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STATUS OF KNOWLEDGE OF THE PACIFIC HAKE RESOURCE

DAYTON L. ALVERSON
Base Director
Exploratory Fishing and Gear Research Base

and

HERBERT A. LARKINS
Chief, Groundfish Investigations
Biological Laboratory

Bureau of Commercial Fisheries
Seattle, Washington

INTRODUCTION

The Pacific hake (*Merluccius productus*) has been known to be relatively abundant in the northeastern Pacific Ocean since the early part of this century. It had long been considered a "trash" fish by U.S. and Canadian trawl fishermen, who commonly attempted to avoid catching it during their exploitation of more desirable species.

Except for studies in California on its eggs and larvae and on its life history, little scientific effort was expended on the Pacific hake before 1960. Especially lacking was information concerning total abundance, seasonal and depth distribution, and population dynamics. Interest in a commercial hake fishery was stimulated in the early 1960's by: (1) the development of an efficient pelagic trawling system, (2) an expanded world market for fish meal, and (3) approval of the highly publicized fish protein concentrate (FPC). At that time, the Bureau of Commercial Fisheries expanded its exploratory fishing and technological and biological research on this species. The U.S. coastal hake fishery began in 1966 but was hampered by decreasing prices for fish meal and the appearance off Washington and Oregon of a large Soviet hake fishing fleet.

GENERAL BIOLOGY

Pacific hake is often classified as a demersal species, but its distribution and behavior suggest a largely pelagic existence, although it is often found near the seabed over the continental shelf. It feeds almost exclusively on a variety of pelagic fishes and animal plankton; inhabits oceanic and neretic areas; grows relatively fast, especially during its first 4 years (Figure 1); and matures at the age of 3 or 4 years. Few individuals older than 9 years have been observed from unexploited stocks, and the maximum age is about 16 years. Mature hake on the average weigh about 2.68 pounds (1 kg) and are 20.5 inches (52 cm) long; maximum observed length has been about 33.5 inches (85 cm). The sharply descending right portion of age-frequency curves suggests rather high natural mortality, and comparisons of age composition of the catch in different years suggest variable year-class strength (Figure 2). The species is pelagic-spawning; fecundity ranges from about 80,000 to 500,000 eggs per female, depending on body size (MacGregor, 1966).

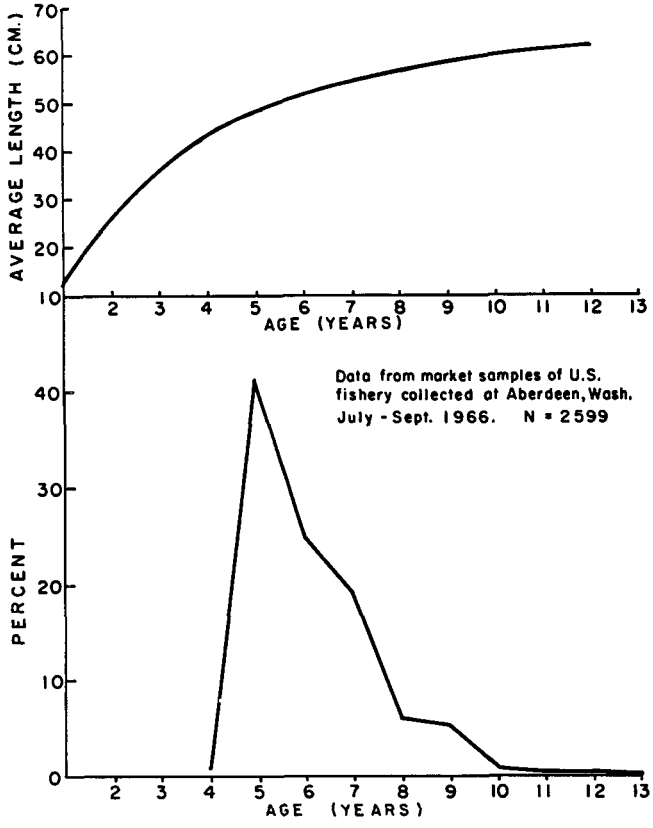

FIGURE 1. Relation between age and length (upper panel) and age composition (lower panel) of Pacific hake in 1966 commercial landings.

DISTRIBUTION

The Pacific hake has been reported from the Gulf of Alaska (Alverson, Pruter, and Ronholt, 1964) to the Gulf of California (Starks and Morris, 1907). Although this range represents the extreme zoogeographic distribution, large accumulations of this species appear to be limited to the coastal areas between Baja California, Mexico, and central Vancouver Island, British Columbia (Figure 3). Pacific hake have

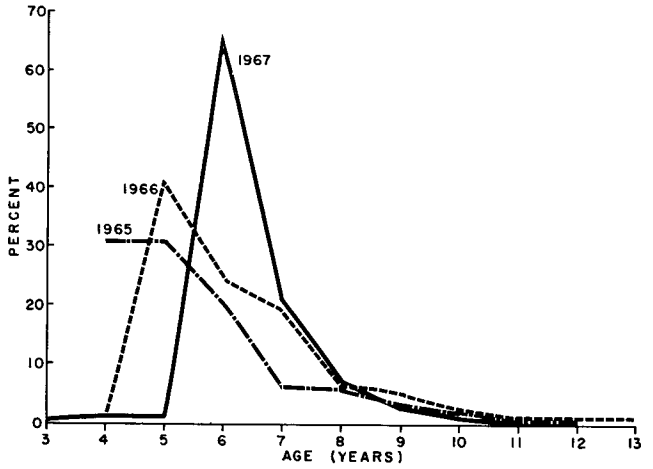

FIGURE 2. Comparison of age composition of Pacific hake in 1965–67 commercial landings showing annual progression of the dominant 1961 year-class.

