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Distribution, Growth and Behavior of the Spotted Hake in the Chesapeake Bight

Charles A. Barans

College of William and Mary - Virginia Institute of Marine Science

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DISTRIBUTION, GROWTH AND BEHAVIOR OF THE SPOTTED HAKE
IN THE CHESAPEAKE BIGHT

A Thesis
Presented to
The Faculty of the School of Marine Science
The College of William and Mary in Virginia

In Partial Fulfillment
Of the Requirements for the Degree of
Master of Arts

By
Charles A. Barans
1969
This thesis is submitted in partial fulfillment of the requirements for the degree of Master of Arts

Charles A. Barans

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Spotted hake, *Urophycis regius*, were collected in the York River estuary and the Chesapeake Bight during groundfish surveys between January, 1966 and July, 1968.

Hake are present in the York River estuary between March and June. They were not in the estuary when the bottom water temperature at the mouth of the Bay was less than 6.5°C or greater than 25.0°C. Hake were not found in salinities less than 7% and were caught only at progressively higher salinities as the upriver water temperature increased above 18°C. In April fish upriver were larger than those downriver.

Although hake are widely distributed over the shelf in summer and primarily offshore in winter, they are usually most abundant in waters of 10-12°C; they are seldom in waters of less than 6°C. In spring, the population splits into an inshore, juvenile group and an offshore, adult group. In fall, fish in the north are significantly larger than those in the south.

Hake spawn in the Chesapeake Bight, primarily, in October. During this month the gonads of hake in the north are more fully developed than those of individuals from the south. Analyses of scales and length-frequency distributions indicate that hake attain about 200 mm in their first year. Females grow faster and reach a larger size than males. Equations were developed to express the length-weight relationships and growth curves.

At the laboratory, juvenile adult hake buried themselves in sand and remained buried for long periods. Individuals less than 135 mm long curved their bodies about objects in their tanks. Hake extended their pelvic fins anteriorly when searching the bottom for food. Crustaceans are the most important items in the hake diet. Both pelagic and epibenthic organisms are consumed.
DISTRIBUTION, GROWTH AND BEHAVIOR OF THE SPOTTED HAKE

IN THE CHESAPEAKE BIGHT
INTRODUCTION

The spotted hake, *Urophycis regius* (Walbaum), is a demersal fish that inhabits the shelf waters along the Atlantic and Gulf coasts from Nova Scotia (Hildebrand and Schroeder, 1928) to Brownsville, Texas (Springer and Bullis, 1956). Although the small size and soft body of the spotted hake have limited its use as a food fish, this and other unexploited demersal species may in the future be used in the manufacture of fish protein concentrate (FPC).

The literature contains little on the biology of the hake. Although seasonal distribution (Struhsaker, 1969) and spawning season (Hildebrand and Cable, 1938) have been briefly described for spotted hake in Atlantic waters south of Cape Hatteras, they have not been determined for hake north of the Cape. Estimates of growth (Hildebrand and Schroeder, 1928; Hildebrand and Cable, 1938) disagree greatly. Two reports (McAllister, 1960; Bigelow and Schroeder, 1953) include some information on the behavior of juvenile *U. tenuis* and *U. chuss*, but there is no comparable information on the behavior of young *U. regius*. Spotted hake have been thought to feed primarily on fish (Bigelow and Welsh, 1925) or primarily on crustaceans (Hildebrand and Schroeder, 1928).

The objectives of the present study are: 1) to determine the seasonal distribution of spotted hake in the York River estuary and the Chesapeake Bight; 2) to ascertain the spawning season and growth rates; 3) to describe hiding and feeding behavior as observed in the laboratory; and 4) to determine food habits.
METHODS

Spotted hake were collected during a series of monthly trawl tows in the York River and Chesapeake Bay from January, 1966, to July, 1968. Trawl stations were spaced at 5 or 10 mile intervals from the mouth of the Bay to the head of the York River (Fig. 1). At each station, a 30-foot semi-balloon trawl, with 1\(\frac{1}{2}\)-inch stretch mesh, was towed for 15 minutes at a vessel speed of 2\(\frac{1}{2}\) knots. Hake from each station were counted and measured to the nearest mm. All length measurements in this report refer to total length. Temperature and salinity of the bottom water were recorded for each station.

Information on hake distribution in the Chesapeake Bight was gathered during 1966, 1967 and the winter of 1967-68. The term Chesapeake Bight (Norcross and Harrison, 1967) in this study refers to the oceanic region over the continental shelf between the latitudes 38° 47' N (Cape Henlopen, Delaware) and 35° 15' N (Cape Hatteras, North Carolina). Trawl tows were made each season at stations between Cape Henlopen and Cape Hatteras to a depth of 150 fathoms by the side trawler R/V Sea Breeze. At each station the trawl was towed at approximately 3 knots for one-half hour (1966) or one hour (1967-68), a bathythermograph cast was made and a sample of the bottom water was taken for salinity analysis. During 1966 the sampling gear was a 45-foot semi-balloon trawl with 1\(\frac{1}{2}\)-inch stretch mesh and a 3/4-inch stretch mesh codend liner; during 1967-68 the sampling gear was an Atlantic Western trawl with 78-foot footrope, 54-foot headrope, 8-inch stretch mesh in the body and 4-inch stretch mesh in the codend.
Figure 1. Trawl stations in the York River and Chesapeake Bay.
An index of relative abundance was calculated to determine seasonal shifts in concentrations of hake. The sampling distribution of the numbers of individuals per tow was assumed to conform to the negative binomial distribution (Taylor, 1953), because hake appeared contagiously distributed over the shelf. Data were normalized by the logarithmic transformation

\[ Y = \log_e (x + 1) \]

where \( x \) is the number of hake caught per mile towed at each station. Data from 4 consecutive seasons (spring 1967 - winter 1967-68) were stratified by depth and latitude or temperature and latitude. The mean of the transformed values for each stratum was the index of relative abundance. Computations were made by an IBM 1130 computer.

Large numbers of small hake were caught at several stations during fall and winter. Data on these juveniles were analyzed separately from data on adults.

