FISHERY OCEANOGRAPHY--VI
OCEAN FOOD OF SOCKEYE SALMON

Felix Favorite

A vital part of fishery oceanography is the knowledge of food chains and of the locations of high abundance of food organisms. Life stems from the sun; this is as true in the sea as it is on land. Microscopic single-cell plants, or phytoplankton, drifting in a thick soup of chemical nutrients (compared to the quantities available in most soils) use radiant energy from the sun to live and to multiply. In spring, a quart jar filled with water from the sea surface may contain a million of these cells--in some areas, many millions. Some cells, diatoms for instance, divide and produce two cells within the span of a day or less; if this process continued for a month, each cell would produce over a billion cells. One can easily visualize the significance of the so-called bloom of phytoplankton, which occurs each spring in high latitudes under the required environmental conditions of light, nutrients, and vertical stability in the water column. In the absence of large numbers of marine animals that graze on plankton, such blooms continue until one of the numerous nutrients required for plant growth is depleted.

Only a limited amount of research on nutrient chemistry has been accomplished in the Subarctic Pacific Region. However, if we consider the phosphate-phosphorus distribution (which has been studied) as indicative of nutrient concentrations (even though phosphate is recycled more rapidly than nitrate), it appears that nutrient concentrations are high and show no depletion in any season. Concentrations in the upper 100 meters of these waters are from 5 to over 10 the concentrations in waters farther south between 40° and 20° N., except off the west coast of North America where upwelling carries nutrients from deep water into the surface layer. The high concentrations in the Subarctic Region are also attributed to a vertical movement of deep water (explained in article IV of this series, November 1969 CFR). Some chemical studies indicate that nitrate may be limiting at times, but there is increasing evidence that the phytoplankton may be cropped by herbivorous zooplankton before the bloom reaches the immense proportions suggested by the high phosphate concentrations. Until more exhaustive chemical studies are made, we must accept this conclusion.

Measuring Plant Production Important

Nevertheless, there are methods of measuring the production of plant material over short periods of time, and estimates have been made of the animal life it is capable of supporting. These estimates are important in our control, or management, of the stocks of Pacific salmon (genus Oncorhynchus). Natural spawning areas in some river systems could be expanded and the capacity and number of salmon hatcheries increased to accommodate greater oceanic production. We believe that the hundreds of millions of salmon in the Subarctic Region constitute only a small fraction of the actual number of fish. We are unable, however, to determine how successful increased numbers of salmon would be in competing for food with the other organisms in this ecosystem. We know that the average weight of mature pink salmon (O. gorbuscha), which spend only 1 to 1½ years at sea, can vary 50 percent or more between years, and that it is not uncommon for mature pink and sockeye salmon (O. nerka) to be smaller in years when large numbers return to their natal river for spawning than in years when few return. Even though sockeye salmon usually spend the last 2 or 3 years of their lives growing and maturing in the ocean, their reduced size may be due to increased competition for food during the first year or two after hatching, which are spent in a fresh-water lake.

Experimental Fishing Catches More Salmon At Night

Pacific salmon grow and mature in the marine environment, but the effect of food

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distribution and abundance on their movements is not clear. In our experimental fishing, conducted with gill nets (approximately 3 m. in depth), it was obvious from the start that more salmon were caught at night than during the day. Almost without exception, when our fishing was conducted at night the majority of salmon were caught in the upper third of the nets. This was sometimes interpreted to signify that salmon rose to the surface at night to feed upon plankton or other organisms closely associated with plankton; others believed that salmon can see and avoid the gill net more readily during the day. But studies with sunken gill nets (as deep as 60 m.) have revealed sockeye and chum salmon (O. keta) during day or night at depths of at least 40 m. Chinook salmon (O. tshawytscha) are believed to be at much greater depths at times.