been taken in bottom or mid-water trawls in waters from near the surface to at least 435 fathoms (800 m) deep (Clemens and Wilby, 1961), but are only occasionally taken at depths exceeding 328 fathoms (600 m). Commercial concentrations of Pacific hake have been found at depths between 27 and 273 fathoms (50 and 500 m). The mature or adult population is normally confined to waters overlying the continental slope and shelf except during the spawning season when hake may be found several hundred km seaward in the southern part of the range.

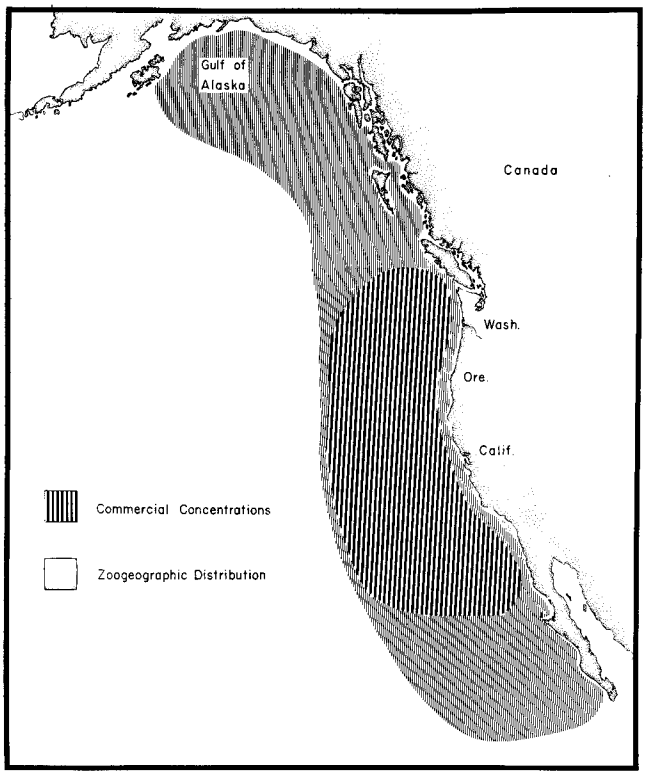

FIGURE 3. Zoogeographic distribution of Pacific hake showing area of commercial concentrations.

Investigations by the U.S. Bureau of Commercial Fisheries and Soviet scientists indicate that the adult portion of the coastal stock occupies the northern portion of the range (northern California, Oregon, Washington, and British Columbia) during the spring, summer, and fall and the southern portion (southern California and Baja California) during the winter. The availability of Pacific hake to bottom and mid-water trawls off Oregon, Washington, and Vancouver Island drops sharply in November and is practically nil in the winter. During late April and May, hake again become available in the northern part of the range, and abundance increases sharply during the early spring. The adult stock remains in the northern areas until late fall.

In the waters adjacent to southern California and Baja California, large quantities of spawning hake have been taken offshore during the winter by the research vessel *John N. Cobb*. The mature stock is concentrated during spawning in the deeper portion of its bathymetric range (100 to 275 fathoms, 200 to 500 m); for the remainder of the year (May through November), it is concentrated in waters overlying the continental shelf at depths less than 109 fathoms (200 m).

The work of Ahlstrom and Counts (1955) provides the best usable data on the general bathymetric distribution of hake eggs and larvae, and hence the distribution of spawning adult stocks. Eggs and larvae

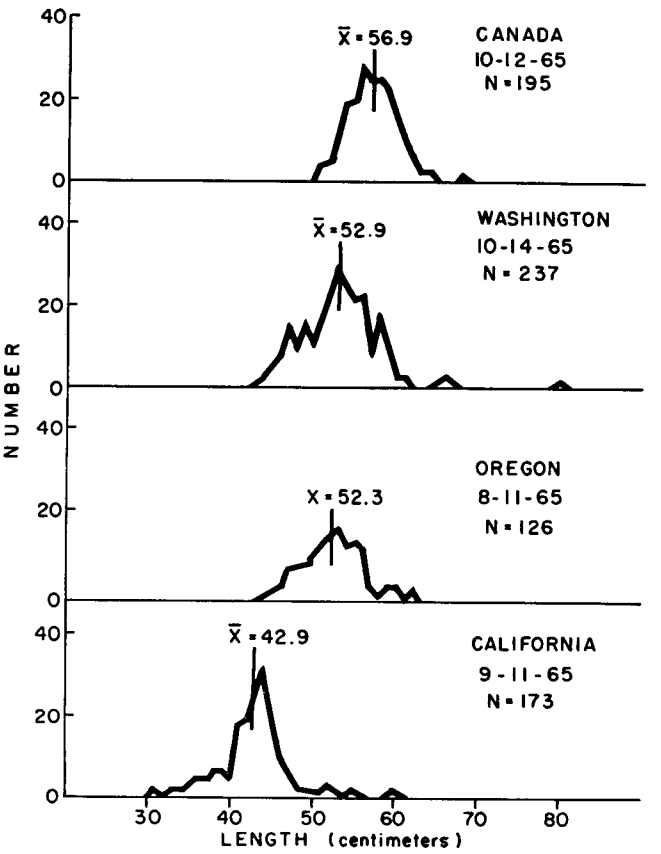

FIGURE 4. Length composition of Pacific hake in 1965 research vessel catches by coastal area showing north-south size cline.

