, eggs may appear as bubbles in anterior half of narrow (<2 mm wide) gonad
2	Maturing (not mature)	Some oblong eggs, >1 mm, but < 5 mm in length and no large empty ovarian capsules (egg sacks), may also contain some ≤1 eggs
3	Mature-ova developing	Some oblong eggs, >5 mm in length, without hooks, may also contain some ≤1 mm eggs and some >1 mm, but <5 mm eggs (exclude fish in Mature-spent condition)
4	Mature-developed	Some large eggs, >20 mm with hooks, may also contain some ≤1 mm eggs, some >1 mm, but <5mm eggs, and some >5 mm eggs without hooks
5	Mature-spent	Large empty ovarian capsules and maturing or mature eggs, may also contain some immature eggs
Males		
1	Immature	Posterior end of gonad small (about 1 mm) in width and almost colorless (slightly milky)
2	Maturing (not mature)	Posterior end of gonad with small (<1 mm diameter) round white follicles
3	Mature-developed	Posterior end of gonad with large (>1 mm diameter) round, white to brown follicles
Unknown		
1	Immature	Empty gonad, no testis or eggs observed
Hermaphrodite		
1	Hermaphrodite	Both eggs and follicles of testis present

[1] See Figure 2 for photographs of gonad condition stages for female hagfish. See Figure 3 for photographs of gonal condition stages for male and hermaphrodite hagfish.

4,838 kg of the Pacific hagfish were caught off California between Trinidad Head and the Oregon-California border. Black hagfish were caught in about 366–457 m (200–250 fm), while Pacific hagfish were usually caught on a mud substrate at a depth of about 110–183 m (60–100 fm). An estimate of catch per trap could be made on only one of the four trips using "Korean traps." That estimate was 1.4 kg of hagfish per trap.

In 1989, six vessels landed hagfish, but almost all the fish were landed by three of those vessels. Fishermen landed 156,123 kg of hagfish at Newport and Astoria (Table 2). Landings were overestimated because some landings included the weight of packaging material and peatmoss or sawdust which was commonly used in processing and handling hagfish at sea. About 40–45% of the hagfish were frozen at sea.

In 1989, the small cylindrical Korean trap produced a catch of about 0.8 kg of hagfish per trap. Usually 2,000–2,500 of this style of trap were fished (Fig. 4). Larger traps, which we were unable to measure or observe, were fished by one vessel. About 500–1,000 of these large traps were fished; they caught an average of 2.7 kg of hagfish per trap.

In 1989, fishermen targeted Pacific hagfish and avoided black hagfish by setting their traps at depths of about 55–

Table 2.—Oregon hagfish landings, 1988–92[1].

Year and month		Weight (kg)	Number of landings	Number of vessels	Year and month		Weight (kg)	Number of landings	Number of vessels
1988	Oct.	4,664	3	1	1991	Jan.	21,864	28	3
	Nov.	7,031	1	1		Feb.	8,068	7	3
						Mar.	26,175	25	4
1989	July	24,978	4	1		Apr.	29,989	33	4
	Aug.	5,321	4	2		June	8,550	11	3
	Sep.	37,375	10	3		July	2,275	4	1
	Oct.	44,255	11	6		Sep.	2,520	1	1
	Nov.	28,394	1	1		Dec.	24,066	22	4
	Dec.	14,800	1	1	1992	Jan.	30,792	34	8
						Feb.	66,112	64	10
1990	Apr.	2,828	4	2		Mar.	87,501	86	11
	May	2,049	3	2		Apr.	55,492	40	10
	July	647	2	1		May	30,960	20	8
	Aug.	16,048	24	4		June	10,316	10	5
	Sep.	9,646	16	3		July	3,752	7	3
	Oct.	4,636	8	4		Aug.	26,411	22	4
	Nov.	22,026	27	4		Sep.	18,078	16	3
	Dec.	18,063	18	3		Nov.	6,631	6	2
						Dec.	4,729	5	2

[1] Hagfish landings in August through October 1989 were gross weights, which included peatmoss or sawdust and containers.

