CONTRIBUTION TO THE BIOLOGY OF THE PACIFIC HAKE, *MERLUCCIUS PRODUCTUS* (AYRES)[1]

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INTRODUCTION

Although Pacific hake give promise of being one of the most abundant fishes indigenous to the continental shelf of western North America, little or nothing has been published on their biology, although their taxonomy has been fully covered (Ginsburg, 1954). In the course of investigating bottomfish, personnel of the California Department of Fish and Game have made routine observations on all fish sampled. A recent compilation of these accumulated facts, plus examination of the literature on Pacific hake are the basis of this paper.

To the present time, only limited use has been made of the Pacific coast hake. In contrast, most, if not all other species of *Merluccius* in the world, are harvested on a far larger scale. Fritz (1960, p. 2) reports 170 million pounds of silver hake (*M. bilinearis*) landed at the ports of eastern United States. California landings have been about one million pounds annually (Paul, 1961, p. 31); most of these were unloaded at northern California ports and used for animal food. However, when more desirable fish have been scarce, hake have been prepared for the fresh-fish markets in limited amounts. North of California hake are present but become increasingly scarce in the landings.

RANGE

The recorded range for Pacific hake is from the Gulf of Alaska (Wilimovsky, 1954, p. 283) south to the Gulf of California (Starks & Morris, 1907, p. 241). This is roughly the limit of the south boreal region of the eastern Pacific Ocean described by Rass (1959). From sampling the adult population by the commercial fishing fleet, their indicated center of abundance is in northern California. The lack of a fishery that would harvest them off southern California may have biased this location to a considerable degree. This is pointed out by the Nissan Fisheries Institute (1937, p. 57) who stated that hake were abundant and a common food fish in Mexican waters. Their report was based upon fishing trials conducted by Japanese trawlers off the Pacific coast of Mexico during 1935 and 1936. Juvenile hake have been collected by the California Department of Fish and Game in the vicinity of Cedros Island, Baja California.

Routine plankton hauls made by the California Cooperative Oceanic Fisheries Investigations have revealed large numbers of hake larvae over the entire area surveyed from San Francisco, California to Cape San Lucas, Baja California, and offshore for at least 350 miles (Ahlstrom & Counts, 1955, p. 312). Their greatest abundance, however, was between Point Conception, California, and San Quintin, Baja California. This location may also have been biased since their collections were made in regions of known sardine (*Sardinops caerulea*) spawning and may not have covered the true spawning range of hake.

SIZE OF FISH

In Commercial Landings

Surveillance of animal food landings and a survey of the ecological relationship of various species entering the otter trawl catch have provided 4,644 total length measurements. These measurements have been collected annually since 1950 at all ports from Eureka to Santa Barbara. The hake length frequencies were plotted separately by port and in each instance, the distribution was almost identical. The fish began entering the catch regularly at a length of about 45 cm; the mode of each distribution was at 57 cm, and the largest individuals at each port were 78 to 80 cm. Some fish smaller than 45 cm appeared in the catch at sporadic intervals. Only at Santa Barbara were fish shorter than 45 cm present to any degree; about 20 percent of the 217 fish sampled there were of that size. The maximum length recorded was 80 cm.

Since there was no size differential between ports, measurements for all ports were combined, grouped by 2 cm intervals, and plotted (Fig. 1).

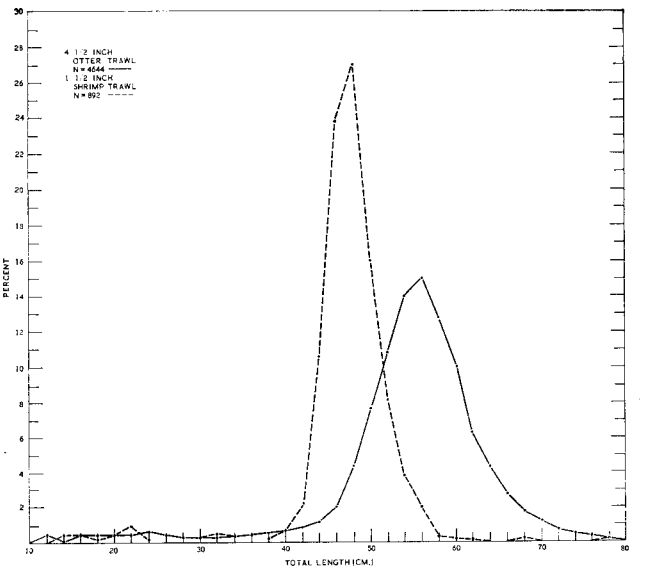

FIGURE 1. Length-frequency distributions of Pacific hake taken by 4½-inch otter trawl nets and 1½-inch shrimp trawls. Shrimp trawl data from Morgan and Gates (1961).