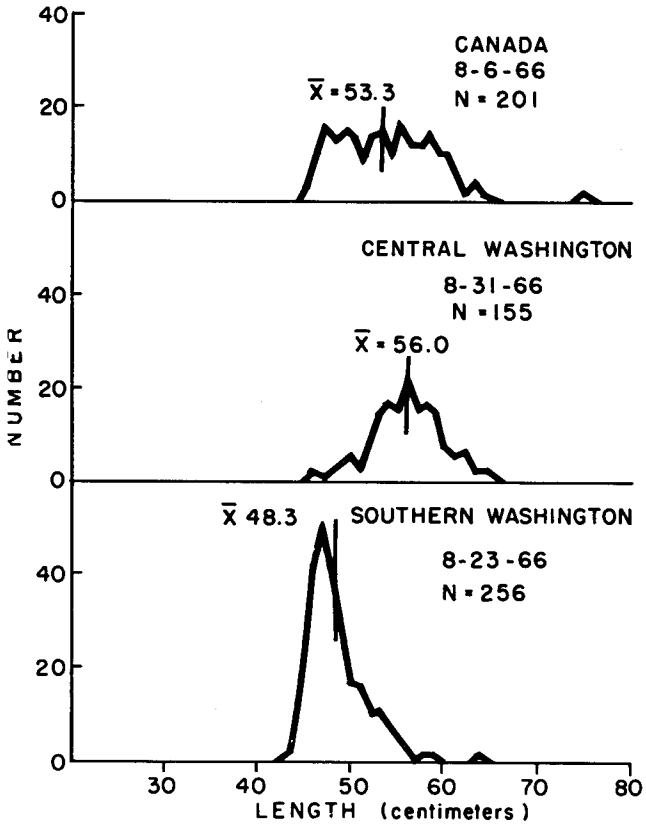

FIGURE 5. Length composition of Pacific hake in 1966 commercial landings from northern area showing irregularity in north-south size cline.

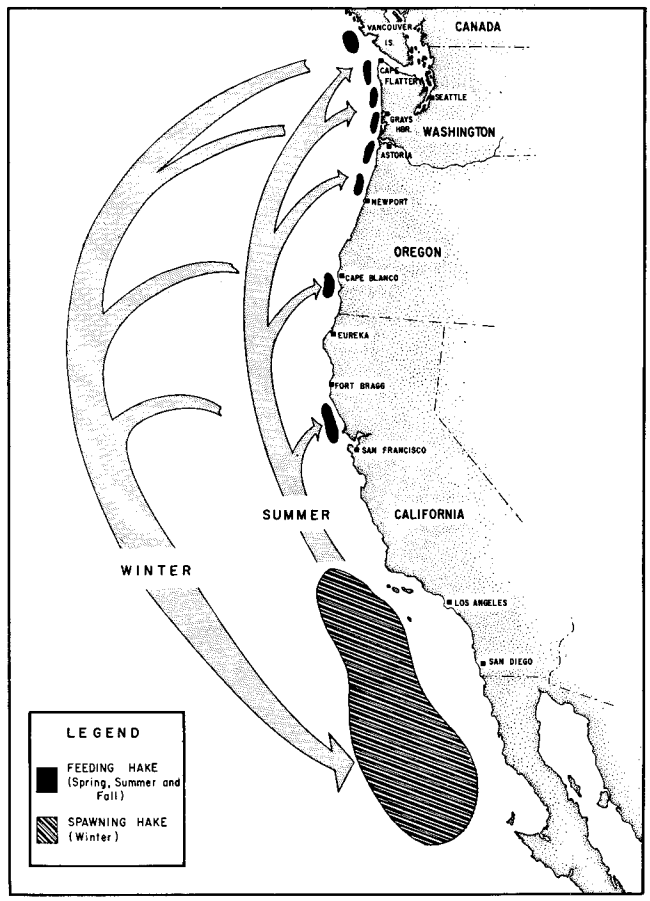

FIGURE 6. Seasonal migrations and distribution of Pacific hake.

of the Pacific hake are abundant off the coast of southern California and Baja California during the late winter and spring (February through April). Concentrations are greatest between Santa Barbara, California and central Baja California, but annual variations in distribution are substantial. Eggs and larvae have been encountered in relatively large numbers several hundred km seaward, but concentrations are generally highest within 199 miles (320 km) of the coast. Large-scale sampling of plankton by the Bureau of Commercial Fisheries in April 1967 revealed no hake eggs or larvae between northern Vancouver Island and the California-Oregon border, offshore to 298 miles (480 km). Except for local, resident stocks in Puget Sound and perhaps other inshore areas, the entire coastal hake population apparently spawns off southern California and Baja California.