3 Major Species Eat Mostly Plankton

We know that three (sockeye, pink, and chum) of the five major species of Pacific salmon are predominately plankton feeders, but that they also consume small fish and squid. To ascertain their feeding habits, the stomach contents of over 5,000 sockeye salmon (caught in gillnets at 82 locations in the central Subarctic Region in 1960) were analyzed. Although another method of capture would have been preferable because salmon tend to regurgitate food when caught in a gill net, the results are interesting. The stomachs were divided into two categories--those collected in May and June, and those collected in July and August. Sockeye salmon caught in the Subarctic Region in May and June are mainly mature fish returning to river systems to spawn; those caught in July and August are mostly immature and will probably spend at least 1 more year in the ocean. Neither group had difficulty finding food over a wide area of the ocean (fig. 1). At 68 of the stations, over 50 percent of the stomachs were at least $\frac{1}{4}$ full. This suggests that salmon obtain food in areas other than the immediate Aleutian Island area, which has been considered the primary "feeding ground" for salmon. The average percentages of the total stomach contents contributed by different taxonomic groups were: amphipods - 43, fish - 18, squid - 16, euphausiids - 12, copepods - 7, pteropods - 2, and unidentified - 2. Other investigators found for other years that copepods or euphausiids were the dominant organisms in stomachs of sockeye salmon, but it is not known whether these organisms were predominant in the plankton during those years.

No particular organism dominated in the stomachs of fish taken at individual locations (fig. 2), nor was there any particular distribution pattern. This was not surprising because all stations were within the subarctic regime. The distribution of species within taxonomic groups probably differed among stations or groups of stations. But such differences are difficult to demonstrate because identifying characteristics are usually obliterated by ingestion and digestion.

Estimating Food Abundance Near Fishing Stations

Because of the great variety of food eaten by sockeye salmon, an estimate of the abundance of all food organisms in the vicinity of a fishing station would require the towing of numerous sampling devices (with various mesh sizes). These would have to be at various speeds and depths, throughout the water column, and over a large area. Such studies have not been possible. Although we have made vertical plankton hauls with small-mesh nets, the samples were inadequate to estimate the food organisms available to salmon. Once, during the early phases of our work, a two-ship operation took place in which a fishing vessel set a gillnet and an oceanographic research vessel made exhaustive plankton hauls throughout the night at various distances from the net. Unfortunately, no salmon were caught, and we have not had an opportunity to repeat this kind of experiment. Such studies of the relation between food available and food eaten would also require knowledge (still largely lacking) of the rate at which salmon digest food organisms. This merely points out, again, the frustrations and difficulties encountered in fishery oceanography.

Nevertheless, in spring and summer 1961, we made 24-hour investigations of the vertical distribution of macro-plankton at numerous locations. A modified Isaacs-Kidd trawl was towed at 25-m. depth intervals from the surface to 200 m. At three representative stations, the maximum biomasses were at 50, 125, and 125 m. during the day, and 25, 25, and 100 m. at night (fig. 3). The effects of these distributions of food organisms upon the vertical distributions of salmon are still unresolved. The analysis of the contents of a limited number of stomachs from sockeye salmon caught during late winter in 1962 indicated active feeding on amphipods and lanternfishes. It was previously believed that little, if any, food is consumed during this period because