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Otter trawl vessels are required to use nets with 4½-inch (inside the knots) mesh. This relatively large mesh selects only the larger hake that are accessible on the fishing grounds. It is obvious that hake do not become completely vulnerable to commercial otter trawls until they are 57 cm long.

Morgan and Gates (1961, p. 106) recorded the total lengths of hake caught off southern Oregon and northern California in shrimp trawls using 1½- and 1⅝-inch mesh cod-ends. Length frequencies of 892 of their hake have been handled in an indentical fashion as our otter trawl measurements and plotted (Fig. 1). Their data substantiate our conclusion that hake enter the catch when they are about 45 cm long. However, the small mesh they used caught more small fish, so their mode was at 49 cm, and large fish (longer than 60 cm) were relatively scarce. One hake they reported was 78 cm long corresponding with the maximum size taken in our otter trawl fishery. This indicated that the larger fish were able to avoid the shrimp nets, which were also unsuccessful at taking smaller hake although the 1½-inch mesh used in them should have retained fish much smaller than 45 cm, if they were accessible. In fact, these same nets retained rex sole (*Glyptocephalus zachirus*) as small as 8 and 9 cm. Hickling (1933, p. 71) reported European hake (*M. merluccius*), about 30 cm long, were completely retained by trawl nets with 80-mm mesh (about 3¼-inches).

Investigations have revealed that European hake are not available on the bottom in large numbers until the end of their second year of life, at a length of about 20 cm (Hickling, *ibid,* p. 50). A similar situation may prevail on our coast so that hake are not available in numbers to bottom-fishing trawls until they are 40 cm long. Hake killed by explosives fired near the surface in geophysical explorations off our coast during 1961 were uniform in length, ranging from 38 to 48 cm. Some small fish were found in our samples from the otter trawl fishery; the smallest was 12 cm long but only 129, or 2.8 percent, of the 4,644 measured were shorter than 40 cm.

SIZE BY SEX

Some of the hake sampled from San Francisco (1,194), Fort Bragg (173), and Eureka (547) were sexed. The ratio of males to females was 1: 1.9 at San Francisco, 1: 2.4 at Eureka, and at Fort Bragg all hake in the sample were females. The familiar picture of females reaching a larger size than males is exhibited by hake. The maximum size for males was 66 cm and for females it was 76 cm. Fish as long as 80 cm were measured but not sexed. There were no differences in the length frequencies of males or females between ports so the measurements were combined by sex, grouped by 2 cm intervals and plotted. The modal length for males was 55 cm and for females 59 cm (Fig. 2).

SIZE AT MATURITY

From the limited number of small fish observed it has been difficult to determine with any accuracy the size at which hake mature. Both male and female fish which were over 40 cm were mature. Only one fish shorter than 40 cm, a female 38 cm long, was mature. This fish was observed during October and, although the ovary was filled with maturing eggs, it was small. Obviously it was the first maturity for this specimen. Based on our limited observations, maturity appears to take place at a length of about 40 cm for both males and females.

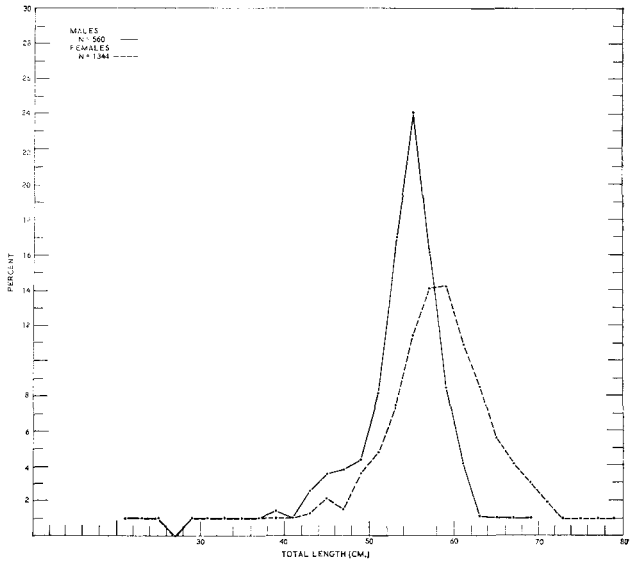

FIGURE 2. Length-frequency distributions of male and female Pacific hake in California landings.