Catches of Pacific hake during exploratory fishing surveys between Vancouver Island, British Columbia, and Baja California have suggested that during the summer the average length (and presumably age) of hake decreases from north to south (Figure 4). This size gradient, however, is often non-existent or even reversed within smaller areas (Figure 5). This difference in average length appears to be associated with increased availability of juveniles in the southern portion of the range and an almost complete absence of juveniles off Washington and British Columbia.

Investigations of the seasonal and annual distribution and abundance of Pacific hake allow us to propose the following hypotheses concerning hake migrations:

1) Within the geographic range occupied by Pacific hake, the adult segment of the population exhibits a large-scale north-south movement.
2) The movement is to the north during the spring and summer and to the south during the late fall and winter (Figure 6).
3) The northward migration of adults is accompanied by movement towards shore and into shallower water (Figure 7).
4) The southward migration is accompanied by movement into deeper water and seaward.
5) Spawning occurs during the winter when the species occupies the southern portion of its geographic range.
6) The young live in the waters over the continental shelf but apparently do not make the large-scale migrations demonstrated for the adult portion of the stock, although 1- and 2-year-olds have been collected as far north as central Oregon.

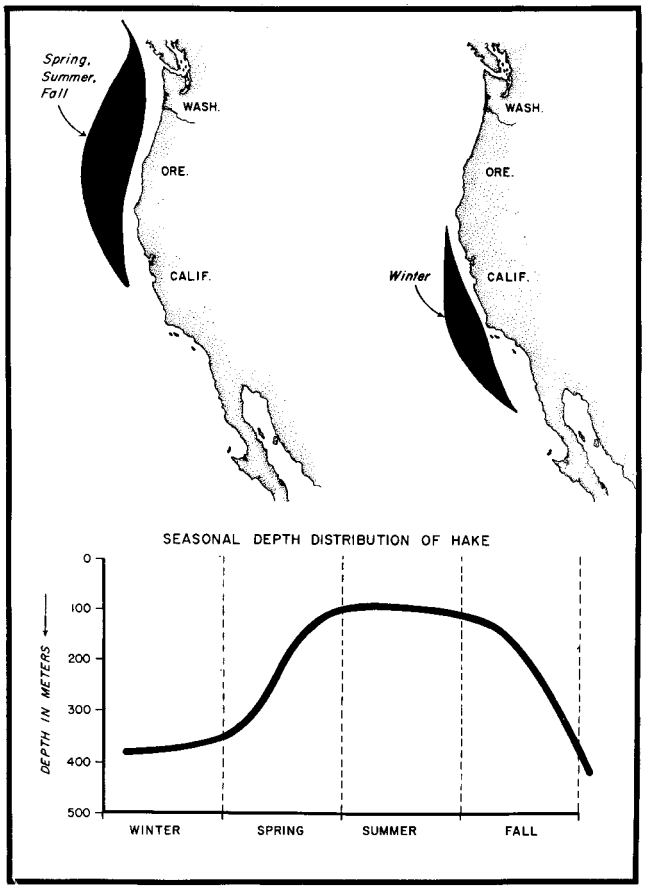

FIGURE 7. Seasonal depth distribution of Pacific hake related to geographic area.

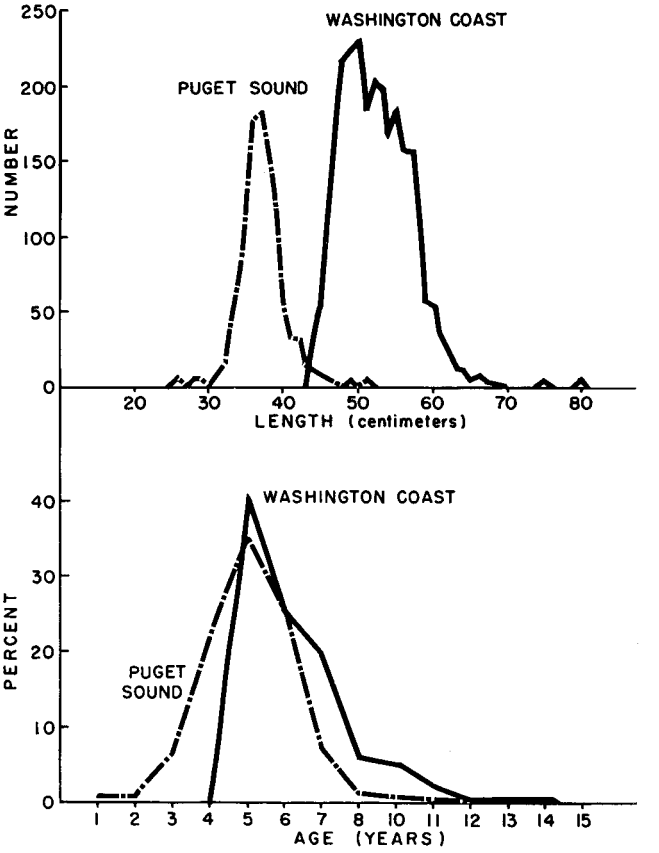

FIGURE 8. Length-frequency distributions (upper panel) and percentage frequency distributions of ages (lower panel) in 1966 commercial landings of Pacific hake from coastal Washington and Puget Sound.