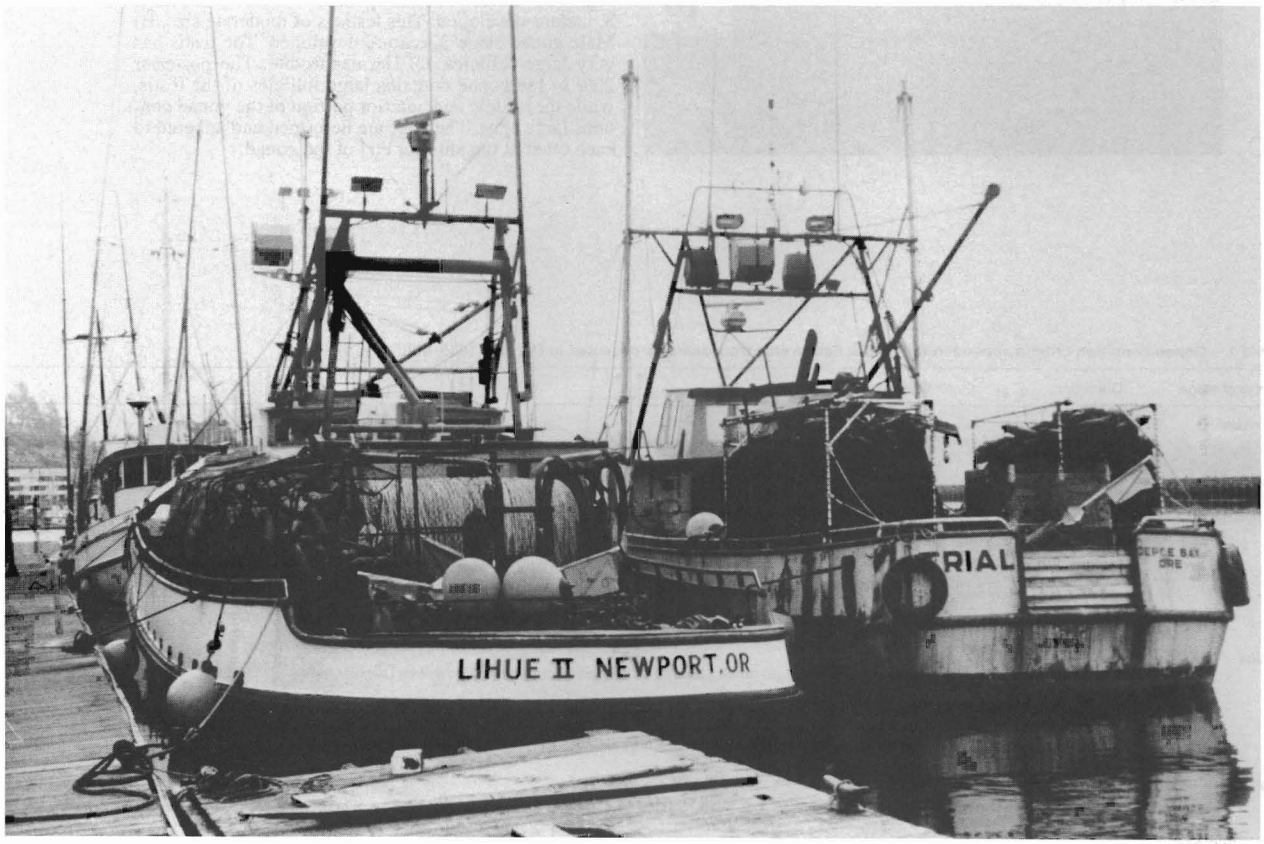

Figure 4.—F/V *Lihue II* and F/V *Trial* were two of the vessels that used the Korean traps for catching Pacific hagfish off Oregon in 1989. Fishing gear (traps, buoys, groundline, and flags) common to this fishery is on the back of the vessels.

105 fm; black hagfish were caught in only one set. That set, the deepest of the year at about 103 fm, resulted in an estimated catch of 200 pounds (91 kg) containing a mix of black and reportedly small Pacific hagfish.

In 1990, Oregon hagfish landings dropped, but since that reduction in poundage, there has been a modest increase in landings, mostly of Pacific hagfish. In 1990, 11 vessels landed 75,924 kg of hagfish from 102 trips. In 1991, 12 vessels landed 124,506 kg of hagfish from 131 trips. In 1992, 15 vessels landed 340,774 kg of hagfish from 310 trips.

Sampling Results

Samples were obtained from all four commercial landings in 1988 (360 Pacific hagfish and 635 black hagfish) and 5 of the 31 landings (428 Pacific hagfish) in 1989. In 1989, 20 samples came from incidental or research catches: 11 from trawl catches on NMFS and OSU research cruises, three from Dungeness crab traps, two from sablefish traps, and four from research traps modified with escape holes (Table 3).

Table 3.—Summary of hagfish samples taken in 1988–89.

Date	Source	Location of catch[1]	Depth (fm)	Number taken	
				Black hagfish	Pacific hagfish
10–10–88	Hagfish trap	Newport	200	220	0
10–13–88	Hagfish trap	Newport	?	304	0
10–24–88	Hagfish trap	Newport	?	111	102
11–16–88	Hagfish trap	Brookings-Eureka	63–100	0	258
01–22–89	Crab trap	Astoria	50	0	5
02–06–89	Crab trap	Astoria	55	0	32
04–05–89	Crab trap	Astoria	50	0	5
05–26–89	OSU trawl	Central Oregon	159–200	9	0
05–26–89	OSU trawl	Cape Lookout	65	0	1
06–04–89	Sablefish trap	Astoria	400–550	45	0
06–13–89	Hagfish trap[2]	Newport	210	120	0
07–03–89	OSU trawl	Cascade Head	85–119	0	2
07–08–89	Research trap	Cape Falcon	75	0	28
07–08–89	Research trap	Cape Falcon	75	0	14
07–17–89	Hagfish trap	Cape Falcon	55–75	0	106
08–18–89	Hagfish trap	Cape Falcon	62–74	0	68
09–11–89	Hagfish trap	Newport	80–86	0	100
08–04–89	NMFS trawl	Bodega Head	160	0	1
08–12–89	NMFS trawl	Oregon-Calif.	63	0	1
08–15–89	NMFS trawl	Coquille River	73	0	1
08–29–89	NMFS trawl	Tillamook Head	81	0	1
09–03–89	NMFS trawl	Grays Harbor	68	0	1
09–16–89	NMFS trawl	Heceta Head	230	26	0
09–16–89	NMFS trawl	Heceta Head	322	19	0
09–22–89	NMFS trawl	Newport	350	43	0
09–26–89	Hagfish trap	Newport	77–84	0	1
09–26–89	Hagfish trap	Newport	77–84	0	76
09–26–89	Research trap	Newport	77–84	0	11
10–10–89	Research trap	Newport	72–80	0	32
11–21–89	Hagfish trap	CF–CL	60–84	0	78