Distribution patterns were plotted from data collected during eight consecutive seasons (spring 1966 through winter 1967-68). Seasonal isotherms were constructed from bottom temperatures recorded at each station and represent the general condition during the sampling period.

In October, 1967 and March, 1968 hake were collected between Cape Cod and Cape Hatteras during groundfish surveys sponsored by the U. S. Fish and Wildlife Service Bureau of Commercial Fisheries (BCF) Biological Laboratory at Woods Hole, Massachusetts. The October survey was a joint American-Russian effort. The American stern trawler R/V Albatross IV used a No. 36 Yankee otter trawl, and the Soviet side trawler R/V Albatros used a 27.1 meter herring trawl. All trawl tows were \( \frac{1}{2} \) hour in duration. Fish were measured to the nearest cm. The March survey was conducted only by the R/V Albatross IV.

Data on maturity of spotted hake in the Chesapeake Bight were collected
during cruises conducted by the Virginia Institute of Marine Science (VIMS) in 1966 and 1967. In November 1966, notes were made on the presence of running ripe females in catches. In 1967, ovaries from several collections of hake were weighed to the nearest gram. The state of gonad development was determined for male and female hake caught between 35-41° N latitudes during the October, 1968, groundfish survey conducted by the BCF at Woods Hole. Information on the state of gonad development was grouped by the latitude at which the corresponding samples of fish were collected. Groups consisted of data from hake collected between 35° 00' - 35° 59' N, 36° 00' - 36° 59' N, etc. Few hake were collected between 39° 00' N and 40° 59' N, so data from these fish were combined.

Data from hake caught during 1966 were used in growth analysis, since the 45-foot semi-balloon trawl with a ½-inch stretch mesh codend liner was considered a less selective gear than the Atlantic Western trawl with 4-inch stretch mesh in the codend. Samples of fish were randomly chosen for measurement. Lengths were measured to the nearest mm. Length-frequency distributions by sex were assembled from selected collections of the VIMS 1967 and 1968 offshore surveys and monthly York River surveys.

Scales were taken from 83 specimens caught at 38° 21' N latitude in August, 1967 and 142 specimens caught between 40° 03' N and 35° 58' N in October, 1968. Although an attempt was made to take scales from a point just below the first dorsal fin, this was not always possible because many hake lost a large number of their scales during capture. Scales (8 to 12 from each fish) were mounted between glass slides and viewed with a 45x dissecting microscope.

For behavioral observations, approximately 125 spotted hake were collected by otter trawl at Station Y00 on April 8, 1968. At the laboratory fish were placed in 50 X 60 X 80 cm polyethylene containers
and shallow wet tables approximately 14 X 87 X 300 cm. After 14 days at room temperatures which daily fluctuated between 16 and 19 C, the hake were transferred to wet tables where the water temperature was 16 C. At the time of transfer the 15 surviving fish ranged in length from 107 to 180 mm. The high initial mortality may have resulted from handling, crowding or thermal shock at the time of capture. Four hake lived for more than 70 days. Hake readily ate small pieces of herring (approximately 1 cm$^3$) which were kept frozen until just before feeding. The number of feeding periods was reduced from three each day to one every two days because of the decrease in acceptance of food during successive feedings.

Stomach contents of approximately 600 fish were examined to estimate the most important food items in the hake diet. Stomachs were obtained from fresh or preserved specimens collected during spring, summer, fall and winter 1966 and 1967. Specimens were classified by depth and location of capture as offshore (60-83 fathoms), inshore (7-20 fathoms), and estuarine (within Chesapeake Bay and York River). Recurring food items were identified to species and their importance was estimated by considering relative abundance and size (length) of each kind.
DISTRIBUTION

YORK RIVER ESTUARY

Each spring juvenile spotted hake enter the lower Chesapeake Bay and adjacent river system from offshore. Hildebrand and Schroeder (1928) and Hildebrand and Cable (1938) reported the seasonal appearance of U. regius in Chesapeake Bay and Beaufort Inlet respectively, but the period of residence and extent of penetration have not been described.

Although spotted hake were caught at the mouth of the bay in almost every month during 1967, the major period of residency in the York River was March-June (Fig. 2). The total number of hake caught at all stations in the estuary during each month was used as an estimate of relative abundance for that month. The largest monthly catch during 1966-68 was in April, 1968 when 314 were caught at seven stations from the mouth of the Bay to Y25. The annual maximum abundance occurred during April or May. The annual maximum extent of upriver movement, determined by presence or absence of hake from upriver stations, generally occurred during April and May. In 1967 and 1968 spotted hake were collected at station Y25, 25 miles above the mouth of the York River. In 1966 seven hake were caught at station P30 approximately 5 miles above Y25. Although some hake may move beyond this point, the greatest number was usually caught 5 to 10 miles downriver from the station of maximum penetration.

Several possible sources of error must be kept in mind when interpreting data from the mid-channel trawl tows. Although hake were probably more abundant and extended further upriver in the more saline
Figure 2. The distribution and relative abundance of spotted hake in the York River estuary (data from 15 minute trawl tows).
1966

MARCH

APRIL

MAY

JUNE

JULY

1967

1968

NONE

STATIONS
deep areas of the estuary than in the shallow areas, no data are available on the relative abundance of hake alongshore. The trawl sampled approximately the same bottom area in both the open bay and narrow river. If hake are concentrated in the progressively narrowing channel of the river, an increase in relative abundance at upriver stations may be a reflection of increased population density.

Hake were distributed over a wide range of bottom water temperatures and salinities in the estuary. The relationship between hake abundance and the temperature and salinity (T-S) at each station is shown in Figure 3. Histograms represent the proportion of the monthly hake catch at each of the corresponding T-S values. This method of presentation shows the movement of spotted hake into cool water of low salinity and their withdrawal with increasing temperature.

Spotted hake did not enter the estuary when the bottom water temperature at the mouth of the Bay was less than 6.5°C. Although hake were collected at upriver stations during March of 1966 and 1967, when the water temperature at COO was above 6.5°C, no hake were caught in March, 1968, when the bottom temperature at COO was only 6.2°C. Hake were found throughout their spring range of distribution in April, 1968 very shortly after the limiting temperature was exceeded.