SIZE OF MATURE STOCK

The size of the standing stock of Pacific hake that inhabits the waters off Oregon and Washington during summer (based on sonic surveys and test fishing) has been estimated at 609.5 thousand short tons (455 million kg) by U.S. biologists and near 1,206 thousand short tons (900 million kg) by Soviet fishery scientists. The estimated sustainable yield at these population levels ranges from about 174 thousand to 349 thousand short tons (130 million to 260 million kg) annually. The Pacific hake resource off California, estimated to be in the order of 3.6 million tons (2.7 billion kg), is reported to be second in size only to the northern anchovy (*Engraulis mordax*) in the California current system.

STOCK COMPONENTS

Available data are insufficient to indicate whether or not segments of the coastal Pacific hake population are isolated genetically. The apparent migration pattern and the distribution of eggs and larvae suggest one large homogeneous offshore population. This indication, however, does not preclude the possibility that after spawning, segments of the adult stock colonize specific regions of the continental shelf. Evidence is good that Pacific hake from the inside waters of Puget Sound, and perhaps the Strait of Georgia, are a separate stock or population from those in coastal waters (Figure 8). Not only are the spawning grounds widely separated, but the growth rate of the Puget Sound stock is substantially lower than that of the offshore population. Enough Pacific hake are present in Puget Sound during the winter to support a yield of 6 thousand tons (4.5 million kg) per year.

GENERAL BEHAVIOR

During the period that the mature stock inhabits the water overlying the continental shelf and slope, Pacific hake form schools which may be characterized as long, narrow bands (Nelson, 1967). The axes of these schools are usually oriented parallel to the isobath with the exception of the schools near the continental break (about 98 fathoms, 180 m, depth). At times these schools lie normal to the depth contours and extend in an offshore direction. In such instances the inner portion of the school is closer to the seabed than the outer portion. That is, the school maintains approximately the same depth in the water column regardless of the depth of the water.

The length of the schools may vary from several hundred yards (meters) to 11.8 miles (19 km). Usually the schools range from 0.16 to 1.99 miles ($\frac{1}{4}$ to 3.2 km) wide, but a width as great as 7.96 miles (12.8

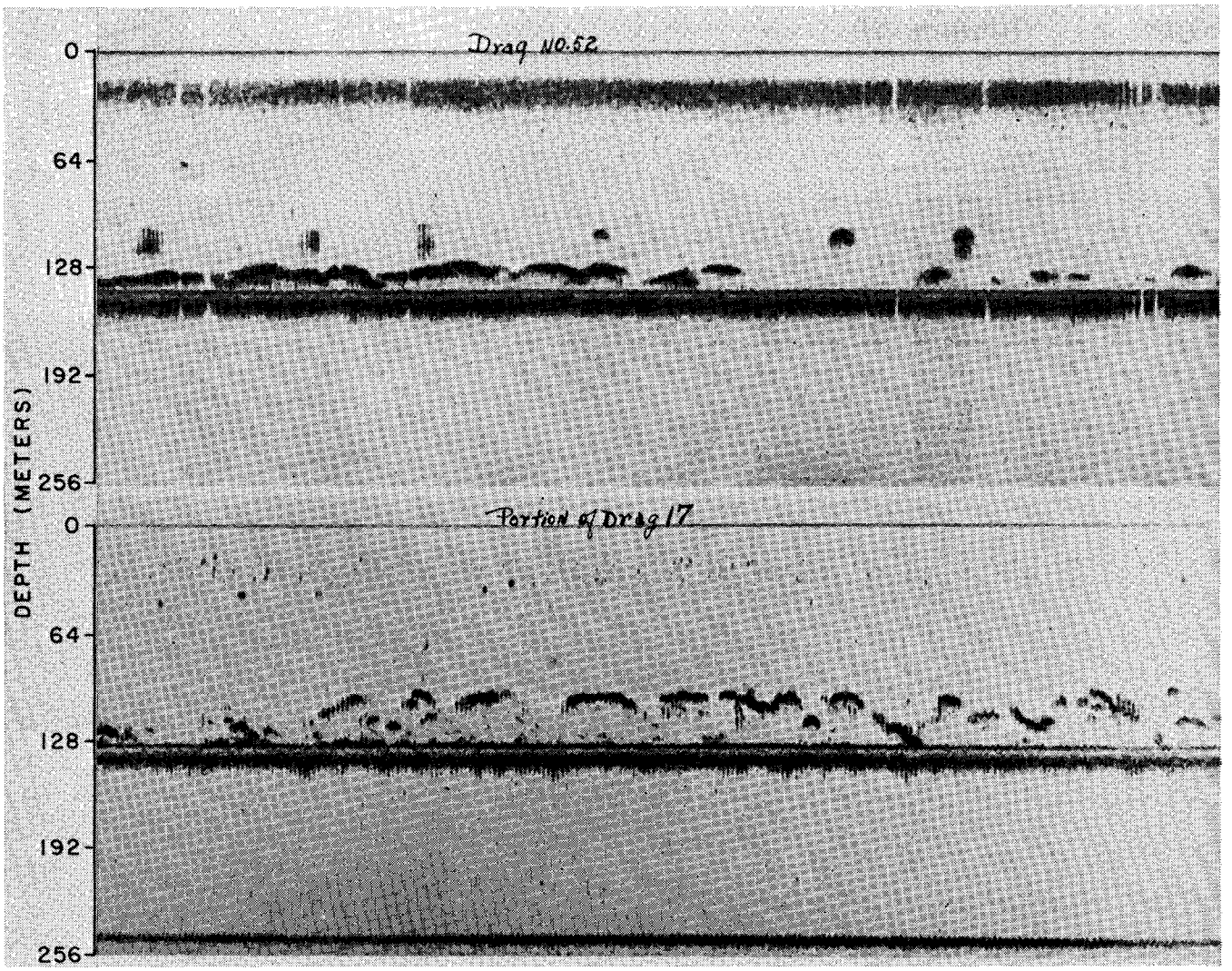

FIGURE 9. Echogram showing Pacific hake at various depths off the bottom.