[1] Central Oregon means from Cape Lookout to Florence, Oregon-California means the border between Oregon and California, and CF - CL means Cape Falcon to Cape Lookout. Bodega Head is located just north of San Francisco, Calif.
[2] Hagfish traps were being used as bait holders inside sablefish traps.

Length

During 1988–89, seven commercial landings of Pacific hagfish were sampled for length (Table 4). Due to sorting in 1989, the length frequencies are not strictly comparable, but combining all the samples, length was 20–67 cm with a mean of 39.6 cm. Fish caught on a single trip between Brookings, Oreg., and Eureka, Calif., resulted in a sample of smaller fish with a mean length of 33.2 cm. The other six catches from Newport to Cape Lookout had a mean length of 42.7 cm.

Three commercial landings of black hagfish were sampled in 1988 (Table 5)

Table 4.—Length frequency distributions for Pacific hagfish sampled from commercial landings in Oregon, 1988–89[1] (M = male; F = female).

Total length (cm)	Date landed														Total length (cm)	Date landed													
	10-24-88		11-16-88		7-17-89		8-18-89		9-11-89		9-26-89		11-21-89			10-24-88		11-16-88		7-17-89		8-18-89		9-11-89		9-26-89		11-21-89	
	M	F	M	F	M	F	M	F	M	F	M	F	M	F		M	F	M	F	M	F	M	F	M	F	M	F	M	F
20				1											44	0	3	2	1	1	2	1	1	0	7	3	3	4	4
21				0		2									45	0	1	3	2	2	4	0	0	1	6	0	7	1	4
22				5		0									46	0	0	0	2	3	0	0	2	0	10	6	5	1	2
23			1	6		1							1		47	2	1	1	2	2	4	2	1	3	10	2	2	4	5
24		3	2	7		3				1			0		48	1	2		0	1	0	5	3	0	4	0	2	2	2
25		1	1	11		3				0			0		49		1		1	1	1	4	1	1	8	3	2	0	5
26		0	4	7		5				1			0		50		0			0	2	1	2	1	5	1	4	2	2
27		1	1	6		2				0			0		51		0			1	3	0	2	1	3		3	1	2
28		4	0	7		3				0			0		52		1			1	2	4	2	0	2		1	1	4
29		5	4	8		2				1			0		53					3	2	3	0	1	0		2	0	1
30		5	2	12		0				0			0		54					3	0	1	3	0	1		1	1	2
31		5	1	11		1				0			0	1	55					2	0	5	0	1	0		0	1	2
32		8	5	8		3				0			1	0	56					0	1	3	0	0	0		2	1	1
33	1	4	2	6		3				0			0	1	57					1	2	2	1	0	0		0	1	0
34	1	4	4	9		2				1	1		1	0	58					2	0	0	0	0	0		2		0
35	0	3	4	5		0			1	0	0		1	0	59						0	3	0	1	0		0		1
36	0	7	2	5	1	1		1	0	0	0	1	1	2	60						1	1	0		1		0		1
37	1	2	3	10	4	2		0	0	1	0	0	0	1	61						1	2	0				0		
38	1	3	3	4	0	1	1	1	0	2	0	2	1	0	62								0				0		
39	1	1	3	5	3	1	0	0	1	4	0	2	0	1	63								0				1		
40	2	2	1	4	0	1	1	0	2	1	3	4	0	2	64								0						
41	3	5	1	3	2	3	2	1	1	0	1	2	2	3	65								0						
42	0	3	2	6	0	1	0	1	3	3	1	1	1	0	66								0						
43	0	1	0	4	1	3	0	2	2	6	2	2	0	0	67								1						

[1] Table excludes hagfish whose sex was not determined.

and none in 1989. Length was 20–52 cm with a mean of 34.5 cm.

Experimental (research) traps were fished too infrequently to test our hypothesis that traps with escape holes of a certain size could allow escapement of small hagfish while retaining large hagfish. The research traps were used by commercial fishermen who provided samples from about five traps. Total catch was only 57 Pacific hagfish with a mean size of 42.7 cm from traps with 1.9 cm-diameter escape holes and 28 fish with a mean size of 42.8 cm from traps with 1.3 cm-diameter escape holes. In July 1989, fishermen unsuccessfully attempted to catch Pacific hagfish with traps with 2.5 cm diameter holes.