LENGTH-WEIGHT RELATIONSHIP

A sample of 58 female Pacific hake, collected at Santa Barbara and Morro Bay, October 17-18, 1961, was used to compute a length-weight relationship. Measurements were made to the closest two mm on a flat measuring board and weights were determined within 1/64-pound on a five pound capacity Chatillion spring scale. Two individuals which exceeded the capacity of the scale were weighed on scales available at the processing plant. Weights were converted to hundredths of a pound.

The formula for female Pacific hake was calculated to be Weight (lbs.)$=0.0000115$ Length (cm) $^{3.06682}$ or $\log W = 3.06682 \log L - 4.95216$.

The average lengths and weights of hake, sexes combined, processed for animal food are available for the past five years. These data correspond with the calculated line for female hake (Fig. 3).

AGE DETERMINATIONS

No age determinations have been made in the past. However, studies currently under way indicate that otoliths are satisfactory for determining age. Otoliths have been used with fair success for determining the ages of *M. merluccius* (Hickling 1933, Bagenal 1954, and Figueras (1955) and *M. hubbsi* (Angelescu *et al.* 1958). Scales of the Pacific hake are highly deciduous

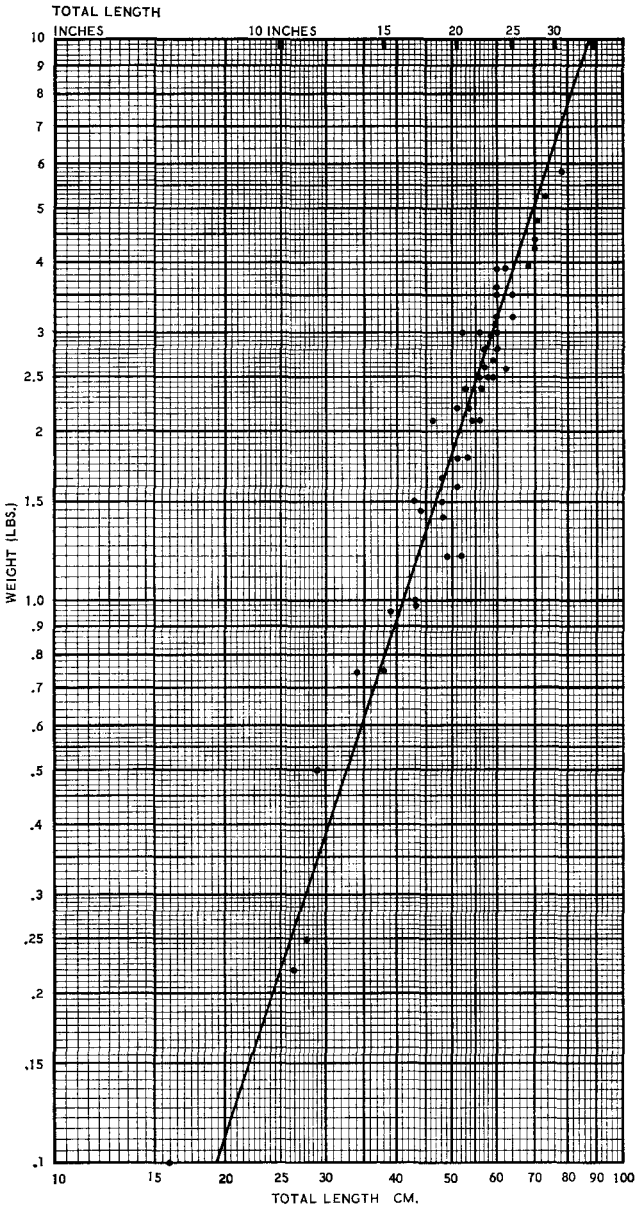

FIGURE 3. Length-weight relationship of Pacific hake. Solid line calculated from a sample of 58 female hake collected at Santa Barbara and Morro Bay, October 17-18, 1961. Dots represent average lengths and weights obtained while sampling the animal food landings.

and nearly impossible to find in trawl caught fish. Consequently, no attempt was made to use scales in age work.