km) has been recorded. In a vertical plane most of the schools are from 3.28 to 10.9 fathoms (6 to 20 m) thick. During daylight the schools lie just off the seabed; at times the bottom of the school is in contact with the seabed. When the schools lie off the bottom, the lower portion of the school can range from 1.1 to 10.9 fathoms (2 to 20 m) above the ocean floor. The distance above the seabed varies during each day and within the season. Most of these schools form on the continental shelf at depths between 19 and 109 fathoms (35 and 200 m); the greatest number of schools or concentrations encountered during exploratory cruises were at depths between 27.3 and 82 fathoms (50 and 150 m). The schools may persist for several days or disperse within several hours after they have been detected only to regroup several hours later.

In the vertical plane during daylight, the schools seem to be confined to a relatively narrow bathymetric zone, all within the same general depth strata. Density of the schools ranges from nearly constant to highly variable—or schools may be composed of a series of clusters or patches throughout (Figure 9). We have no evidence, however, that the hake form vertical feather-like schools such as those observed for herring-like fishes.

During the summer when the adult population is distributed over the continental shelf, the schools characteristically rise and disperse in the water column during the evening—a tendency that has been confirmed by acoustical studies and experimental fishing. Echo-sounding studies suggest that movement begins between 1800 and 2100 hours, and that by 2300 the schools have lost their integrity. Data from experimental fishing imply a general scattering of the fish throughout the water column during darkness. By dawn the fish descend and begin to regroup in schools near the seabed, in the same general region where they were detected the previous day but not necessarily in the exact area.

Observations of hake spawning in Port Susan, Puget Sound, suggest the presence of one large contin-

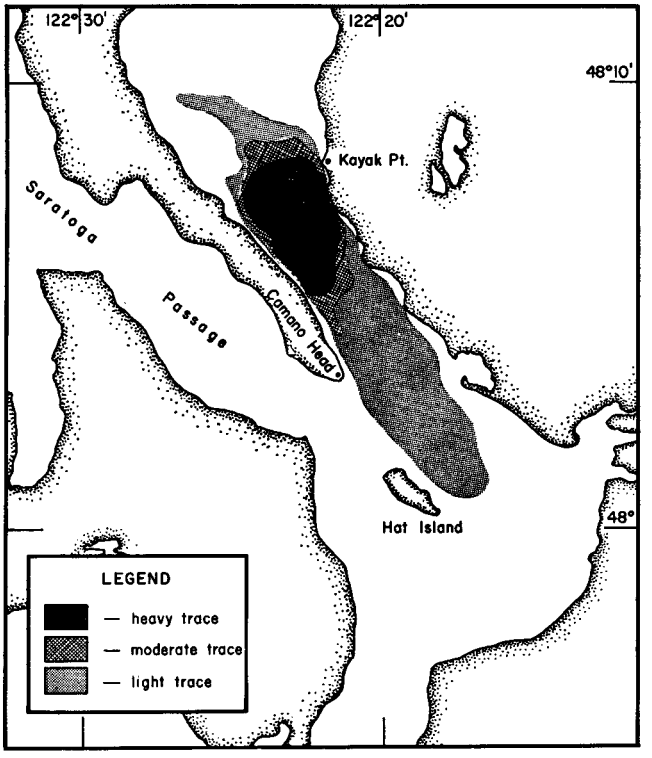

FIGURE 10. Distribution of Pacific hake in Port Susan, Puget Sound, during the spawning season.

uous body of ripening or spawning fish that increases in density toward the center of the spawning area (Figure 10). These schools may be as thick as 40 m in the vertical plane. The population of adult hake off California in winter appears to congregate in several schools of uniform density, but density did not appear to be as high as in Puget Sound.

Although spawning schools of Pacific hake in Puget Sound tend to become more scattered as darkness approaches, pronounced vertical dispersal has not been observed. Similarly, surveys off southern California indicate that spawning hake do not engage in the kind of vertical movement observed on the continental shelf. Although there is apparently some movement of nearly ripe fish, most of this diel migration occurs at depths of 98.4 to 218.6 fathoms (180 to 400 m) over bottom depths of, at times, greater than 1,092.9 fathoms (2,000 m); no fish appear to migrate above the thermocline.