Weight-Length

I used a simple regression of paired lengths and mean weights at length in the form of $\log_{10}$ length (cm) against $\log_{10}$ weight (g) to determine the weight-length relationship $W = aL^b$ (Table 6). No weight corrections were made for either state of gonad maturity or amount of food contained in the gut. The regression had a high r^2 value of 0.972083 to 0.991506. Black hagfish were slightly heavier than Pacific hagfish at the same length.

Maturity

It was difficult to determine the sex of many fish under 30 cm long, although fish as small as 20 cm had gonads that often contained granular material, which appeared to be tiny eggs. Consequently, the sex ratio was based on only mature fish, since small, immature fish could not always be sexed. The 5 mm egg length minimum size for mature females and minimum testis diameter of 1 mm for mature males was arbitrary. Small, immature females had ovaries with round eggs under 1 mm long, or ovaries contained material with a bubble-like or granular appearance. Eggs larger than 1 mm were oblong. Most large females contained eggs longer than 5 mm, whereas, the smallest females did not (Fig. 5). Most hagfish with large eggs or which had recently spawned (indicated by the presence of large empty ovarian capsules) contained at least one additional size group of eggs with an average length <5 mm. Testes did not show much obvious physical change in color or texture until around 1 mm in diameter; the testis of large males was usually at least 1 mm in diameter.

Hagfish sampled from commercial landings in Oregon were often mature, and the percentage of mature fish increased in 1989 over that observed in 1988. Mature Pacific hagfish were 26% of the sampled catch in 1988 and 69% in 1989. Although few commercial landings of black hagfish have been landed in Oregon, samples collected in 1988 contained 40% mature fish. In 1989, a sample was obtained from small cylindrical, commercial traps which were used as bait holders in sablefish traps. About 48% of the black hagfish caught in these traps were mature.

Table 5.Length frequency distributions for black hagfish sampled from commercial landings, 1988 (M = male, F = female, U = sex not determined).

	Date landed								
Total length (cm)	10–10–88			10–13–88			10–24–88		
	M	F	U	M	F	U	M	F	U
20						2			
21						1			1
22						4			0
23	5					3			0
24	2	1				9		1	0
25	5	1	1			10		2	0
26	5	1	2			6		1	1
27	6	2	0			13		3	0
28	8	6	0			12		4	2
29	5	3	0			14		1	0
30	4	6	1			15	1	4	2
31	7	6				11	1	2	
32	10	2				11	1	4	
33	7	1				16	1	2	
34	10	4				18	4	0	
35	5	5				19	2	5	
36	10	9				20	4	5	
37	4	6				23	4	2	
38	3	14				19	5	0	
39	4	7				16	7	4	
40	6	7				15	1	7	
41	0	9				15	1	8	
42	1	4				13	3	6	
43	1	3				10		1	
44	1	6				3		2	
45		0				2		3	
46		4				3		1	
47						1		0	
48								1	
49								0	
50								0	
51								0	
52								1	

Table 6.—Weight and length characteristics by species and sex for Oregon hagfish samples from Oct. 1987 to Oct. 1988.

	Weight-length characteristics			
Species and sex	Intercept	Slope	$W = aL^b$	r^2
Pacific hagfish, male	–2.215851	2.65009	$W = 0.006084L^{2.65009}$	0.984246
Pacific hagfish, female	–2.296721	2.68130	$W = 0.005050L^{2.68130}$	0.991506
Black hagfish, male	–2.443552	2.80513	$W = 0.003560L^{2.80513}$	0.981467
Black hagfish, female	–2.737398	2.99399	$W = 0.001831L^{2.99399}$	0.972083

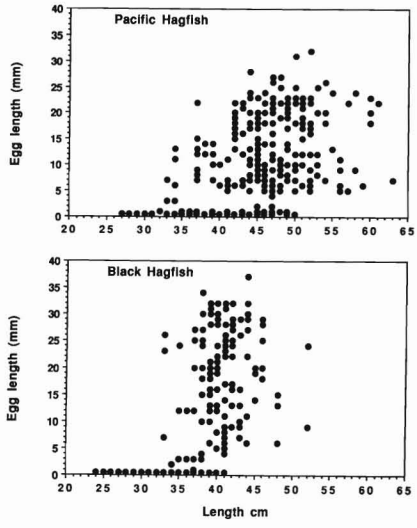

Figure 5.—Average length of hagfish egg group (largest size group of eggs) by fish length from samples of Oregon commercial landings, 1988–89.

