THE ACCUMULATION OF FISH DEBRIS IN CERTAIN CALIFORNIA COASTAL SEDIMENTS

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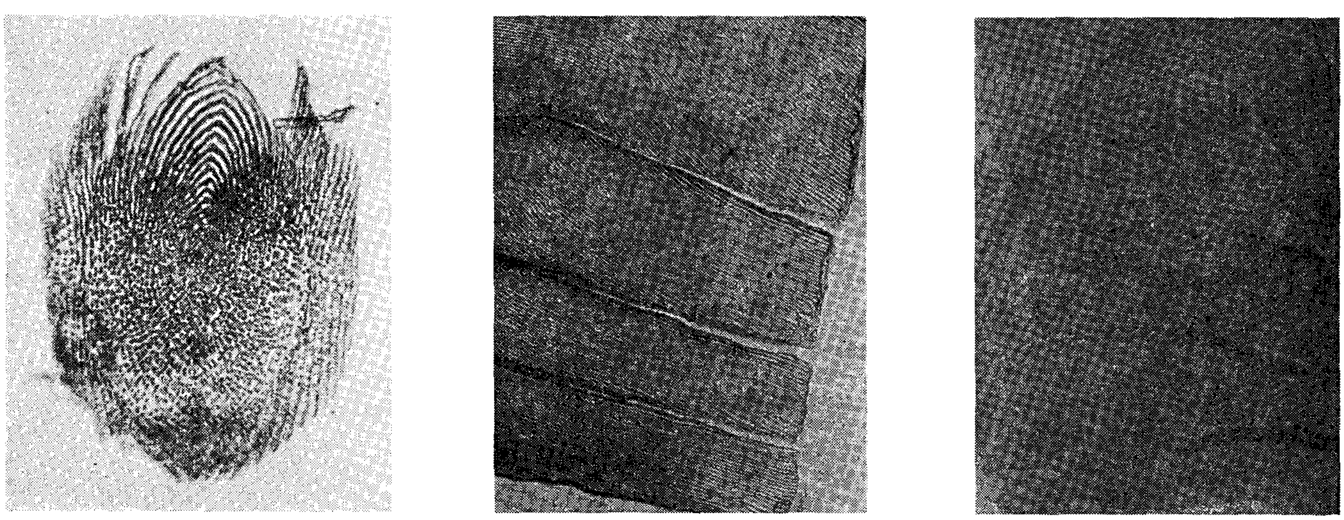
The fact that the remains of fish, such as scales and bones, are found in coastal marine sediments should, perhaps, not come as a surprise. Well preserved fish remains have been found in California marine sedimentary formations from Upper Cretaceous through Pliocene times. Furthermore, scales and bones of various species were reported in the surface sediments of the Catalina Channel by David (1947).

This paper presents some of the results of an initial attempt to study the distribution of fish remains at depth in the sediment. The discussion is limited to certain aspects of the distribution of fish scales. The main purpose of the paper is to point out the existence of material which could allow the introduction of a relatively long-time perspective into the character of the fisheries and oceanographic conditions off California.

The sediments used in the study were collected from the Santa Barbara Basin, off Santa Barbara, California. The basin has an oval configuration with the long axis parallel to shore. The sill depth is 475 meters and the area encompassed below sill depth is 600 km^2. The oxygen concentration at sill depth is about 0.4 ml/l. The oxygen concentration in the near-bottom water falls to 0.0 ml/l in the middle of the basin at 580 meters, (Emery, 1960). The floor of this basin is an exception to usual basin floors. Here bottom-living animals and their sediment mixing effects have been consistently excluded by the virtual absence of oxygen in the bottom water. This anoxic water forms from the consumption of dissolved oxygen in the bacterial decomposition of organic matter, and the restriction of vertical circulation in the bottom waters. Thus sediments falling to the floor of the basin accumulate undisturbed and in serial order. There is evidence of occasional disturbance, but it is estimated that this amounts to a few percent of the total length. There are, however, slump or turbidite layers which constitute about ten percent of the core length. These are easily recognized by a marked color contrast at various levels in the cores.

Undisturbed sediments such as these provide an excellent framework for the study of ocean history. The absence of mechanical disruption allows the preservation of delicate organic remains such as the fish scales seen in Figure 1. The absence of mechanical disruption also preserves lithologic patterns. Major lithologic patterns, if they exist, allow physical correlation between adjacent cores. In addition if annual variations exist in the supply of certain components of



a. b. c.

FIGURE 1. Representative fish scales found in the Santa Barbara Basin sediments.
a. Pacific hake, 72 centimeters below surface.
b. Pacific sardine, 89 centimeters below surface.
c. Northern anchovy, 79 centimeters below surface.

the sediment, for example a high contribution of land-derived detritus during a pronounced rainy season, then a yearly lithologic pattern may be preserved.

