farther off the coast, its place being taken by water containing a mixture of forms including estuarine and neritic species. The tropical water may turn back to the coast near Montague Island or even further south, and strong tropical influence may reach the east coast of Tasmania as in August 1940, when a number of tropical diatoms and dinoflagellattes were collected there by F.R.V. "Warreen". Southern, sub-antarctic forms are found at times as far north as Twofold Bay. These water movements are discussed in greater detail in a paper now in press.

Enough has been said to show that regular hauls for phytoplankton on the east Australian coast can give very useful information regarding water movements. We now know the indicator species, and once we know the relation between water movements and pelagic fish occurrences we should be able to predict the movement of these fish from regular phytoplankton hauls. Unfortunately, up to the present we have had too many gaps in the plankton record to allow of our plotting water movements or relating the seasons with phytoplankton occurrences. It is, perhaps, not easy to justify such an intensive plankton programme without a large pelagic fishery. At the same time, such a programme could help to economise effort in the actual fishery as soon as water movements could be interpreted in terms of fish production.

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3

SOME RECENT ADVANCES IN THE STUDY OF THE BIOLOGY AND RACIAL DIVISION OF PACIFIC TUNAS

by

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ABSTRACT

Valuable results are being obtained from research into those factors of the life history of the tunas which are of basic importance to the development and management of the fisheries for them. Methods of racial study by means of morphometric measurements have been developed and are being applied to data from several areas in the Pacific. The growth of yellowfin tuna and skipjack is being studied by means of size frequency measurements, and the results indicate conclusively that these species are rapidly growing and that the commercial stocks consist at any time of only a small number of year classes. This has important implications regarding possible effects on stability of yields under heavy exploitation. Spawning grounds of several tuna species have been located in various places in the Pacific, and it is likely that the several species all spawn pretty generally throughout much of their ranges. Studies are going forward to determine the variation of quantity of spawning in space and time, a knowledge of which is important to judging possible fluctuations in recruitment to the commercial stocks.

Scientific investigation of the life history and ecology of commercially valuable fish species has the pragmatic objective of furnishing a factual basis upon which man may obtain the greatest production of food from the fishery for members of the species. Knowledge of facts concerning the biology of a fish species is valuable in this respect in two ways. First, by attaining an understanding of the behavior of the fish, particularly as related to seasonal and environmental changes, means may be devised for their more efficient capture and so increase the production of the fishery. This we seek to do in developing a fishery for little exploited species. As a fishery becomes more effective, however, we eventually reach a condition when increasing fishing intensity may result in actually decreasing the production, give rise to large fluctuations in the catch, or otherwise produce undesirable results. The second useful purpose of biological research is to assemble the facts regarding those fundamental factors in the life history and behavior of the fish which will enable us to understand, and indeed to predict with some assurance, the effects of changing effectiveness of fishing; to reach an understanding

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of what is often termed the "population dynamics" of the species.

Both in the Atlantic and Pacific, the tunas have been the objects of commercial fishing from the earliest times and, likewise, they have attracted the attention of marine biologists for hundreds of years. Due to their large size and their pelagic, oceanic habitat, however, knowledge of their ways of life is very meagre, even in view of the hundreds of papers which have been written concerning them. Except perhaps for the research conducted in certain parts of the Mediterranean Sea and adjacent regions of the Atlantic Ocean, and some work on the West Coast of the United States, and in Australia, no intensive studies of tunas have been undertaken, except by Japanese scientists. Japanese fishery scientists, who were very active in studying the tunas prior to the war, directed some attention to the study of the life history and racial distribution of the Pacific tunas, but their primary attention was directed towards elucidating the distribution and ecology of the several species for the purpose of expanding and developing the fishery for them. Research into those aspects of the biology of the tunas which are essential to developing an understanding of the population dynamics of the stocks of those species, and upon which any conservation, national or international, must be based, has been generally scanty everywhere. There has, however, been notable recent progress in this field. It is with this category of recent tuna research that this paper will be primarily concerned.

Although all sorts of knowledge about the tunas is of value to their wise utilization, certain aspects of their biology are of basic importance to fisheries development and management, such as the limits of independent populations, and the factors determining the abundance of fish in a population and fluctuations therein. It will be a long time before we have a complete understanding of these aspects of the biology of the tunas, but some fragments are beginning to emerge.

RACIAL STUDIES.

Of basic importance to the management of any fishery is a knowledge of the units—called "races", or "stocks", or "populations"—into which the species is separated. Such a unit is composed of individuals, inhabiting a certain part of the sea, which freely intermix and interbreed with each other, and which intermix and interbreed with members of other units little or not at all. These population units must be treated as entities in any plan for developing and managing a fishery. A fishery, however intense, on one population will have no effect on other, unfished populations of the same species. Conversely, where a single population inhabits a large region, fishing in one part of the region has a direct and important effect on the population in every other part. We thus perceive the importance of determining whether each species of Pacific tuna is separated into several separate populations or is composed of a single, vast, ocean-wide population.