Males comprised 30% of the mature Pacific hagfish and 39% of the mature black hagfish. The smallest mature male Pacific hagfish was 26 cm long. Almost all mature males were over 32 cm, while 50% and 100% maturity were 35 cm and 42 cm, respectively (Table 7). The smallest mature Pacific hagfish female was 30 cm long; 50% and 100% maturity were 42 cm and 51 cm, respectively. The smallest mature male black hagfish was 28 cm long, and 50% and 100% maturity were 34 cm and 41 cm, respectively. Female black hagfish first matured at a length of 33 cm, and 50% and 100% maturity were 38 cm and 42 cm, respectively.

Table 7.—Length and percent maturity for hagfish by species and sex from samples collected in Oregon, October 1988 through October 1989 (M = male, F = female).

Length (cm)	Percent mature			
	Pacific hagfish		Black hagfish	
	M	F	M	F
26	25.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0
28	0.0	0.0	11.1	0.0
29	0.0	0.0	14.3	0.0
30	0.0	5.9	16.7	0.0
31	0.0	0.0	30.0	0.0
32	20.0	5.3	35.7	0.0
33	33.3	21.4	36.4	50.0
34	42.9	27.8	58.8	0.0
35	60.0	20.0	78.9	0.0
36	60.0	18.8	81.8	33.3
37	50.0	40.0	81.0	47.1
38	83.3	21.4	72.7	63.6
39	62.5	50.0	87.5	68.0
40	77.8	28.6	76.9	88.9
41	75.0	41.2	100.0	94.3
42	100.0	62.5	100.0	100.0
43	100.0	54.5	50.0	100.0
44	100.0	77.8	100.0	100.0
45	100.0	73.1	100.0	100.0
46	100.0	89.5	100.0	100.0
47	92.3	91.7		100.0
48	100.0	90.9		100.0
49	100.0	94.1		100.0
50	100.0	92.9		100.0
51	100.0	100.0		
52	100.0	100.0		100.0
53	100.0	100.0		
54	100.0	100.0		

Time of Spawning

Sampling of Pacific hagfish was conducted during most months of the year for egg length, presence of hooks on eggs, and presence of large empty egg capsules to determine spawning time(s).

Pacific hagfish females with large eggs or empty egg capsules were found throughout the year, and hooks were noted in July (Table 8). This suggests that some spawning occurs throughout the year. Sampling of black hagfish females was conducted only during months of May through October. Large eggs, hooks, and empty egg capsules were found throughout this period (Table 9).

Egg Characteristics

Mature Pacific and black hagfish females often contained more than one size group of eggs and sometimes had three distinct size groups of eggs (Fig. 2F). Usually only one size group of eggs were over 5 mm long in a female, although there were exceptions. For example, contained throughout a single gonad, one could find one size group of eggs ranging in length from 19 to 22 mm, a second size group of eggs ranging from 1 to 4 mm, and a third size group of eggs <1 mm long. An ovary often contained over 200 eggs <1 mm long, but the number of eggs >5 mm was relatively low.

Pacific hagfish females contained up to 76 eggs that were >5 mm long, but the average was about 28 eggs. The average egg length for eggs >5 mm was 14.3 mm, with a maximum egg length of 32 mm. Black hagfish females contained up to 42 eggs >5 mm long, and the average was about 14 eggs over 5 mm long. The average egg length for eggs >5 mm was 21.4 mm, with a maximum egg length of 38 mm. There did not appear to be a strong correlation between length of mature females and number of eggs >5 mm long for either species (Table 10).

Hermaphroditism and Abnormal Gonads

Two (0.2%) Pacific hagfish were obviously hermaphroditic, while none of the 897 black hagfish sampled appeared to be a hermaphrodite. One Pacific hagfish hermaphrodite was 53 cm long, and contained a well developed testis and five large, apparently deformed eggs. The length of the eggs ranged from 10 to 15 mm. The fish also contained 14 wide, empty egg capsules that were about 8 mm long. An empty, wide egg capsule suggests that an egg was recently released from the capsule. The second hermaphrodite was 49 cm long with 13 eggs between 17 and 21 mm long (Fig. 3B). One additional egg was 8 mm long. Five of the eggs were abnormally shaped and stuck together at the anterior end of the gonad. The tes-

Table 8. — Average egg length by month for Pacific hagfish females from Oregon landings, 1988 through October 1989[1].

Egg length (mm)	Number of females											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
5–0	1	1		0			9	9	40	9	15	
11–15	0	4		0			6	0	12	1	18	
16–20	2	4		1			12	8	20	1	5	
21–25	0	1		0			5	3	26	6	2	
26–30	0	1		0			4	1	1	0	0	
>30	0	0		0			2	0	0	0	0	
Total number of fish with eggs >5 mm	3	11		1			38	21	99	17	40	
Number of fish with empty egg capsules	0	4		0			11	3	29	4	0	
Number with eggs with hooks	0	0		0			3	0	0	0	0	

[1] Table excludes observations on eggs <5 mm long.

Table 9.—Average egg length by month for black hagfish females from Oregon landings, 1988 through October 1989[1].