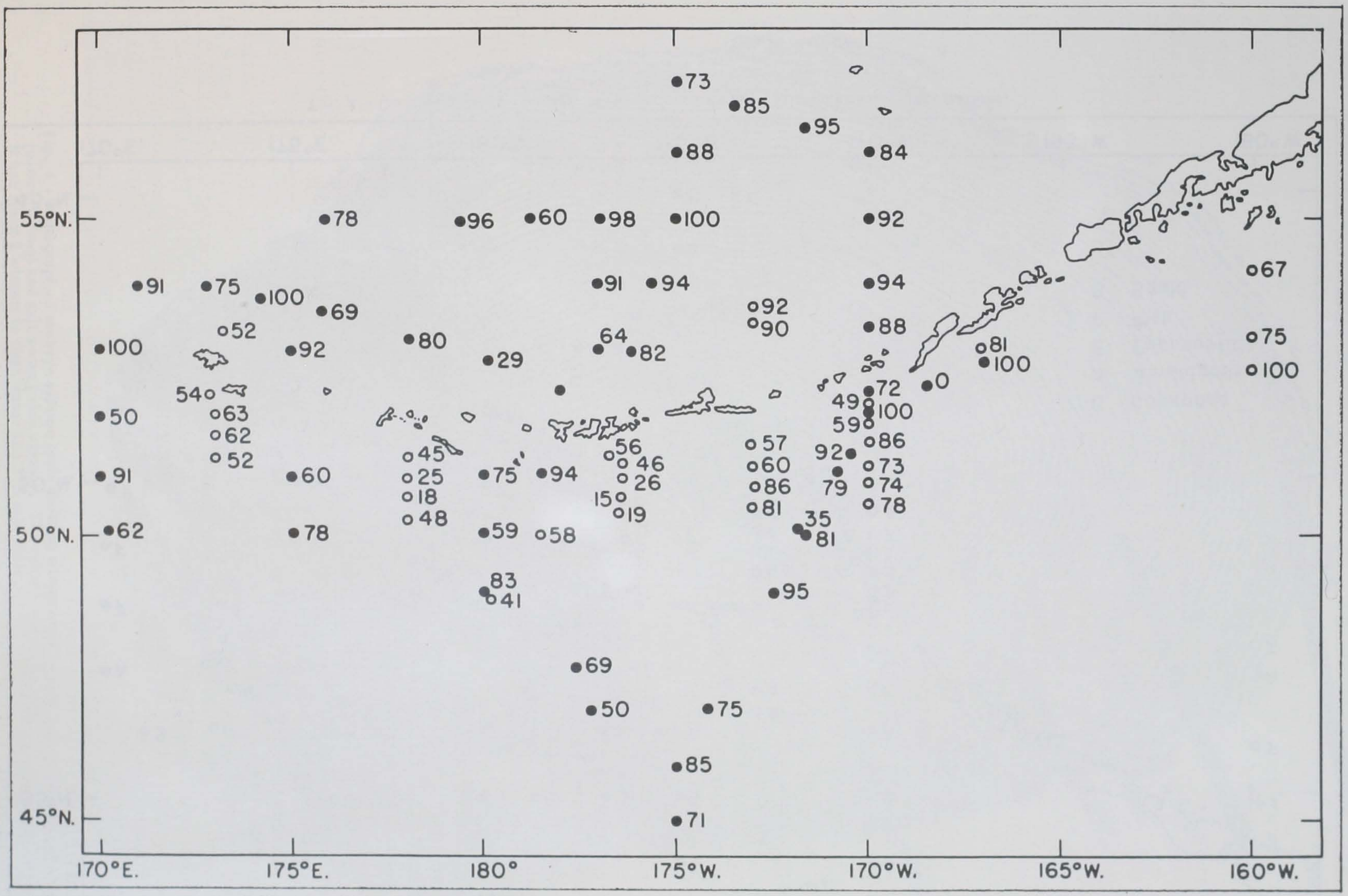

Fig. 1 - Locations of fishing stations from which 5, 880 sockeye salmon stomachs were obtained in May and June (closed circles) and July and August (open circles), 1960. Numbers indicate percentages of stomachs having a significant food content.