Although temperature at COO seems to limit entrance into the estuary, temperature and salinity together appear to limit upriver movement and cause withdrawal. The lowest salinity at which hake were collected was 7%. Maximum penetration occurred during all three years at bottom temperatures between 9 and 18°C. Hake withdrew from low salinity waters each year before the bottom temperature at the mouth of the Bay reached 25°C. The highest temperature at which hake were taken was 24.8°C at station COO in August, 1967.
Figure 3. Monthly distribution of spotted hake in the York River estuary in relation to the temperature and salinity of the bottom waters.
Spotted hake do not enter the estuary each fall when upriver water temperatures are similar to those found in the spring. This may be explained by a behavioral change with age or a physiological change which decreases their tolerance of low salinities. The fact that hake over 225 mm in length are sometimes present at COO in the spring but seldom penetrate into low salinity waters tends to support the second explanation.

The single mode in length distributions of hake from the York River estuary suggests that hake were of a single year class (Fig. 4). Each length-frequency histogram represents either the entire monthly catch between the mouth of the Bay and fresh water or the sum of all individuals from catches of less than 25 hake and a subsample of 25 individuals from catches of over 25 hake. Growth of hake in the Estuary is discussed later.

Hildebrand and Cable (1938) noted that spotted hake in the Newport River were of greater length than those at the entrance of Beaufort Inlet. A similar situation existed in the York River estuary in April, 1968. Graphic analysis of the mean lengths of hake from each station revealed a progressive increase in length upriver, with the exceptions of station Y25 at which a single 100 mm hake was caught and stations Y10 and Y15 which had equal mean values (Fig. 5). An analysis of variance and a multiple range test (Duncan, 1957) showed a significant difference at the 1% level between mean lengths of fish caught in the Bay and lower river and the mean lengths of hake from the middle and upper river stations. The mean lengths of hake from lower and middle river stations were significantly different at the 1% level from those from both the Bay and the upper river station Y20. This overlap of station groupings indicates a regular progression of mean length upriver during April. Only in 1968 were catches large enough to make statistical analysis practicable.

No hake were collected at river stations in February or March of 1968.
Figure 4. Monthly length-frequency distribution of spotted hake from the York River estuary.
Figure 5. The means, interval estimates and ranges of the total lengths of spotted hake from the York River estuary in April, 1968. Numbers represent sample sizes; vertical lines represent ranges in length; horizontal lines represent mean lengths; rectangles represent the confidence interval ($\bar{x} \pm t_{.05} S_x$).
By May, only a remnant of the differential distribution was evident. Although the mean length of hake from station Y00 was significantly smaller than those from the other stations (CO0, Y10, Y15, Y20), there was no significant difference between mean lengths of hake from CO0 and Y00. In June, there was no significant difference between mean lengths of hake from the Bay stations (CO0 and C10) and the lower river station (Y00).

Movement of large hake (>100 mm) upriver followed by continued entry of small individuals (<100 mm) into the estuary may have caused the progressive upriver increase in mean length during April. By May, the larger fish may have returned downstream after they advanced to a point determined by their physiological tolerance.

CHESAPEAKE BIGHT

The spatial distribution of spotted hake in the Chesapeake Bight follows definite seasonal patterns. In spring, the hake population was split into an inshore group along the coast and an offshore group along the edge of the shelf. This pattern formed a V with the apex at approximately 36° N latitude; hake were absent from the area between the two groups (Figs. 6 and 7). In summer, hake were widely distributed from near shore to the edge of the shelf, except for a small central area north of 37° N. In fall, they were either spread over the entire shelf or intermediate between their summer and winter distributions. By later winter, hake were primarily distributed along the edge of the shelf.

The bathymetric distribution of spotted hake also varied with season. In spring 1967, hake were concentrated in shallow and deep waters north of 37° N (Fig. 8), with fewer fish at intermediate depths (11-60 fathoms). South of 37° N, large concentrations were between 41 and 150 fathoms. In summer, few hake were caught in the 21-40 fathom interval north of 37° N, and none were caught within the deepest interval (91-150 fathoms). South of 37° N, hake population density increased sharply with increasing depths;
Figure 6. Seasonal distribution of spotted hake in the Chesapeake Bight. Spring: May, 1966; summer: August-September, 1966; fall: November, 1966; winter: February-early April, 1967.
Figure 7. Seasonal distribution of spotted hake in the Chesapeake Bight. Spring: May-June, 1967; summer: August-September, 1967; fall: November-December, 1967; winter: January-February, 1968.
Figure 8. Distribution of spotted hake in the Chesapeake Bight stratified by season, depth and latitude, with index of abundance representing the mean number of fish (in natural logarithms) caught per mile towed in each stratum.
waters of 91 to 150 fathoms were not sampled. During fall 1967, hake were distributed over the entire depth range (5-150 fathoms) in the north and south. In winter, hake were concentrated primarily between 40-150 fathoms north and south of 37° N, with few or none at depths less than 40 fathoms. Although some may have been at depths greater than those sampled, hake have not been reported from waters deeper than 200 fathoms (Schroeder, 1955; Edwards, Livingstone and Hamer, 1961).

Although hake were found in bottom waters of almost every temperature present over the shelf, they were repeatedly concentrated in waters of 10-12°C (Fig. 9). Spotted hake south of Cape Hatteras have a seasonal distribution that differs from that displayed by hake north of the Cape, but they also appear to prefer bottom water temperatures of approximately 10°C. In winter, they move from deep (60-100 fathoms) lower shelf waters, with annual bottom water temperatures from 10.5 to 13.9°C, into shallow (to 10 fathoms) coastal waters, with a winter low temperature of 10°C (Struhsaker, 1969).

Adult hake were seldom caught in bottom waters of less than 6°C. Avoidance of cold waters was most clearly evident in winter when hake were absent from nearshore waters (5-20 fathoms) where bottom temperatures were less than 6°C, but were abundant along the shelf edge where bottom temperatures were seldom less than 10°C. During spring 1967, no hake were caught at stations within a tongue of cold bottom water (less than 6°C) which extended southward to 37° N between warmer nearshore and offshore bottom waters. In summer, hake north of 37° N were abundant in the depth intervals sampled, except in the interval (21-40 fathoms) occupied by the persistent cold water. By fall, vertical mixing had obliterated the cold water tongue and hake were distributed across the entire shelf.