Egg length (mm)	Number of females											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
5–0					0	8			4	10		
11–15					0	10			7	9		
16–20					0	9			9	10		
21–25					1	11			7	10		
26–30					1	16			14	8		
>30					0	5			12	6		
Total number of fish with eggs >5 mm					2	59			53	53		
Number of fish with empty egg capsules					0	11			12	0		
Number with eggs with hooks					1	0			2	2		

[1] Table excludes observations on eggs less than 5 mm long.

tis was large and located in the posterior 20% of the gonad.

Female hagfish usually contained eggs throughout the entire length of their gonad, while in males the testis was usually located at the posterior quarter of the gonad, although there were exceptions. At least three Pacific hagfish (42–51 cm in total length) and one black hagfish (39 cm) contained a large testis (4–6 mm wide bundles) at the posterior half of the gonad and somewhat smaller testis bundles scattered throughout the anterior half of the gonad.

Table 10.—Average number of eggs >5 mm and average egg length compared to total fish length for Pacific hagfish and black hagfish, 1988–89[1].

Total fish length (cm)	Pacific hagfish			Black hagfish		
	No. of fish	Avg. no. of eggs	Avg. length of eggs (mm)	No. of fish	Avg. no. of eggs	Avg. length of eggs (mm)
33	2	11.0	12.5	3	11.7	18.3
34	3	17.3	10.3	0		
35	0			2	18.5	18.0
36	1	11.0	5.0	4	13.8	18.5
37	6	17.8	12.8	5	8.6	23.2
38	3	15.0	12.7	15	10.6	22.4
39	7	21.1	10.1	17	14.8	18.8
40	4	37.0	9.8	20	11.9	20.7
41	6	18.8	11.5	29	15.0	21.5
42	10	18.0	16.1	16	14.8	22.7
43	12	26.6	14.1	17	15.3	22.7
44	12	22.1	13.9	13	11.6	24.7
45	13	26.1	15.1	8	12.8	24.8
46	14	27.9	13.8	9	16.5	22.1
47	21	23.9	16.7	2	15.0	19.5
48	10	22.6	11.8	4	19.5	9.8
49	16	31.1	14.5	1	19.0	8.0
50	12	29.8	16.5	1	30.0	9.0
51	11	28.9	17.5	0		
52	8	32.6	16.1	2	26.5	16.5
53	6	49.3	15.8			
54	5	30.6	22.0			
55	3	49.0	9.7			
56	4	34.8	15.8			
57	3	25.7	16.3			
58	5	53.0	15.4			
59	0					
60	4	33.5	17.8			
61	2	34.0	20.0			
62	0					
63	1	20.0	7.0			
64	1	33.0	16.0			
65	0					
66	0					
67	1	57.0	10.0			

[1] Table excludes eggs less than 5 mm in length.

Discussion

Oregon hagfish landings have shown a modest upward trend with peak landings in 1992. Fishermen have produced good catches of both Pacific and black hagfish. Korean "eelskin" buyers continue to show interest in Pacific hagfish for their skins when Asian hagfish availability is down and the quality of U.S. west coast hagfish skins is good. Good quality now means "fresh" skins that have few bite marks or other damage. Fresh skins usually means live fish or fish frozen at sea. There is no apparent market at present for either black hagfish skin or the edible flesh of either species.

While hagfish appear to be plentiful off the Oregon coast, no estimate of abundance has been made. Without such data, if the fishery intensifies, overfishing could occur. This has happened off the coast of the Republic of Korea (Gorbman et al., 1990). An additional concern is that if the hagfish fishery continues to be primarily for skins, quality skins must be produced by fishermen or production may be wasted.

The Oregon Department of Fish and Wildlife will continue to require fishermen to maintain logbooks to track fishing catch and effort, and will continue to take samples of commercial landings. Age determination of our samples would provide important information, but presently no reliable aging technique has been determined. Age determination is difficult because hagfish lack scales or bony body parts,

which are usually used to age fish. Fish tagging or marking studies would be useful in determining hagfish longevity and growth rates.

Hagfish sampled from commercial landings in Oregon were often mature, though some landings have contained large quantities of immature fish. Fewer small fish were delivered after July 1989, probably due to sorting at sea to accommodate buyer preference or requirement for fish over 35.6 cm. Market requirements should provide some protection of immature fish in the future and provide an incentive to the industry to develop size selective-traps. A 38 cm minimum size limit for hagfish would insure that a portion of the populations of both Pacific and black hagfish have a chance to spawn.

Our data should be used with caution, because it does not represent the entire Oregon hagfish population. Port sampling, which was the source of most of our samples, has inherent limitations. Some small fish were probably able to escape from the traps, and some small fish were discarded. Samples were often taken after sorting, so they may not represent true population characteristics with regard to average size, size at first maturity and abundance with regard to size. Commercial fishing did not occur in all areas occupied by hagfish.

Although I was not able to sample hagfish in all months, my observations agree with those of Cailliet (1991) who found that neither sex or species showed seasonal patterns in spawning, and also those of Gorbman (1983) and Walvig (1963) who suggest that most species of hagfish spawn throughout the year. My observations also agree with the findings of Gorbman (1983) and Jensen (1966) who concluded that Pacific hagfish have a low fecundity and produce an egg series or clutch of around 20–30 eggs. I also agree with Cailliet (1991) and Gorbman (1983) that hermaphroditism is rare for Pacific hagfish. It appears that hermaphroditism is even less frequent in black hagfish, as was reported by Cailliet (1991).