The diel movement of Pacific hake, the depths at which schools are found off the bottom, and the relative compactness and size of schools are complex, interrelated phenomena that significantly affect the conduct and success of fishing. Knowing the reasons for these behavior patterns is perhaps not as important to fishing success as knowing where and when they occur; in a predictive sense, however, knowing *why* they occur should be of value in planning fishing operations. Alton and Nelson (in press) stated the de-

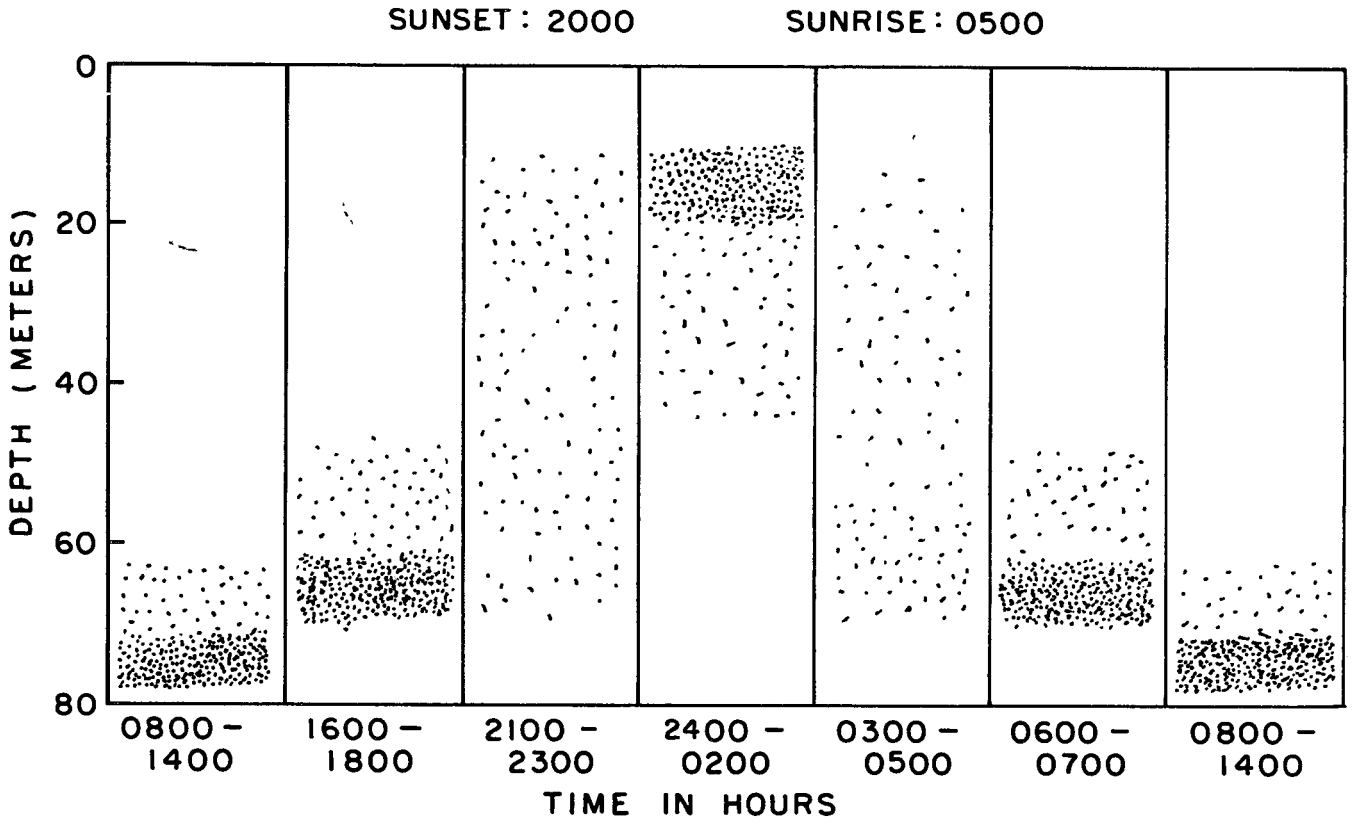

FIGURE 11. Diagram showing diel movement of the euphasiid *(Thysanoessa spinifera)* off the Washington coast.

gree to which hake are congregated or in schools during the day, and indicated that their dispersal at night relates to the feeding habits of the species. In the northern portion of their geographic range, adult hake appear to feed extensively on two species of euphausiids, *Thysanoessa spinifera* and *Euphausia pacifica*. High catch rates by commercial vessels appear to be supported largely by hake that feed almost exclusively on euphausiids; catch rates are lower when the diet of the hake is varied (Alton and Nelson, in press).

On the continental shelf *Thysanoessa spinifera* has been the dominant euphausiid in stomach samples of Pacific hake taken off the Oregon-Washington coast. The diel vertical distribution and migration of this species have demonstrated that hake are near the seabed during daylight, migrate toward the surface during the early part of the night, concentrate near the surface between 2400 and 0200 hours, and migrate toward the bottom at dawn (Figure 11). The timing of the diel migration of the euphausiid is similar to that of Pacific hake (Figure 12) and suggests that the daily migration and schooling of hake may be largely influenced by the distribution and abundance of its food.

DESIGN OF FISHING RATIONALE

Analysis of biological samples collected off Oregon, Washington, and British Columbia from 1964 through 1967 indicates that growth is rapid in juveniles but approaches an asymptote within 1 or 2 years after maturity; natural mortality of the adults appears to be at least 40% annually and perhaps is much higher. Only mature fish are available in the summer range from northern Oregon to British Columbia. If these preliminary findings are substantiated, it would seem that high yields could be sustained by applying a rather high rate of exploitation on the standing stocks off the Pacific Northwest during summer. This rationale provides almost complete protection for the fast growing juvenile segment of the population that also represents a substantial spawning potential for the near future.