Spotted hake may move southward as they migrate offshore and northward
Figure 9. Distribution of spotted hake in the Chesapeake Bight stratified by season, temperature and latitude, with index of abundance representing the mean number of fish (in natural logarithms) caught per mile towed in each stratum.
as they migrate onshore. The decrease in abundance north of $37^\circ$ N from fall to spring (Figs. 8 and 9) suggests that hake in the north during summer and fall move south in winter. Although there is no evidence, it is possible that part of the population moves south of Cape Hatteras. The magnitude of this southerly movement may be determined by the southern extent of bottom temperatures less than 6$^\circ$C. In spring, hake appear to move north in two groups, one nearshore and another along the continental slope. Perhaps movement from deeper waters onto the shelf occurs progressively later in the north, thereby giving the appearance of movement from south to north.

Hake that appeared to move north in spring were of three size groups. In March, 1968, those nearshore (13 to 20 fathoms) between $36^\circ$ and $37^\circ$ N latitude were from 6 to 11 cm in mean length. Hake collected at two stations in deeper water (62 and 83 fathoms) at approximately $36^\circ$ N were of intermediate mean lengths (24 and 25 cm). A few large hake (28-30 cm) were collected between $36^\circ$ 32' N and $39^\circ$ 32' N at depths ranging from 25 to 150 fathoms. No hake were caught at nearshore stations above $37^\circ$ N latitude nor offshore above $39^\circ$ 32' N latitude.

Although the small (6-15 cm) hake are large enough to swim actively, their movement may be slightly directed shoreward by the bottom drift, which moves onshore during all seasons (Norcross and Stanley, 1967). After reaching the mouth of the Chesapeake Bay, some individuals may then be directed upriver by the inward-moving estuarine currents, as has been suggested for other small fish (Wallace, 1940).

The larger hake (28-30 cm) were probably 2-3 year old fish that overwintered offshore, while the small individuals moving along the coast were spawned the previous fall and overwintered nearshore south of $37^\circ$ N. In October, 1967, hake were differentially distributed by size.
Lengths of hake collected between Cape Cod and Cape Hatteras increased with both increasing latitude and depth. Since hake may have started to move between summer and winter distributions in October, the slight increase in mean lengths with depth was disregarded. There was a significant difference at the 1% level between mean lengths at each latitude (Fig. 10). The difference in mean lengths between hake caught at 40° N and 36° N was approximately 8.5 cm, which represents one or more years growth in older individuals.
Figure 10. The means, interval estimates and ranges of total lengths of spotted hake collected between 36-41°N latitudes in October, 1967, stratified by latitudes. Numbers represent sample sizes; vertical lines represent ranges in length; horizontal lines represent mean lengths; rectangles represent the confidence interval ($\bar{x} \pm t_{.05} S_x$).
SPAWNING

Hake spawn in the Chesapeake Bight, primarily during October. In early October, 1967, running ripe females were caught at 40° 13' N, while further south hake were near spawning condition but not running ripe. In October, 1968, the proportion of hake with gonads in the spawning condition increased with increasing latitude, a condition more pronounced in males than females (Fig. 11). The proportion of hake with developing gonads remained relatively constant in females, but decreased with increasing latitudes in males. Variability in the ratio of spent to unspent fish probably resulted from the difficulty in distinguishing between developing and partly spent gonads, especially in males. The proportion of immature hake generally decreased with increased latitude.

In late August, 1967, when many hake were in a developing or near spawning condition, ovaries of 40 females from 38° 40' N latitude ranged from 1 to 65 g ($\bar{X} = 17.8$g) in wet weight. Ovary weight increased ($r=0.668$) with increasing fish length (Fig. 12). Seventeen hake (42.5%) with ovary weights greater than 5% but less than 10% of their total body weight were considered developing; 13 hake (32.5%) with ovary weights greater than 10% of their total body weight were considered near spawning.

Two large females (385 and 350 mm) may have been partly spent. Their ovaries weighed 41g and 35g respectively, while a small female (339 mm) had ovaries of 65g.

By late November most hake were spent. On November 16, 1967, 23 females were collected at 38° 45' N, 73° 34' W. Sixteen (69.6%) were considered spent (Fig. 12). Their ovaries ranged from 1 to 6g wet weight.
Figure 11. Latitudinal differences in development of gonads of spotted hake.
Figure 12. Ovary weights of spotted hake from the Chesapeake Bight in August and November, 1967.
Ovaries of the remaining 7 (30.4%), considered partly spent, ranged from 6 to 11g. The average ovary weight (6.5g) was much less than the August average of 17.8g.

On November 11, 1966, several running ripe females were caught at 35° 57' N latitude 74° 52' W longitude. Fourteen days later, large numbers of small (x TL = 45 mm) hake were collected further to the north (36° 51' N). These juveniles were probably the product of spawning that took place about 2 months earlier (late September). The largest part of the same year class may have been present in the plankton and unavailable to the sampling gear. The ripe females were probably remnants of a larger group that had spawned earlier the same season.

Although the majority of spotted hake probably spawns before November, some fish may continue to spawn through the month of March. Massmann et al. (1961, 1962) reported that U. regius larvae were in surface waters off Chesapeake Bay from September to April. A 7 mm larva was collected as early as mid-September, 1961, and a 17 mm larva as late as April, 1963 (Dr. E. B. Joseph, personal communication).

If the planktonic stage lasts approximately 2 months, it is possible for the larvae to be transported in the southerly surface drift, (Norcross and Stanley, 1967) from 38-40° N to 35-36° N latitudes before they develop benthic habits. Large numbers of small hake were caught near shore between 35 and 36° N in winter and early spring. Apparently, the northerly movement of juveniles each spring starts from this area.
AGE DETERMINATION

Scale samples were taken from 225 hake collected in August, 1967 and October, 1968; scales from 193 fish were readable. The relationship between scale radius and body length was not calculated because scales, taken from several locations on the fish, differed in shape.