I have observed hagfish[9] from submersibles in depths of 124–221 m. This coincides with fishery data from logbooks maintained by Oregon hagfish fishermen who indicate that Pacific hagfish are common in 119–219 m primarily on soft substrate. Most of the fish that I observed were identified as Pacific hagfish, *E. stouti*, and they were observed with their heads protruding out of holes in the mud, coiled on mud, and slowly moving along substrate consisting of mud or muddy sand. They were less commonly seen on mixed cobble and small boulder where they were sometimes found partially under rocks and sponges (Fig. 6).

Several management options might help prevent overfishing. Gear restrictions might include limits to the number and size of traps per vessel. There is probably a maximum number of traps that can be tended within a reasonable soak period to insure quality fish. Fishermen report that hagfish bite one another when crowded or under stress, and some fishermen and buyers recommend a short soak time of around 4 hours. Limited entry into the hagfish fishery might help prevent overfishing while also ensuring that an adequate share of

[9] Personal observation from submersibles *Delta* and *Mermaid II* off the Oregon coast, Sept. 1988, Sept. 1989, Sept. 1990, and Sept. 1991.

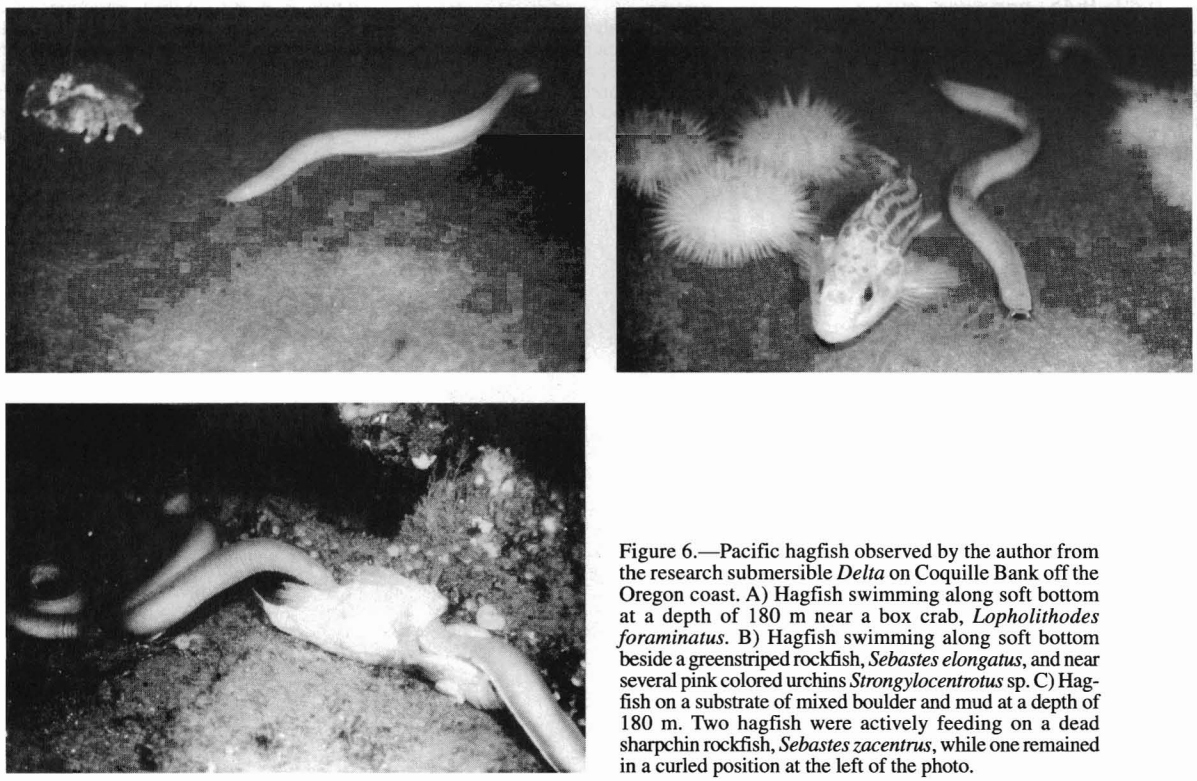

Figure 6.—Pacific hagfish observed by the author from the research submersible *Delta* on Coquille Bank off the Oregon coast. A) Hagfish swimming along soft bottom at a depth of 180 m near a box crab, *Lopholithodes foraminatus*. B) Hagfish swimming along soft bottom beside a greenstriped rockfish, *Sebastes elongatus*, and near several pink colored urchins *Strongylocentrotus* sp. C) Hagfish on a substrate of mixed boulder and mud at a depth of 180 m. Two hagfish were actively feeding on a dead sharpchin rockfish, *Sebastes zacentrus*, while one remained in a curled position at the left of the photo.

the resource is available for participants and helping to reduce the possibility of overcapitalization in the fishery.