The solution of this problem is being approached primarily by means of comparing measurements of body form of tunas from different areas of the Pacific. Since it appears impractical to have one person or one team of persons take similar measurements on specimens of one species of tuna from all the widely separated places where they occur, it has been necessary to attempt to standardize the measuring technique so that data gathered by different observers in different places may be comparable. The basis of this standardization among American workers has been the list of dimensions and counts employed by Godsil and Byers (1944) in their systematic study of the California tunas. Marr and Schaefer (1949) have redescribed these dimensions and counts, as well as several additional ones which may be useful, and have set forth methods of taking them. It is hoped that these measurement methods will become fairly standard among workers elsewhere in the Pacific.

The analysis and comparison of measurement data on the body form of tunas is troublesome, even when the original data are all taken in a comparable fashion. Since, as is well known, the ratio of the size of one body part to another changes with the size of the fish as it grows, such ratios cannot be compared directly without suitable correction for this factor. Schaefer (1948) in describing the relative growth of Central American yellowfin tuna (*Neothunnus macropterus*) and Schaefer and Walford (1950) in comparing body dimensions of yellowfin tuna (*Neothunnus*) from the Atlantic and Pacific, have based such correction on linear regressions between one dimension and another, or between such dimensions transformed according to some simple mathematical formula. Godsil (1948) dealing with extensive data on Pacific yellowfin tuna and albacore (*Thunnus germo*) has employed a simple curvilinear relationship between dimensions for the same purpose. These procedures, while probably the best available, must yet be employed with caution, because they cannot completely correct the data for size-connected variations which may then be confused with true population differences. This difficulty arises from the fact that the regression equations employed represent straight lines or simple curves which can be at best but good approximations to the complex true relationship between the variables. Thus it may be, in comparing body dimensions of samples of differing size composition, especially where large samples make detection of small differences possible, that even with a correction for variation of dimension with fish size, there will be found differences due to the residual difference between the equation chosen to represent the relation between variables and the true (unknown) relationship, in addition to the real difference between populations which we are trying to measure. Thus, for example, Godsil (1948) has found differences between repeated samples from the same region (and presumably the same population) greater than those attributable to chance. He has explained this on the basis of a presumed difference between schools due to lack of complete mixing between schools of different history in early development, but this seems to us unlikely. Whatever the cause, however, biological or merely procedural, the phenomenon is real and must be dealt with. The means of doing so will not be gone into in detail here; in essence it will consist either of employing as a standard the observed variation between repeated samples from a locality, or of selecting samples for comparison so that they are of nearly equivalent size composition, with the latter being perhaps somewhat preferable theoretically.

The work of Godsil (1948) has indicated that both the yellowfin and albacore tuna of the American West Coast are probably racially distinct from those of Hawaii and from those of the western side of the Pacific. His samples from other than the American West Coast were, however, very small and further verification is indicated.

The author is presently engaged in analysis of fairly extensive data on Hawaiian yellowfin tuna to compare with those from the American West Coast and elsewhere. We have for comparison also a small sample from the Society Islands, a few sets of measurements from Japan, and a few from the Phoenix and Line Islands. From the latter places more specimens are currently being collected by POFI research vessels. Our analyses have not, as this is written, progressed far enough to permit even tentative conclusions to be drawn. In addition to these data on yellowfin tuna, we have collected and commenced analysis of sizeable samples of Hawaiian skipjack (*Katsuwonus pelamis*) and big-eyed tuna (*Parathunnus sibi*) to serve as a basis of comparison with measurements of specimens from other parts of the Pacific. We shall, as these studies progress, begin to obtain an idea of the population divisions of the Pacific tunas.

AGE AND GROWTH.

The population dynamics of a fish stock are intimately connected with the age and rate of growth of its members. A population of a slow-growing, long-lived species is less subject to fluctuations in abundance due to variations in size of entering year classes than is a population of a fast-growing, short-lived species. Where the population is composed of many age groups which go through life slowly, failure or super-abundance of a single age group has small effect on the total stock of fish. Where the population is composed of but a few age groups, variations in abundance of one of them has a relatively large effect on the total stock.

Studies of the age and growth of Pacific tunas have been very meagre. Kishinouye (1923) believed that "The growth of tunnies seems to be very rapid", and that *Thunnus orientalis*, *T. germo*, and *N. macropterus* reached a meter in length and about 11 kilos in weight in two years. Aikawa and Katō (1938), however, deduced a rather slower growth from their studies of age based on rings on the vertebrae which they took, albeit without much apparent justification, to be annual markings. Brock (1944) concluded from studies of length-frequency data on albacore landings that "only a few year classes are present in the temperate water fisheries for this species, and that these are immature". I have previously published (Schaefer 1948) some rather scanty length frequency data for *N. macropterus* taken off Costa Rica, from which it appears that in the spring months there is a distinct mode near 60 cm. and another near 85 cm. which were believed to be most probably composed of one year old and two year old fish, respectively.