Several facts support the validity of scale marks as annuli. The average lengths of hake of given age groups were similar to modes in length-frequencies. The number of scale marks increased with the length of the fish and was usually 1 less than the number of rings in cleared otoliths from fish of similar lengths.

An annulus is characterized by a sharp change in direction (toward the scale edge) and closer spacing of many circuli (Figs. 13 and 14). The closely spaced circuli appear as concentric rings about the focus. In several scales newly formed circuli cut across older circuli at the annulus. Most scales were difficult to interpret.

The annulus probably is formed during late February or early March. During these months the bottom waters of the northern Chesapeake Bight are the coldest (Bigelow, 1933). The absence of annuli at the edge of scales from hake caught in October indicates that hake were in or at the end of a growing period.

The majority of scales lacked annuli representing the first winter, which occurs only several months after most hake are spawned. Scales without an annulus were from hake approximately 1 year old; these hake were considered age group I. Scales with one annulus represented hake of
Figure 13. Scale of female spotted hake (TL=355mm). Arrows mark annuli.
Figure 14. Scale of female spotted hake (TL=312mm). Arrows mark seldom formed inner annulus (inside), second annulus and false annulus (outside).
age group II. Otoliths had a first winter annulus, therefore the number of annuli in otoliths was one greater than in scales of the same fish.

The results of age determinations from scales (Tables 1, 2 and 3) are consistent with results from length-frequency analysis (p. 33). The mean lengths of fish of each age group are reported in cm, although lengths of fish caught in October were recorded in mm. There is little overlap in length ranges of fish between age groups. The largest female (362 mm) was 3 years old and the largest male (261 mm), 2 years old.

GROWTH ANALYSIS

Analysis of information derived from scales indicates that spotted hake grow rapidly. The mean lengths of age group I males (17.3 cm) and females (20.2 cm) from south of 37° N were considered to represent the average first years growth (p. 37). Although length at the end of the first year is comparable to that reported by Bigelow and Schroeder (1953) for U. chuss (200 mm), this length represents a greater proportion of the spotted hake's maximum length. Female spotted hake reach approximately half of their maximum length during the first year; males reach more than half of their maximum length during the first year.

Females grow faster and live longer than males. In October, the difference between mean lengths of age group I males and females was 4.2 cm in hake collected north of 37° N and 2.9 cm in hake collected south of 37° N. The difference between mean lengths of age group II males and females was 6.1 in the north; the sample of hake from south of 37° N contained only one age group II female (28 cm). No age group III males or females were collected south of 37° N.

Hake of both sexes appear to grow more rapidly in northern than in southern latitudes. Age group I males from north of 37° N averaged 3.9 cm longer than males from south of 37° N. The difference between age
### TABLE 1
Mean lengths (cm) of spotted hake by age group and sex.
Hake were collected north of 37°N in August, 1967.

<table>
<thead>
<tr>
<th>Age group</th>
<th>FEMALES</th>
<th>MALES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
<td>II</td>
</tr>
<tr>
<td>Number of fish</td>
<td>10</td>
<td>17</td>
</tr>
<tr>
<td>Mean length</td>
<td>22.3</td>
<td>31.3</td>
</tr>
<tr>
<td>Range in length</td>
<td>19-24</td>
<td>27-34</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>13.35</td>
<td>6.36</td>
</tr>
<tr>
<td>Standard error</td>
<td>4.22</td>
<td>3.97</td>
</tr>
<tr>
<td>Yearly increment</td>
<td>22.3</td>
<td>9.0</td>
</tr>
</tbody>
</table>

### TABLE 2
Mean lengths (cm) of spotted hake by age group and sex.
Hake were collected north of 37°N in October, 1968.

<table>
<thead>
<tr>
<th>Age group</th>
<th>FEMALES</th>
<th>MALES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
<td>II</td>
</tr>
<tr>
<td>Number of fish</td>
<td>18</td>
<td>14</td>
</tr>
<tr>
<td>Mean length</td>
<td>25.4</td>
<td>31.1</td>
</tr>
<tr>
<td>Range in length</td>
<td>21-28</td>
<td>29-34</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>1.76</td>
<td>1.80</td>
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<tr>
<td>Standard error</td>
<td>0.42</td>
<td>0.48</td>
</tr>
<tr>
<td>Yearly increment</td>
<td>25.4</td>
<td>5.7</td>
</tr>
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</table>

### TABLE 3
Mean lengths (cm) of spotted hake by age group and sex.
Hake were collected south of 37°N in October, 1968.

<table>
<thead>
<tr>
<th>Age group</th>
<th>FEMALES</th>
<th>MALES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
<td>II</td>
</tr>
<tr>
<td>Number of fish</td>
<td>19</td>
<td>1</td>
</tr>
<tr>
<td>Mean length</td>
<td>20.2</td>
<td>28.0</td>
</tr>
<tr>
<td>Range in length</td>
<td>18-23</td>
<td>28</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>1.58</td>
<td>1.00</td>
</tr>
<tr>
<td>Standard error</td>
<td>0.36</td>
<td>7.8</td>
</tr>
</tbody>
</table>
group I females from the north and those from the south was 5.2 cm. The large individuals of age group I in the north had little effect on the mean length of that year class, as is shown later, because of the great numbers of smaller individuals in the south.

It is possible that hake (210-250 mm) from north of 37° N were not of the same age group as the smaller (200 mm) individuals from the south. A great difference in growth pattern must exist between hake spawned in fall and those spawned in winter or early spring. In fall optimum growth conditions probably exist in the surface waters of the Chesapeake Bight. During winter and early spring, plankton populations in the surface waters are probably quite poor. Although the larger northern hake may represent age group II, no intermediate age group was recognized in length-frequency analyses.

LENGTH-FREQUENCY ANALYSIS

The length-frequency distributions of hake in the York River estuary (Fig. 4) suggest that hake were all of age group I. In April, the modal lengths of fish entering the estuary ranged from 100 to 135 mm. The modal lengths of hake in June ranged from 185 to 200 mm. Estimates of growth during residency are confused by recruitment of smaller fish during April and May. Growth increments were calculated from the mean lengths of fish in monthly catches. The greatest increase in mean length was 76 mm during the April-June residency in 1968. The smallest increase was 62 mm during March-June, 1966.