Limiting the number of traps, length of groundline in the fishery, and the time of fishing could help lessen gear conflicts between the hagfish fishery and other fisheries. Hagfish trap fishing has the potential of preempting grounds that are also used by fishermen using different gear such as trap, trawl, troll, and longline. Reilly (1983) mentioned that trawlers generally move out of areas when crabbing occurs due to the hazard presented to their gear by crab traps. Hagfish fishermen have reported that they can avoid most gear conflicts with shrimp trawlers by fishing at night, when shrimping does not occur.

Holes in traps that allow the escape of small hagfish would reduce the amount of sorting at sea for marketable sized fish and may help protect a portion of the spawning population. Size-selective traps must permit an economically adequate catch of large hagfish. Melvin and Osborn (1992) report that larger hagfish can be selected by using larger escapement holes in traps. They compared traps with escape hole sizes of 0.38, 0.42, 0.45, and 0.48 inches. Traps with 0.48-inch escapement holes best selected for hagfish ≥12 inches in length (over 90%). When these traps were fished for 24 hours, there was a reduction of hagfish/trap catch from 104 in traps with 0.38 inch holes to 44 fish in traps with 0.48 inch holes.

Acknowledgments

I am grateful to the fishing industry in Oregon for its help in monitoring the hagfish fishery and providing fish for samples. National Marine Fisheries Service Biologists Ken Weinburg and Mark Wilkens and Douglas Markle from Oregon State University were most helpful in providing hagfish samples from research cruises. Captain Richard Arnold and Scot Arnold of F/V *Lihue II* and Captain Stuart Arnold of F/V *Trial* provided hagfish samples and detailed information on the development of their hagfish fishery. I also thank Kristine Barsky, Paul Wilde, Jim Hardwick, Sus Kato, Darcy Wildermuth, Brian Culver, Chris Neville, Rick Harbo, and Brian Paust for their exchange of information on the developing hagfish fishery and hagfish research in their respective areas. Aubrey Gorbman and Robert Demory provided constructive advice to improve the project and report.

Literature Cited

Adam, H., and R. Strahan. 1963. Notes on the habitat, aquarium maintenance, and experimental use of hagfishes. *In* A. Brodal and R. Fange (Editors), The biology of Myxine, p. 33–41. Scandinavian Univ. Books, Oslo.

Cailliet, G. C. 1991. The biology and fisheries potential of hagfish. Moss Landing Mar. Lab., Moss Landing, Calif., Calif. Sea Grant Final Rep., R/F-129.

Dawson, J. A. 1963. The oral cavity, the 'jaws' and the horny teeth of *Myxine glutinosa*. *In* A. Brodal and R. Fange (Editors), The biology of Mixine, p. 231–255. Scandinavian Univ. Books, Oslo.

Foss, G. 1963. Myxine in its natural surroundings. *In* A. Brodal and R. Fange (Editors), The biology of Myxine, p. 42–45. Scandinavian Univ. Books, Oslo.

Gorbman, A. 1983. Reproduction in cyclostome fishes and its regulation. *In* W. S. Hoar, E. J. Randall, and E. M. Donaldson (Editors), Fish physiology, p. 1–29. Acad. Press, N.Y.

_____ , H. Kobayashi, Y. Honma, and M. Matsuyamal. 1990. The hagfishery of Japan. Fisheries 15(4):12–18.

Hart, J. L. 1973. Pacific fishes of Canada. Fish. Res. Board Can., Bull. 180, 740 p.

Hixon, M. A., B. N. Tissot, and W. G. Pearcy. 1991. Fish assemblages of rocky banks of the Pacific northwest. U.S. Dep. Inter., Minerals Manage. Serv., Final Rep. OCS Study, MMS-91-0052, 410 p.

Jensen, D. 1966. The hagfish. Sci. Am. 214: 82–90.

McInerney, J. E., and D. O. Evans. 1970. Habitat characteristics of the Pacific hagfish, *Polistotrema stoutii*. J. Fish. Res. Board Can. 27(5):966–968.

Melvin, E. F., and S. A. Osborn. 1992. Development of the west coast fishery for Pacific hagfish. U.S. Dep. Commer., NOAA, Wash. Sea Grant Prog., Final Rep. NMFS, NA90AA-H-SK142, 47 p.

Pearcy, W. G., D. L. Stein, M. A. Hixon, E. K. Pikitch, W. H. Barss, and R. M. Starr. 1989. Submersible observations of deep-reef fishes of Heceta Bank, Oregon. Fish. Bull. 87:955–965.

Reilly, P. N. 1983. Effects of commercial trawling on Dungeness crab survival. *In* P. Wild and R. Tasto (Editors), Calif. Dep. Fish. Game, Fish Bull. 172:165–169.

Walvig, F. 1963. The gonads and the formation of the sex cells. *In* A. Brodal and R. Fange (Editors), The biology of Myxine, p. 530–580. Scandinavian Univ. Books, Oslo.