The existence of anaerobic conditions within the sediments must also contribute towards the preservation of organic remains. Anaerobic bacteria are unable to effect the breakdown of organic matter as completely as aerobic bacteria, and complex organic molecules are relatively immune from bacterial attack. Furthermore, anaerobic sediments appear to have a relatively high pH of about 8.0 thus insuring the preservation of inorganic carbonates and apatites, the latter being an important constituent of fish bones and scales, the former of fish otoliths.

The core samples used for this study were four cores obtained in the east central part of the basin, 34° 14′ N; 119° 58′ W, at a depth of 570 meters. The cores average 90 cm in length and have a combined area of 90 cm^2. The report of Emery and Bray (1962) provides the basis for estimating the age at the bottom of these cores at about 1000 years. The time equivalent of 1 cm, the subsampling distance, is then roughly ten years. For the purposes of this paper it will be assumed that a constant rate of sedimentation has prevailed. Preliminary examinations of laminae (yearly lithologic patterns) present in these sediments indicate this is a reasonable assumption.

The general procedure used in recovering fish scales and other coarse debris from sediment was the following. The core was exposed and the main lithologic features noted. The core was then cut into one centimeter thick slices parallel to the stratification. The individual slices were placed in a 10 percent hydrogen peroxide solution for about one half hour in order to disaggregate the sediment. The resulting slurry was wet-screened through 0.5 and 0.06 millimeter mesh screens. Material such as scales, bones, and otoliths, was retained almost exclusively on the coarser screen. The scales were manually picked under a low-power binocular microscope and were permanently mounted on glass slides. Identification was made by comparison with a reference collection of scales assembled from the Scripps Institution of Oceanography Fish Collection.

The raw data from these cores is a centimeter by centimeter tabulation of numbers of scales. Three species have been identified and counted: the Pacific hake, *Merluccius productus,* the Pacific sardine, *Sardinops caerulea,* and the northern anchovy, *Engraulis mordax.* In these cores the three species account for 80 percent of the total scales.

By means of the correlation of lithologic patterns within the cores the data from the four cores have been projected into a single composite core. This procedure should emphasize scale abundance patterns over distances greater than the arbitrary sub-sampling distance of 1 cm. On the other hand, correlation errors should tend to mask abundance variations occurring at or near this distance. That is to say only abundance variations that are consistent for equivalent time pe-