Sampling of tuna catches to determine size composition of the populations which they represent is peculiarly difficult because, like some other pelagic fish, they tend to school by size. It is important, therefore, to sample many schools, rather than merely to measure many fish, if the sum of the samples is to be representative of the whole population. We were very fortunate to discover shortly after we began our tuna studies in the Hawaiian area that the local flag-line fishery and the system of marketing the fish caught by it provided almost ideal ready-made size frequency data for the yellowfin and the big-eyed tuna (*Parathunnus sibi*) of the large sizes which that fishery pursues. The fishery is conducted by means of set lines which are fished twenty to thirty fathoms below the surface and catch large yellowfin and big-eyed tunas, marlin, swordfish, and a few albacore. Each line captures only a few fish each day, so that in the aggregate the catch of the fishery samples rather widely the tuna population present at the depths fished. The fish are sold at auction, one fish at a time, and the auction market which handles about 80% of the landings at Honolulu has kept for the past two

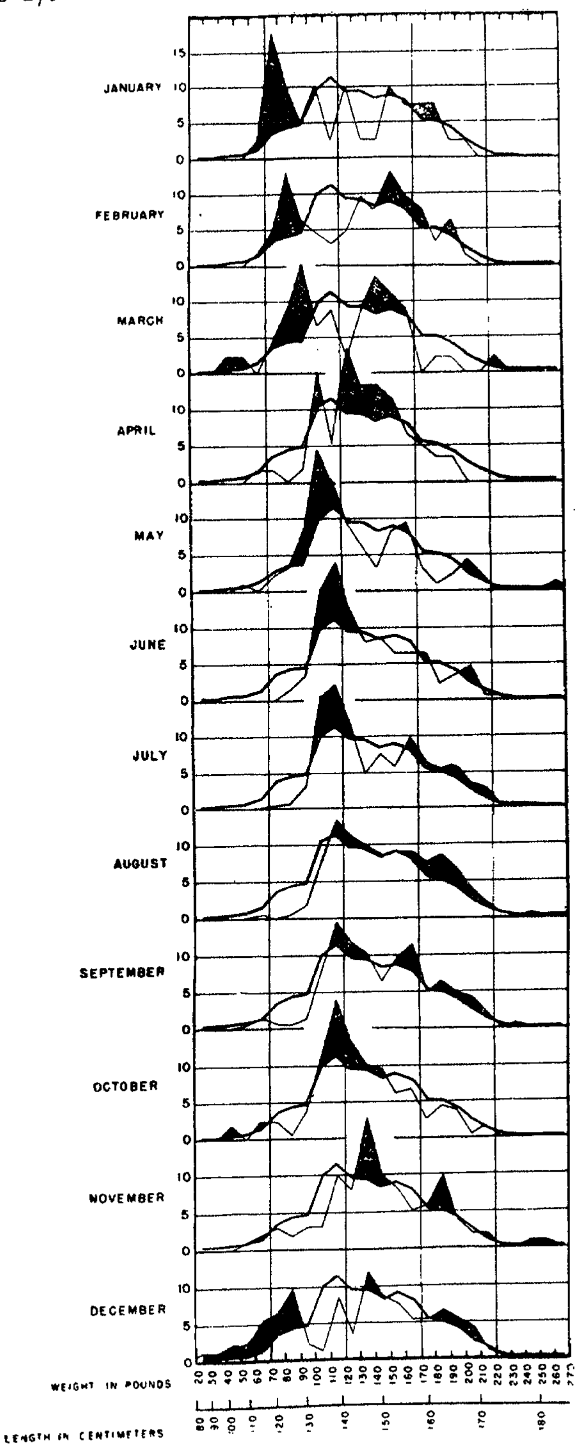

Figure 1. Monthly percentage size frequency distributions of flagline landings of yellowfin tuna at Honolulu, and deviations of monthly distributions from the year's average, for the year 1948. (Fine line, monthly frequency distributions. Heavy line, year's average frequency distribution. Positive deviations of monthly distribution from year's average shaded).