Otoliths were collected during October and November, 1961, to supplement otoliths already on hand. All collections were made during winter months (October-February). Thus in many cases the annulus had not yet been formed. However, for the purposes of this paper, ages were calculated as if the annulus had been formed. That is, most of the fish listed here as one-year-olds had as yet not completed one full year of life. This method necessarily biases the average size at any age in a negative manner, particularly the younger ages.

Age determinations were made on otoliths from 464 hake. Sexes were combined for age groups I, II, and III; for the older age groups males were very scarce in the fishery at the time the otoliths were collected and were not used in age determinations. Therefore, groups IV and older represent female growth characteristics only (Fig. 4 and Table I).

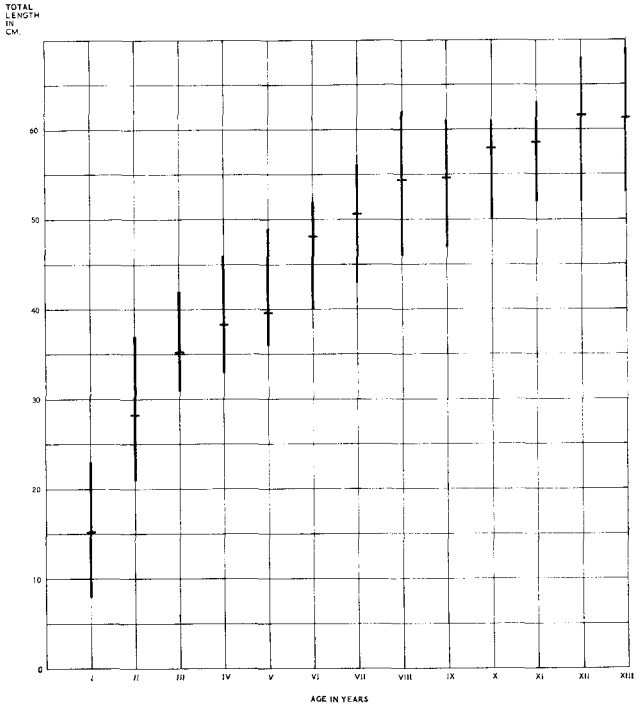

FIGURE 4. Growth curve of Pacific hake. Age groups I, II, and III represent combined sexes; age groups IV and older represent females only. Average size and range is shown for each age group.

As reported in the section on maturity, all hake over 40 cm were mature and only one fish shorter than 40 cm was observed to be mature. This means that the larger three-year-old fish and most of the four-year-olds would spawn. The mature 38 cm specimen was three years old.

TABLE I

Average total lengths of Pacific Hake by Age

Age	Number	Average Length (Cm)	Size Range (Cm)
I	186	15.5	8–23
II	93	27.4	21–37
III	91	35.4	31–42
IV	9	38.7	33–46
V	10	39.8	36–49
VI	9	48.1	40–52
VII	9	50.8	43–56
VIII	14	54.4	46–62
IX	10	54.5	47–61
X	10	57.9	50–61
XI	10	58.6	52–63
XII	7	61.6	52–68
XIII	6	61.3	53–69

DISTRIBUTION IN SPACE AND TIME

Space

Information on depth of capture is available for some of the samples collected at San Francisco and Eureka. At San Francisco, 96 percent of the sampled hake came from 124 fathoms or shallower, with 41 percent from water 50-74 fathoms deep. At Eureka, 88 percent were caught at depths shallower than 99 fathoms, with 43 percent in 25-49 fathoms. The remaining fish in both areas had been scattered throughout the deeper water with a small concentration at 175-199 fathoms. The deepest catch for both areas was from 275-299 fathoms (Table II). In all cases, the hake from the deeper areas were taken during the winter, coinciding with the spawning season as indicated by the occurrence of larvae (Ahlstrom & Counts, *op. cit.*, p. 312).