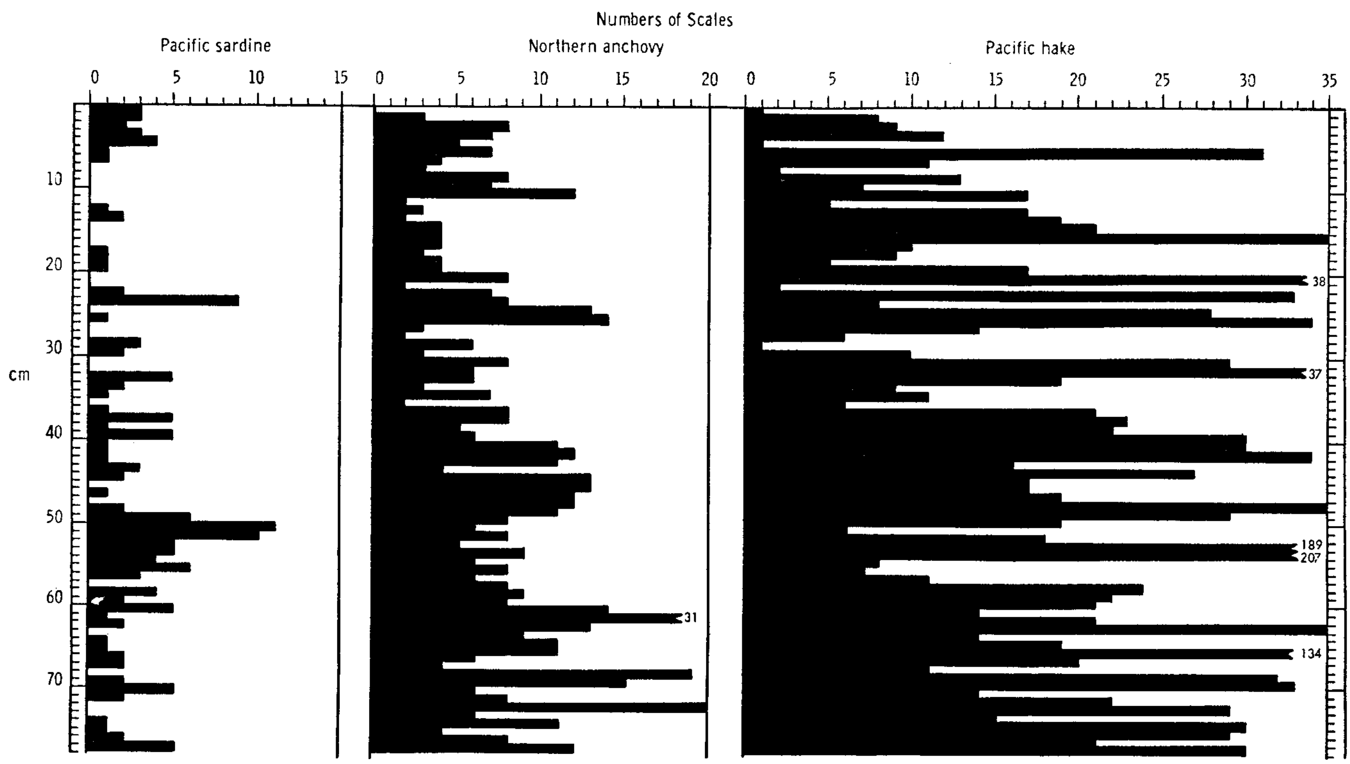


FIGURE 2. A plot of numbers of scales versus the core depth in centimeters. The occurrence of unusually high scale counts at a few centimeter levels in the case of the Pacific hake represents a high scale concentration in one of the four cores. In such cases the mean of the three other cores is taken to be more representative of the scale concentration at that level.

riods of over 50 to 100 years should be emphasized. The data have undergone a further modification in that only the finely stratified sediments have been retained for analysis. The intervening turbidite layers are assumed to have been quickly deposited and the top and bottom of such layers are considered isochronous.

The data for each of the three species are presented in Figure 2 as: a histogram plot of numbers of scales versus the centimeter depth in the core and in Figure 3 as a plot of cumulative numbers of scales versus the centimeter depth in the core. The numbers of scales are accumulated starting at the surface. If few scales are encountered in a region of the core, the slope of the cumulative curve will tend to the vertical, and if many scales are encountered the slope of the cumulative curve will tend to the horizontal. In addition to the cumulative curves a representation of the frequency distribution for the three species is given in Figure 3. The presence of a number of scales in a centimeter section greater than or equal to the median number of scales per centimeter section is designated by a crossed square. An open square indicates a number of scales less than or equal to the median number. The median values of individual species are consistently included with the high or low value groupings to provide as even a split of the data as possible. In the case of the Pacific sardine and northern anchovy the median values are included with the low values group. In the case of the Pacific hake