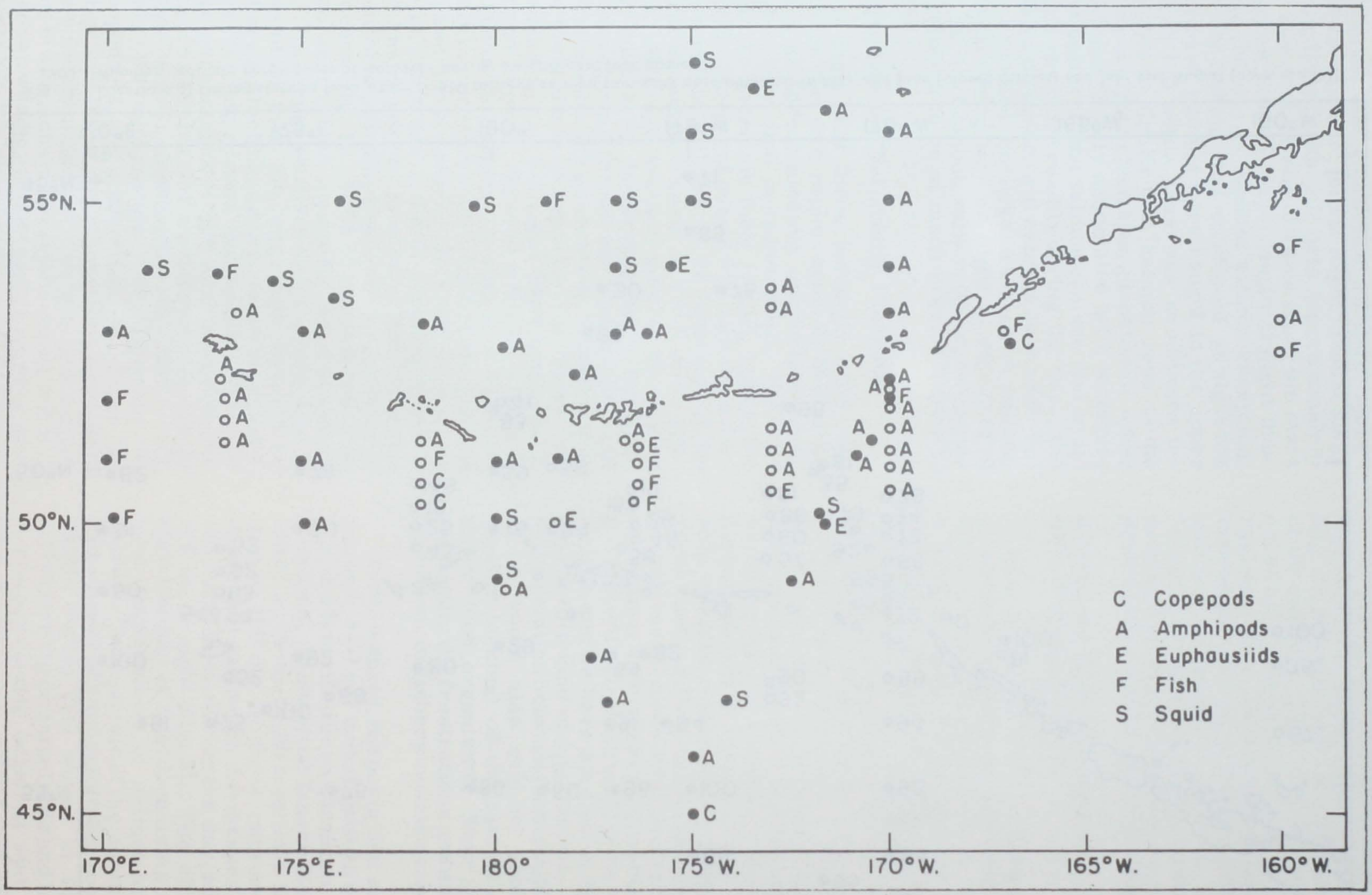

Fig. 2 - Dominant food organisms in stomachs of sockeye salmon at individual stations.

Fig. 4 - Photograph of sockeye salmon scale showing winter growth zones that formed in fresh water (narrow arrows) and salt water (wide arrows). The salmon was in its sixth year at time of capture: it had spent 2 winters in fresh water and 3 in salt water. (Photo: K. Mosher)