TABLE II

Depth distribution of 1,986 Pacific Hake at four localities

Depth Fathoms	Eureka		San Francisco		Monterey		Morro Bay	
	No.	Percent	No.	Percent	No.	Percent	No.	Percent
0-24	2	1	178	14	0	0	0	0
25-49	122	43	349	27	195	54	0	0
50-74	84	29	524	41	20	6	18	26
75-99	44	15	131	10	10	3	33	48
100-124	1	tr	51	4	31	9	18	26
125-149	1	tr	3	tr	5	1	0	0
150-174	5	2	3	tr	102	28	0	0
175-199	14	5	31	2	0	0	0	0
200-224	4	2	1	tr	0	0	0	0
225-249	8	3	1	tr	0	0	0	0
250-274	0	0	2	tr	0	0	0	0
275-299	2	1	2	tr	0	0	0	0
Total	287	101	1,267	98	363	98	69	100

Alverson (1951; 1953) reported taking a few hake as deep as 300-304 fathoms off Washington. Hake have been reported as deep as 491 fathoms off California (Clemens & Wilby, 1961, p. 163).

Much of our information indicates hake inhabit the relatively deep water of the continental shelf and beyond. However, this does not prevent them from chasing their prey on the surface and even into the surf where they become stranded (De Witt, 1952, p. 438). Van Hyning and Ayers (1960, p. 5) reported observing hake in brackish water within the Columbia River estuary.

Although hake have been recorded from these extreme depths, by far the greatest bulk has been taken from the bottom or near-bottom areas of the continental shelf. Experimental mid-water trawling has resulted in large catches of nearly pure hake but these have been rather sporadic. Schaefers and Powell (1958, p. 9) reported catching 5,500 pounds, mostly hake, in a 20-minute mid-water trawl. They also show Sea Scanar recorder traces of hake and rockfish (*Scorpaenidae*) that were located off Washington and British Columbia. During daylight hours there is a definite layer of fish from near the bottom to about 15 fathoms above the bottom. At night this layer was much higher in the water and more scattered. A similar diurnal movement has been noted in the hake fisheries of the Atlantic Ocean and has been associated with feeding.

Time

At Eureka hake were relatively scarce during January-March, making up less than one percent of the sample, and reached their peak abundance during July-September (55 percent). The sequence at San Francisco was similar: one percent of the fish were taken during January-March and 52 percent during July-September. Small samples from Fort Bragg and Morro Bay indicated peak abundance at these localities during April-June (Table III). There has not been enough sampling at Santa Barbara to determine seasonal abundance. Fish kills made during geophysical explorations off northern California tended to corroborate these data. Hake first appeared near Eureka during April and were last observed off Crescent City during August. On these surveys hake were observed only between Drakes Bay (near San Francisco) and Crescent City.

TABLE III

Occurrence, by quarter-year periods, of Pacific Hake in Otter Trawl samples at five California ports

Port	Jan.-Mar.		Apr.-June		July-Sept.		Oct.-Dec.		Total	
	No.	Per-cent	No.	Per-cent	No.	Per-cent	No.	Per-cent	No.	Per-cent
Eureka	6	tr	730	29	1,401	56	367	15	2,504	100
Fort Bragg	0	0	63	72	21	23	4	5	88	100
San Francisco	13	1	635	40	833	52	111	7	1,592	100
Monterey	0	0	200	55	63	17	100	28	363	100
Morro Bay	2	3	38	55	16	23	13	19	69	100

INTERSPECIFIC RELATIONS

Hake as a Predator

The food habits of hake have not been the object of any intensive study. However, some random observations on several hundred fish have been recorded. Hake apparently are opportunists, feeding on whatever is present.

Juvenile hake have been found gorged with pelagic red crabs (*Pleuroncodes planipes*), euphausiids, and small squid (*Loligo opalescens*). Stomachs of adult hake have contained anchovies (*Engraulis mordax*), small hake, queenfish (*Seriphus politus*), sanddabs (*Citharichthys* spp.), slender sole (*Lyopsetta exilis*), curlfin turbot (*Pleuronichthys decurrens*), euphausiids, the clam (*Solemya panamensis*), pink seaperch (*Zalembius rosaceus*), and large squid (Fitch, personal communication). Van Hyning and Ayers (*op. cit.*) and De Witt (*op. cit.*) reported that hake feed heavily on anchovies at times. In some cases they chase their prey into the surf with such abandon that they have been stranded by a falling tide.