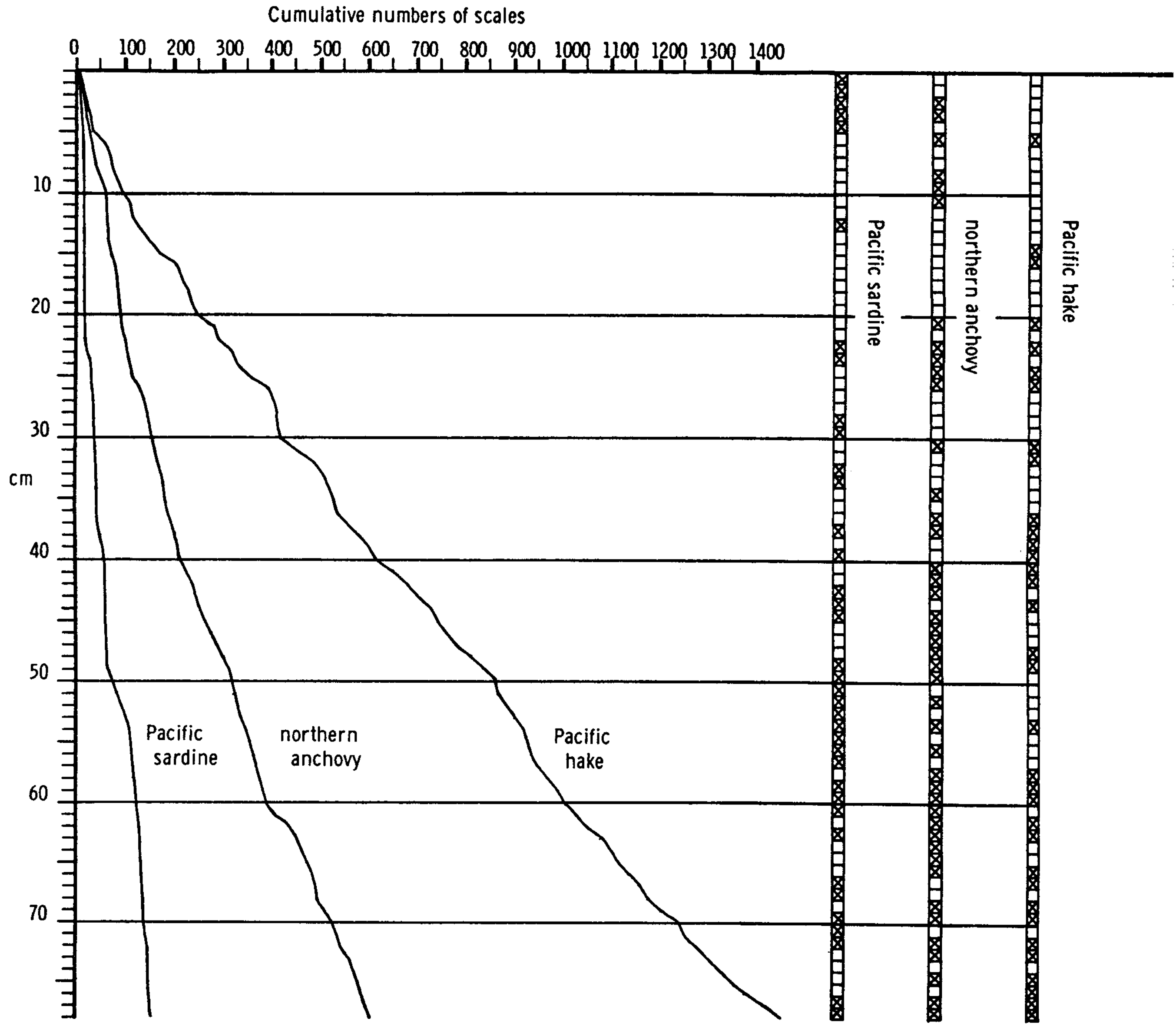


FIGURE 3. A plot of the cumulative numbers of scales of the Pacific hake, the northern anchovy, and the Pacific sardine versus the core depth in centimeters. A plot of the frequency relative to the median versus the core depth in centimeters. An open square indicates the number of scales for that centimeter is below or equal to the median number of scales per centimeter. A crossed square indicates a number of scales higher than the median number. Note—core length is foreshortened about 10 percent due to removal of turbidite layers.

the median values are included with the high values group.

The greatest number of scales that have accumulated in these sediments are those of the Pacific hake. A median number of 19 scales was found per centimeter; the total number encountered was 1430. The scales of the northern anchovy are next in abundance. The median number per centimeter was 7 and the total number was 605. The least abundant scales in these sediments are those of the Pacific sardine. This species has a median value of 1 scale per centimeter and a total number of 160.

An interesting aspect of the scale data is the sequential pattern accumulation. Inspection of Figure 2 shows that there are regions within the composite core where the abundance level of scale accumulation is consistently above or below the median value. This imparts a step aspect to the cumulative curves. In the case of the Pacific sardine steps in the cumulative curve indicating a marked increase in the level of abundance are present at 0–5 cm, 22–23 cm, 37–40 cm, and 49–50 cm. The latter step is by far the most pronounced. A number of steps are present in the cumulative curve of the northern anchovy notably at 7–10 cm, 2–28 cm, and 60–64 cm. The cumulative curve of the hake also shows a number of steps. It is instructive to note that the steps in the cumulative curve for each species do not necessarily occur at the same depths in the core. This suggests the steps in the abundance levels are probably not a reflection of changes in the rate of sedimentation.

The frequency curve representation in Figure 2 provides a convenient basis for an objective analysis of the sequential pattern of scale accumulation. Miller and Kahn (1964) suggest the runs test of Wallis and Roberts (1956) may be applied to test for non-random tendencies in geologic time series such as this. In a random pattern the probability that a data point will be above the median value is one half; the probability of a data point being below the median value is similarly one half. This leads to the expectation that the number of consecutive data points (runs) above and below the median will be $n/2 + 1$ where n is the total number of data points. The departure from randomness of a series can be tested by the standard normal deviate of Wallis and Roberts. Applying this procedure to the scale data one finds the number of runs in the case of the Pacific hake is 32, in the case of the northern anchovy 36, and for the Pacific sardine 27. The expected number of runs is 40. The associated probabilities, that is, the probabilities of random series having an equal or greater number of runs are: the Pacific hake 0.26, the northern anchovy 0.22, and the Pacific sardine 0.005.

This analysis of the scale data implies that the scale abundances of the Pacific sardine are aggregated at certain levels of the core. Such a pattern of aggregation suggests changes in the abundance of the source of these scales. That is, over the last 1000 years the scales of the Pacific sardine found in these sediments seem to reflect periodic changes in the abundance of the Pacific sardine. Although similar abundance changes at specific levels in the core can be noted in the case of the northern anchovy and the Pacific hake, the runs analysis suggests that in the case of these two species there is not a marked tendency towards aggregation in time.

In summary, it may be inferred that relative to the Pacific sardine there has existed for the past 1000 years a more constant supply of northern anchovy and Pacific hake scales to these sediments.

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