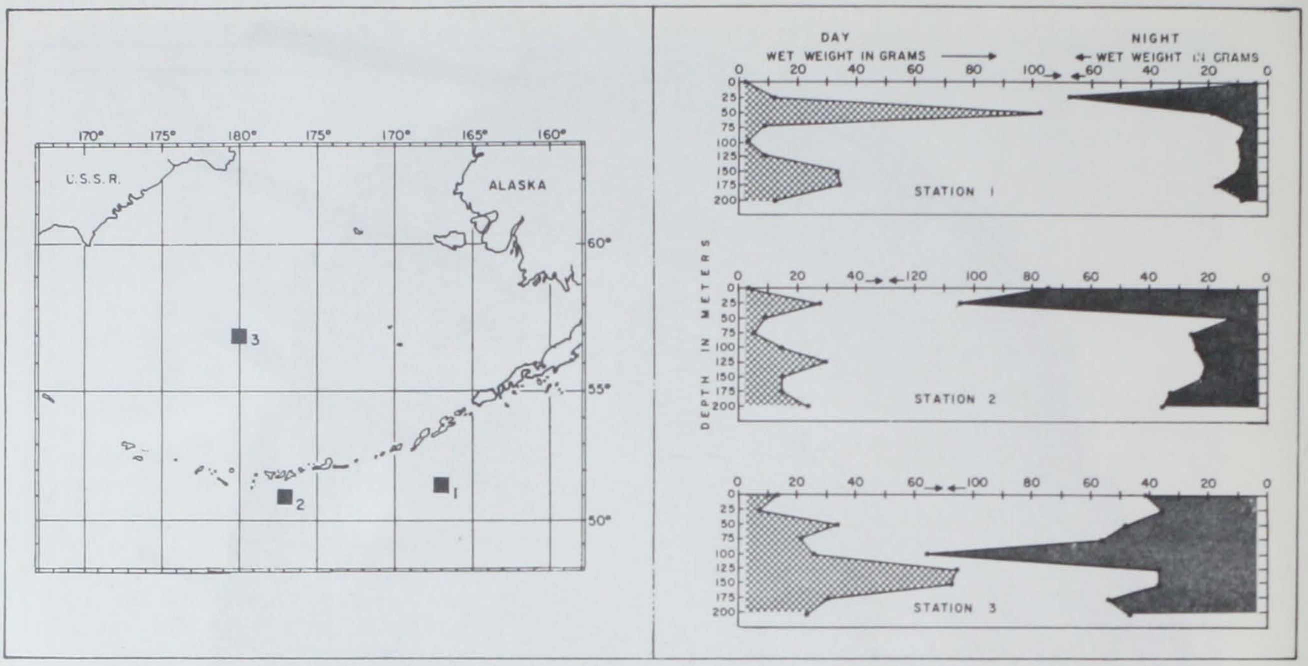

Fig. 3 - Vertical distribution of biomass at 25-m. depth intervals at three stations, during the day and at night, as determined by catches in a 3-foot Isaacs-Kidd midwater trawl.

the narrow spacing of circuli on the scales suggests little growth. The narrow spacing during winter is significant. It permits us to ascertain the age of the salmon by counting year-marks, which are analogous to the rings in a cross-section of a tree trunk (fig. 4).

Study Biomasses of Environmental Waters

We are completing biological studies along a line of stations south of Adak Island to ascertain if the various environmental waters, such as the Alaskan Stream and the Subarctic Current, and the Ridge Area which separates these two systems, have characteristic biomasses. It appears that the phytoplankton bloom is greatest inshore in early spring--but that the standing stock of zooplankton is greatest in the Ridge Area. This has been interpreted to mean that grazing by large numbers of zooplankton in offshore areas prevents the standing stock of phytoplankton (as indicated by the nutrients) to attain its immense potential. Extensive grazing in turn seriously restricts the potential plankton production in the Subarctic Region.

Further estimates of potential primary production are being made on the basis of cloud cover data obtained from ESSA satellite photographs. Monthly averages of daily cloud cover indicate that previous estimates based upon sporadic ship reports are not representative; thus values of incident radiation, corrected for shielding by clouds, are in error. Production of phytoplankton is directly related to incident radiation. Even though zooplankton cropping may exist, knowledge of areas of minimum cloud cover in spring could possibly denote areas of high primary production and, therefore, possible feeding areas for adult salmon before or during their spawning migration to natal streams in late spring.

Thus we are entering a predictive phase. This, of course, is the ultimate goal of all oceanography programs--to obtain enough knowledge of the conditions and processes in a particular system to make long- and short-range predictions. Some scientists feel that we are at least 10 years, and perhaps many decades, away from such a goal. This period of time may be a gross underestimate or overestimate, depending upon the requirements and use of the prediction. Yet each step should pave the way to ultimate success. In the next article, the last in this series, I will describe our attempts to forecast ocean current flow in the salmon environment.