Seasonal length-frequency distributions of fish from the Chesapeake Bight are presented in Figure 15. During the winter (January through March) 1966, the first mode of hake caught south of 37° N was at 95 mm. This mode represents larger individuals of age group I, which was not completely available to the sampling gear. The following season (May),
Figure 15. Seasonal length-frequency distributions of spotted hake in the Chesapeake Bight north and south of 37°N latitude.
the first mode was at 105 mm; in August and September, there was a well
defined first mode at 170 mm. By November this mode, representing fish
just over one year old, was at 205 mm and for the first time a mode
occurred at 45 mm. This mode represented only the largest individuals
of the new year class. The progressive change in modal length suggests
a mean growth increment of approximately 200 mm during the first year.
The period of most rapid growth was between May and November. These
estimates are based on the assumption that the shift with time in the
first mode in a series of length-frequency distributions from a single
population of fish represents a progressive increase in mean length of the
age group.

The first mode in the length-frequency distribution of hake caught in
October, 1967 (similar to the 1966 mode) represents age group I, because
no hake less than 15 cm in length were caught at any station in the Mid-
Atlantic Bight, Chesapeake Bay or York River system in October. All areas
were sampled with gear that had collected much smaller individuals during
other periods of the year. The peak in length-frequencies at 20 cm
represents mean growth of the spotted hake in their first year.

The other modes of the seasonal length distributions are not easily
interpreted. The amount of overlap and the differential rate of growth
between sexes makes following them through successive seasons impossible.
Growth of preceding year classes can be estimated by analyzing one large
sample that adequately represents the population. The October, 1967
length-frequency distribution (Fig. 16,a) represents 8532 hake collected
throughout the Mid-Atlantic Bight. The modes at approximately 32, 35 and
40 cm probably represent additional age groups. The modes at 24 and 27 cm
may be a product of sampling error and overlap in lengths of age group II
males and large age group I females. In the March distribution (Fig. 16,b)
Figure 16. Length-frequency distributions of spotted hake collected between Cape Cod and Cape Hatteras.

a) 8532 hake from October, 1967.

b) 126 hake from March, 1968.
the skewed shape of the first curve, with a mode at 7 cm, indicates that the trawl was catching only larger individuals of age group I.

North of 37° N, hake of age group I were larger at the end of each season than those in the south. At the end of the first year of growth the mean length was slightly less than 250 mm in the north and approximately 200 mm in the south. Hake south of 37° N were considered more representative of the population, because they were more numerous during all seasons. In October, 84.4% of the sample from the Mid-Atlantic Bight was caught south of 37° N. In March, 1968, 79.4% of the total catch and all the hake less than 23 cm in length was caught south of 37° N.

There was a difference between the total number of hake caught in fall and spring. In October, 1967, the total catch by the Albatross IV in the Mid-Atlantic Bight was 1449 spotted hake; the total catch in March, 1968, was 126, 11.5% of the October catch. Surveys used the same gear and made approximately the same number of trawl stations.

A series of monthly length-frequencies (May-November, 1967) showed that females grow faster than males. Similar results were gained from the scale based age-growth analysis. The divergence of the modal lengths of females and of males occurred at a length of about 180 mm in June. In September (approximately one year after the year class was spawned), there was a 50 mm separation between the modal lengths of males and females collected in the north and 25 mm between those from the south. Although samples from August and November contained large females of other age groups, the first peaks in their length distributions clearly show the differences between modal lengths of males and females of age group I.

LENGTH-WEIGHT RELATIONSHIP

Length-weight relationships are based on 683 male, 910 female and 133 spotted hake of undetermined sex caught in the Mid-Atlantic Bight and York
River estuary between May, 1967, and February, 1968. Measurements were made to the nearest mm and g. The length-weight relationships were calculated by an IBM 1130 computer using the least squares method, where both variables were converted to common logarithms.

Data from males and females were analyzed separately because of the large difference in maximum lengths. There was no difference between modal lengths of males and females smaller than 180 mm (p. 37). The fish of undetermined sex ranged in length from 60 to 145 mm, so these lengths were added to the data of both males and females before analysis. The length-weight relationships were expressed by the equations:

males: \( \log W = -5.225 + \log L \times 3.066 \)

females: \( \log W = -5.208 + \log L \times 3.063 \),

where \( W \) is the weight in grams and \( L \) is the total length in millimeters. Although there was a significant difference at the 5% level between the two regressions, the graphs appear to coincide (Fig. 17).

GROWTH EQUATIONS

Equations which described growth were obtained with an analog computer. A growth curve was graphically fitted to ages and average lengths that had been determined from scales (Ricker, 1958). Maximum lengths were estimated from the literature (Bigelow and Welsh, 1925; Hildebrand and Schroeder, 1928).

The growth curves (Fig. 18) which best fitted available length data were represented by the equations:

males: \( L_t = 300 \left(1 - e^{-0.96t}\right) \)

females: \( L_t = 407 \left(1 - e^{-0.72t}\right) \),

where \( L \) is total length in millimeters and \( t \) is time in years. The equations which best represented growth in weight were:
Figure 17. The relationship between length and weight of male and female spotted hake from the Chesapeake Bight.
Figure 18. Growth curves of male and female spotted hake.
FEMALES
$L_t = 407(1 - e^{-0.72t})$

MALES
$L_t = 300(1 - e^{-0.96t})$
males: \( W_t = 229 \left(1 - e^{-0.96t}\right) \)

females: \( W_t = 526 \left(1 - e^{-0.73t}\right) \),

where \( W \) is weight in grams and \( t \) is time in years.
HIDING BEHAVIOR

Hake display behavior patterns which appear to have survival value in an environment that offers little protective cover. They become less conspicuous by burying themselves in the substrate and hiding in or near objects on the bottom.

To test the spotted hake's ability to burrow and to determine if a substrate preference exists, containers of beach sand and others of soft mud were placed into tanks containing hake. In preliminary experiments glass bowls were used. Each bowl was 180 mm in diameter and contained approximately 70 mm of sand or mud. All behavioral experiments were carried out in the polyethylene containers and wet tables. Observations were made from a distance of one meter or more from the edge of the container. Except in one experiment, hake were kept in constant dim light in which activities were clearly visible.