This same argument might also be used to justify a commercial fishery on the spawning stocks off California during winter, but two serious reservations are involved. First, although many millions of fish would be in the general spawning area, the location and size of individual schools have been highly variable and not conducive to high harvest efficiency. Second is

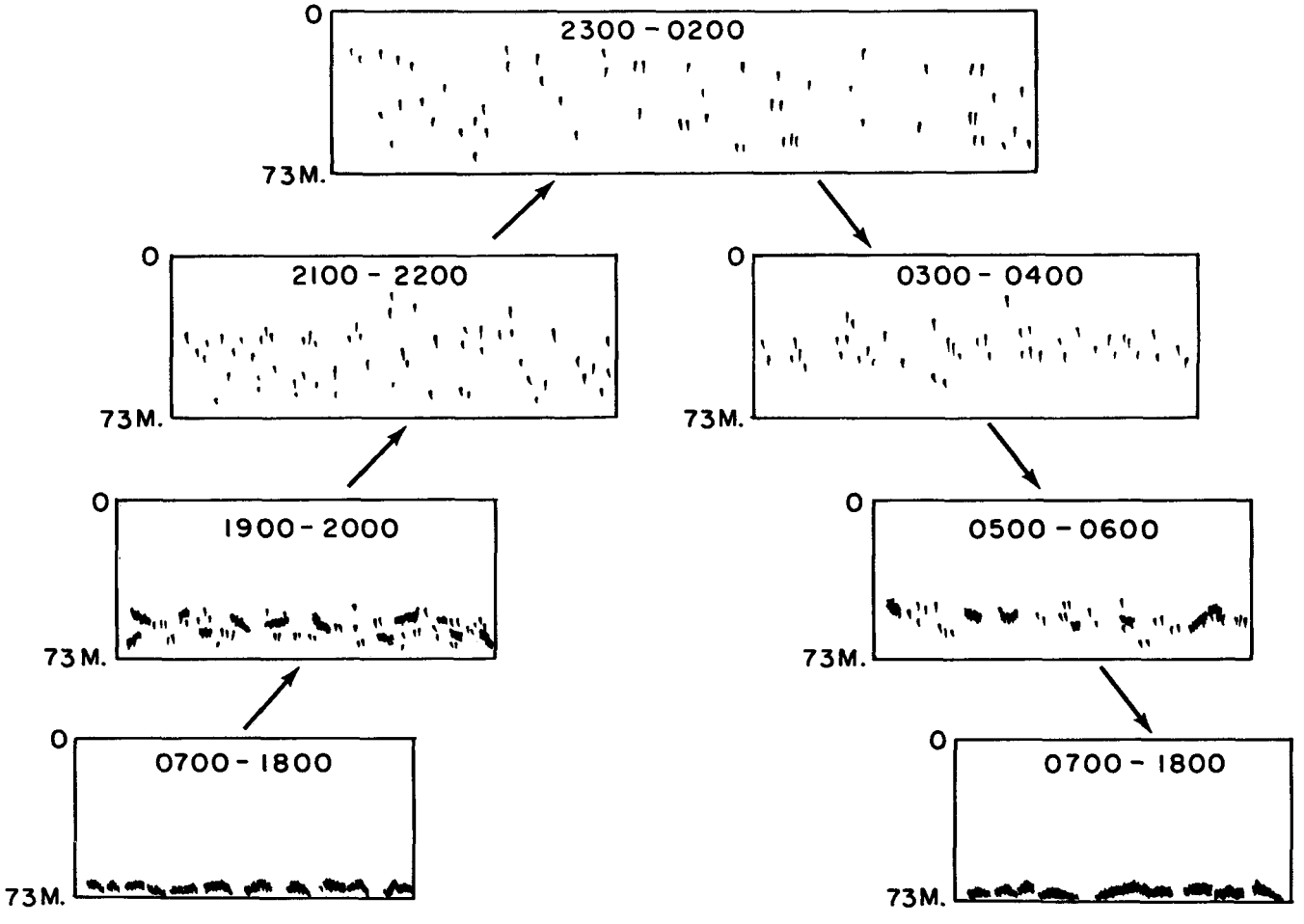

FIGURE 12. Diagram showing diel movement of Pacific hake off the Washington coast.

the possible effect of an intense fishery on the spawning behavior of hake. During the heavy concentration of Soviet fishing off Washington in 1966, it became difficult to detect schools of hake with acoustic gear; some fish were being caught by the Soviet vessels, but the normal concentrations had apparently been dispersed. Should this happen to the spawning schools there could be a resultant decrease in spawning success through a reduction in the density of eggs and sperm.

If extreme variations in year-class strength do occur they will affect the management and efficient harvest of the hake resource because the bulk of available fish are typically in only one or two age groups. When a weak year class reaches the age that would normally dominate the total catch, the catch per unit of effort might be seriously reduced. On the other hand when an unusually strong year class is recruited, high natural mortality would prevent it from supporting the fishery at a high level for more than 1 or 2 years. Therefore, a system of indexing the relative abundance of juvenile hake 1 or 2 years before their recruitment to the fishery should be beneficial to the managers for setting quotas, to the industry for allocating their fishing and processing efforts among the other fisheries, and to the resource itself by preventing over-fishing when the population is weak.

Although the concerted research on the Pacific hake in the past few years has provided the information required by industry to establish a fishery, a considerable amount of knowledge must still be gained before a coast-wide, international management scheme can be developed.

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