The above cases represent only a few random observations and do not represent any qualitative or quantitative food habits study.

Hake as Prey

The large number of hake larvae that have been caught in the CCOFI nets indicate that this species is a handy food item for larger predatory fishes. Our observations have revealed that young hake often are food for several species of rockfish, and albacore tuna (*Thunnus germo*) feed regularly on zero age group hake. Large hake, arrowtooth flounders (*Atheresthes stomias*), and a bigmouth sole (*Hippoglossina stomata*) have been observed with young hake in their stomachs.

Adult hake have been found in the stomachs of Pacific lancetfish (*Alepisaurus richardsoni*), California bluefin tuna (*Thunnus saliens*), sablefish (*Anoplopoma fimbria*), lingcod (*Ophiodon elongatus*), soupfin shark (*Galeorhinus zyopterus*), great white shark (*Carcharodon carcharias*), and an electric ray (*Torpedo californicus*). Hake otoliths have been identified among the stomach contents of several marine mammals, including California sea lions (*Zolophus californianus*), an elephant seal (*Mirounga augustirotris*), Pacific white-sided porpoises (*Lagenorhynchus obliquidens*), and a Dall porpoise (*Phocoenoides dalli*) (Fitch, personal communication; Ripley, 1946).

Use

The animal food fishery in California started in 1953 and has been expanding each year. This industry has been the principal hake user in California (Best, 1959; 1961). In Oregon, hake have not been used to as great an extent for animal food because there is a tendency for hake-fed mink to become anemic and to lack pigment in the underfur, making their pelts valueless. A new process has been developed in which hake are subjected to a heat and acid treatment, making them much better mink food (Adair *et al.*, 1960; 1961).

Hake have also been used to some extent for pet food and in experimental diets at fish hatcheries operated by California, Oregon, and U.S. Fish and Wildlife Service. In most instances, the results at hatcheries were favorable; however, anemia did occur in some cases. These tests have been reported by Wales (1944), Burrows *et al.* (1951), Robinson *et al.* (1951), Hublou *et al.* (1955), and Jeffries *et al.* (1954). Jones (1959, p. 8) estimated that 50-60 million pounds of hake could be harvested annually from Pacific Northwest waters.

During World War II some experiments were carried out by the Oregon Agricultural Experiment Station to determine the Vitamin A content of hake liver and viscera. Large numbers of hake had been noted off the Oregon coast and some 1,500 pounds of hake livers were landed for experimentation. These tests indicated 1.65 million units of Vitamin A per pound of liver and 0.34 million units of Vitamin A per pound of viscera (Sinnhuber & Law, 1948). The Fisheries Research Board of Canada ran tests on an eight pound sample of hake liver and found the liver to contain 31.5 percent oil and 6,000 U.S.P. units of Vitamin A per gram (Bailey, 1943).

No references could be found on the reduction of hake. Jones (*op. cit.* p. 5) indicated hake have a moisture content of 80 percent and a fat content of one to two percent. Fish meal made from Alaska pollock, *Theragra chalcogramma*, a species similar to hake, had a yield of only 10 to 12 percent (Wigutoff & Carlson, 1950, p. 72). This meal had a protein content of about 62 percent. Moisture content of pollock was 79 percent according to Landgraf, (1953).

SUMMARY

1. Although Pacific hake are relatively abundant on the Pacific Coast of North America, little use is currently made of them. About one million pounds are landed annually in California.
2. Commercial otter trawl fishing now accounts for the bulk of the catch. The fish begin entering the catch regularly at a size of 45 cm; the largest encountered was 80 cm.
3. Pacific hake females reach larger sizes than males.
4. The length-weight relationship for female Pacific hake was determined to be $W=0.0000115(L)^{3.06682}$, where W=weight in pounds and L=total length in cm.
5. Otoliths of Pacific hake are satisfactory for age determinations.
6. Hake were found all the way from the surf and estuarine waters to as deep as 491 fathoms.
7. The greatest concentrations vulnerable to the otter trawl fishery occur during the summer months. Few specimens are captured during the winter.
8. The large number of larval and juvenile hake makes them definite contributors to the food chain. Adult hake are also very efficient predators.
9. The animal food industry is the greatest user of hake at this time. Experimental work has been done on the use of hake as fish hatchery foods and as a source of Vitamin A.

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