Small hake (107 and 135 mm) were repeatedly found buried in the sand. Larger hake (140-180 mm) did not burrow in the bowls of sand, but buried themselves in larger containers (3x 35x58 cm) of both sand and 5 mm gravel. Mud was chosen only once. After hake had been in captivity for about two weeks, they remained buried in the sand for long periods each day. To burrow, hake turned on their sides and rapidly undulated their bodies against the sand (Fig. 19, a-d). Sand covered all but their eyes and snouts within approximately three seconds. Any disturbance in or near the tanks caused the hake to bury completely for a short time. The
Figure 19. Captive spotted hake.

a-d) Hake (TL=109mm) burying itself in sand.

e-f) Hake (TL=135mm) hiding near oyster shell.
posterior portion of the hake's body (beneath the sand) was curved with the concave side upward toward the sand surface. Buried hake prodded with a glass rod retained this body curvature until lifted free of the sand by the rod. When completely exposed, they swam rapidly away.

In October, 1968, I observed five large spotted hake (approximately 250 mm) in the Bureau of Commercial Fisheries' aquarium at Woods Hole, Massachusetts. The fish had been in captivity for about two months and appeared to be well accustomed to their large viewing tank. After short intervals of slowly swimming about the sides and bottom of the tank, each hake returned to the gravel bottom and buried itself in the depression that it had occupied earlier. Buried fish were on their sides with their bodies slightly arched. Their caudal fins and sides were partly covered with gravel. The head and anterior part of the body were elevated above the bottom at a slight angle. This curved position was maintained even when buried hake were approached or touched by other swimming individuals.

Although McAllister (1960) observed young white hake (less than 100 mm) partly concealed in the sandy bottom off Prince Edward Island, Canada, no one has reported that adult white or red hake bury themselves. Bardach and Case (1965) kept several red hake for over two months, but they did not report that the hake buried. However, they reported that captive searobins, Prionotus sp., dug into the substrate.

Juvenile white hake and spotted hake bury themselves, but only spotted hake appear to have retained this protective behavior in adult life. Adult spotted hake in captivity spend much of their time buried in the bottom.

Juvenile U. chuss are commonly found within the shells of live sea scallops, Pecten magellanicus; after they become too large to fit inside the scallop shell, they hide near the scallops (Bigelow and Schroeder,
Red hake also hide around *Spisula* shells and other objects on the bottom (Wicklund, 1966 and Edwards and Emery, 1968). Neither white hake (Musick, MS, 1969) nor spotted hake have been found in scallop shells.

In the laboratory, two small hake (107 and 135 mm) hid about objects placed in their tanks. When the tank or water were disturbed, the small hake curved their bodies around the circumference of an oyster shell (95 mm in diameter) or attempted to bury near or under the shell in the manner described earlier (Fig. 19, e-f). The larger hake flattened their bodies against the side or bottom of the tank, but never approached the shell.

Both small hake also hid in and near a piece of 100 mm plastic pipe (35 mm in diameter). When both shell and pipe were present, hake at first abandoned the shell for the pipe, but later were wrapped around the shell more frequently. Larger hake (140-180 mm) did not approach the shell, pipe, or other objects placed in their tanks. Although adult spotted hake hide around shells on the continental shelf, Edwards and Emery (1968) reported that spotted hake appeared to be associated with objects on the bottom less frequently than red hake. In the laboratory only individuals less than 135 mm curled about objects.

In the sandy environment of the continental shelf, the ability to hide in the substrate or around objects may afford as much protection as either speed or large size. This behavior may also be of value to adult spotted hake as a means of protective cover during periods of inactivity.

**FEEDING BEHAVIOR**

The distinct searching and feeding behavior patterns of spotted hake suggest that *U. regius* possess chemoreceptive pelvic fins similar to those of *U. tenuis* (Herrick, 1904) and *U. chuss* (Bardach and Case, 1965).
Hake searched for food along the tank bottom with their biramous pelvic fins extended forward and downward so that the tips touched the bottom on both sides in front of the head. The anterior portion of the body oscillated slowly from side to side as the fish swam. When either extended pelvic fin contacted a piece of food, the hake would rapidly turn its head and snap in the direction of the food. At this time both pelvic fins appeared to move slightly forward and together. Frequently swimming speed, although slow, caused a hake to miss food that it had sensed with its fins. The hake would then turn sharply in the direction of the food and make a slower pass over the area with its pelvic fins again in "testing" position. Sudden movements or noises near the tanks caused the fish to cease feeding and swim rapidly.

Spotted hake responded positively only to newly introduced food. Hake either passed over or quickly turned away from any food item that had been on the bottom for more than five minutes.

Hake did not feed readily on live Sparionentes in the laboratory. When touched by a searching pelvic fin, the shrimp would make a fast escape movement which, unless in the direction of the hake's mouth, caused the hake to miss it. Many shrimp remained alive in tanks with hake for a period of two months.

Although chemical stimulation of the pelvic fin tips causes a snapping response, which is independent of vision, Herrick (1904) and Bardach and Case (1965) concluded that U. tenuis and U. chuss find and recognize food by sight. The pelvic fins test a food item's "palatability" rather than locate a distant scent source. If captive hake saw food fall through the water, they would follow it to the bottom and "test" it with a pelvic fin before engulfing the item. With the exception of two small individuals which quickly learned to take food from my hand at the surface,
the hake fed on the bottom. Visually directed feeding suggests that hake feed primarily during daylight periods. Edwards and Emery (1968) observed hake searching for food on the bottom during the day; this is also the period during which many organisms which migrate vertically are lowest in the water column. A snapping response may have some value in feeding on the bottom at night.

Hake often swam without searching for food. During this activity the pelvic fins trailed close to the body and dorsal and ventral fins were compressed along the body. Unlike searching, which was done at a reduced speed, this swimming was faster and sometimes very rapid. When swimming along the bottom hake passed several millimeters above food without responding to it. The dorsal and ventral fins were extended when hake were turning, swimming along the sides of the tank, or swimming through the water column. These swimming activities were usually of short duration and were followed by a return to the bottom.

Spotted hake appear specialized morphologically for a relatively inactive life near the bottom. Hake possess a subterminal mouth, a barbel and chemoreceptive pelvic fins. The sensory capabilities of the pelvic fins are restricted to a very nearby chemical stimulus (Bardach and Case, 1965). These characters suggest that hake feed more efficiently on the bottom than in the water column. Spotted hake have well developed air bladders, which are characteristic of fish not capable of rapid vertical migration (Harden Jones, 1957). The passive nature of spotted hake was reported by Edwards and Emery (1968); one hake became caught in the submarine's bumper and remained there for an extended period without attempting to free itself.

Although hake behavior and morphology indicate that hake are restricted to feeding on the bottom, evidence that spotted hake do not
migrate vertically must await comparison of day and night bottom trawl catches or analysis of mid-water trawl catches.
FOOD HABITS

Crustaceans were the most important food items in the diets of hake from the three areas studied. Hake also consumed squid, polychaetes, other invertebrates and fishes. The types and relative importance of food items varied with season and location.

In hake collected offshore (60-83 fathoms) during spring, stomachs contained Sergestes arcticus, Munida iris and Cancer sp. (Table 4). Three unusually large Spisula sp. (?) (125 mm) were found in one stomach. These were of interest because shells were lacking. During the summer and fall, the most common organism was M. iris. Also, in fall many hake stomachs contained Loligo sp. Myctophids were common in stomachs of specimens collected during both fall and winter. In winter, S. arcticus was the most important organism.

Spotted hake from shallow coastal waters (7-20 fathoms) contained the widest variety of food items. S. arcticus was the most abundant organism found in the stomachs of hake collected in spring. In summer both S. arcticus and Crangon septemspinosa were important food items. In fall, Cancer sp. and amphipods increased in importance before hake moved offshore.

Juvenile hake from the Chesapeake Bay and York River fed primarily on Neomysis americana in spring and Crangon septemspinosa in early summer. Hildebrand and Schroeder (1928) also reported that crustaceans were the most important food items in specimens from Chesapeake Bay.

Although the spotted hake diet consists of epibenthic organisms
Table 4. Organisms found in spotted hake stomachs in order of decreasing importance.

**OFFSHORE** (specimens collected from 60 to 83 fathoms)

<table>
<thead>
<tr>
<th>Season</th>
<th>Organisms</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td>Sergestes arcticus* (adults, 60-78 mm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Munida iris (adults, 62-70 mm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cancer sp. (10-20 mm)</td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td>Munida iris (adults)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cancer sp. (35-60 mm)</td>
<td></td>
</tr>
<tr>
<td>Fall</td>
<td>Munida iris (adults, 62-70 mm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lantern fish (60-70 mm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Loligo sp. (at times all stomachs extended with squid)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Amphipods (most were Monoculodes edwardsi, 5 mm)</td>
<td></td>
</tr>
<tr>
<td>Winter</td>
<td>Sergestes arcticus* (juvenile, 35-45 mm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cancer sp. (10-15 mm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lantern fish (pos. Nyctophum affine, 75-90 mm)</td>
<td></td>
</tr>
</tbody>
</table>

**INSHORE** (specimens collected from 7 to 20 fathoms)

<table>
<thead>
<tr>
<th>Season</th>
<th>Organisms</th>
<th>Size</th>
<th>Comments</th>
</tr>
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<tbody>
<tr>
<td>Spring</td>
<td>Sergestes arcticus</td>
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<tr>
<td></td>
<td>Fish (unidentified, 125 mm and Prionotus sp., 60 mm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td>Sergestes arcticus</td>
<td></td>
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<tr>
<td></td>
<td>Crangon septemspinosa (adult)</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Cancer sp. (juvenile, prob. C. irrorata)</td>
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</tr>
<tr>
<td></td>
<td>Fish (Prionotus sp., 32-40 mm; Cobiosoma ginsburgi, 27-30 mm)</td>
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<tr>
<td></td>
<td>Amphipods (gammerids, 2-3 mm)</td>
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<tr>
<td></td>
<td>Isopods (7-12 mm, most were Cirolana polita)</td>
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<tr>
<td></td>
<td>Polychaetes (50-80 mm)</td>
<td></td>
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<tr>
<td>Fall</td>
<td>Cancer sp. (4-12 mm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Amphipods</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fish (juvenile Prionotus sp.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter</td>
<td>Most hake are in deep water</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**BAY** (specimens collected in the Chesapeake Bay and York River)

<table>
<thead>
<tr>
<th>Season</th>
<th>Organisms</th>
<th>Size</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td>Neomysis americana (juvenile, 5-15 mm)</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Crangon septemspinosa (adults, 52 mm)</td>
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</tr>
<tr>
<td></td>
<td>Amphipods (most were Monoculodes edwardsi)</td>
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</tr>
<tr>
<td></td>
<td>Mud crabs (9 mm)</td>
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</tr>
<tr>
<td>Summer</td>
<td>Crangon septemspinosa (adults, 27-62 mm)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Identification by F. A. Chace, Jr., Smithsonian Institute (USNM).
(Munida, Cancer, Crangon), a large part of the hake diet is also composed of pelagic organisms (Sergestes, Loligo, and myctophids). The high frequency of Sergestes, Loligo and myctophids in bottom trawl catches indicates that they do occur near the bottom during some period of the day in specific seasons. It is possible that these organisms rest on or very near the bottom in the course of diurnal vertical migrations. During periods on or near the bottom they could easily fall prey to spotted hake.
LITERATURE CITED


VITA

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Born in Fort Lauderdale, Florida, February 27, 1942. Graduated from Downers Grove High School, Downers Grove, Illinois, June 1960. Concluded active duty in the United States Naval Reserve, December, 1962; received honorable discharge January, 1966. Received B.S. degree in Zoology from the Ohio State University, Columbus, Ohio, June, 1966.

In September of 1966, entered School of Marine Science, College of William and Mary as a graduate research assistant working toward a M.A. in Marine Fisheries Science.