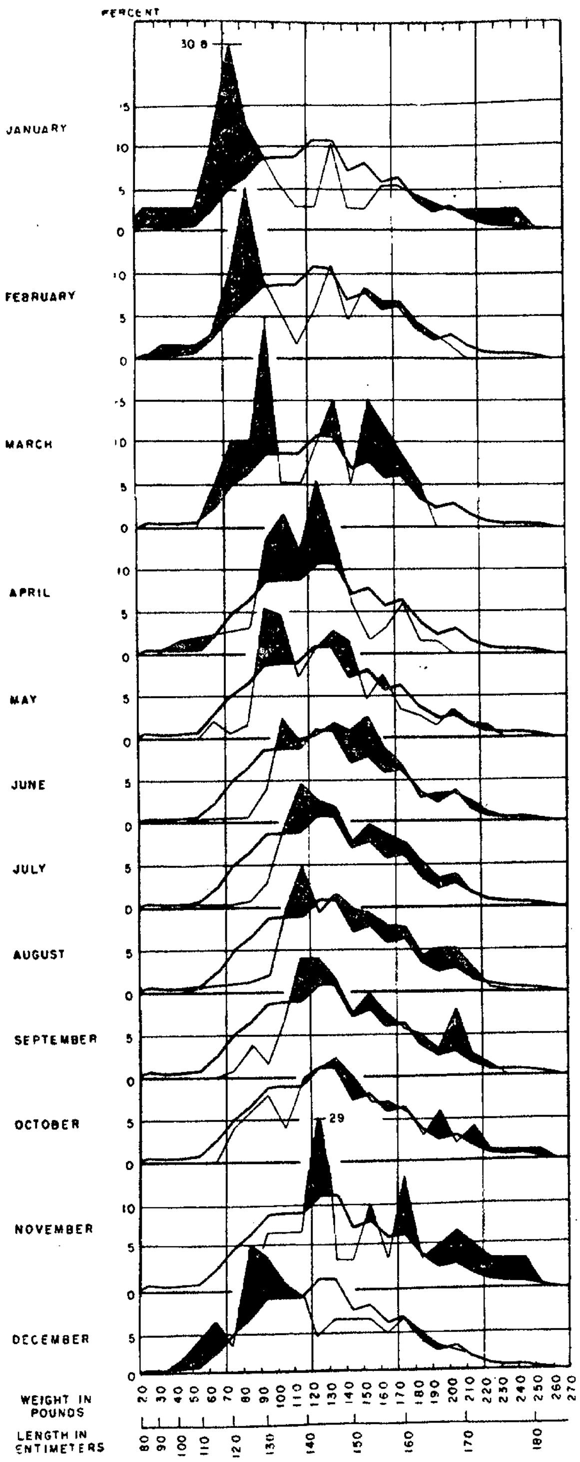

Figure 2. Monthly percentage size frequency distributions of flagline landings of yellowfin tuna at Honolulu, and deviations of monthly distributions from the year's average, for the year 1949. (Fine line, monthly frequency distributions. Heavy line, year's average frequency distribution. Positive deviations of monthly distribution from year's average shaded).

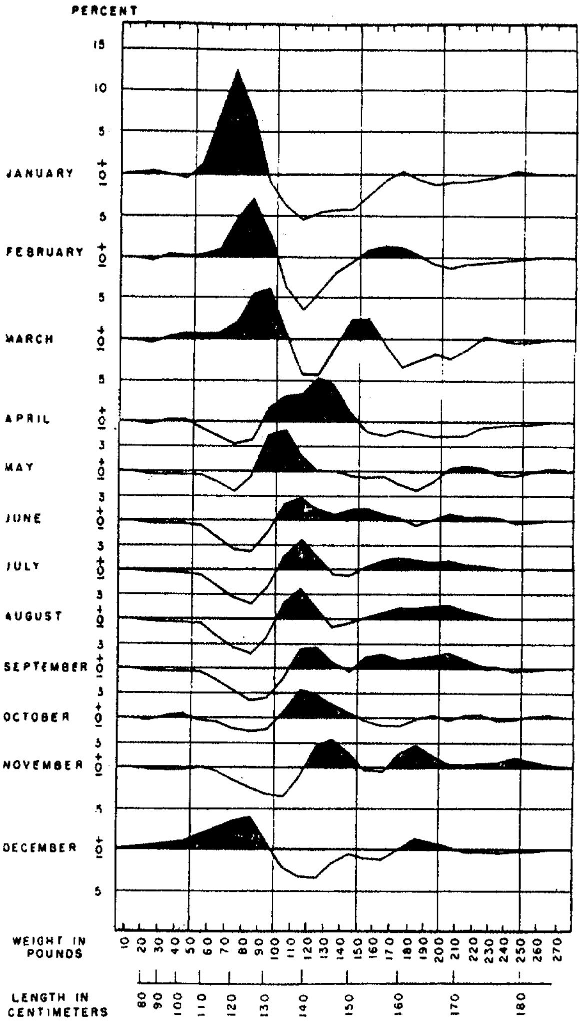

Figure 3. Deviations of monthly percentage size frequency distributions from the average percentage size frequency distribution of all 1948 and 1949 samples of yellowfin tuna taken by flag-line.

years records of the species and weight of each fish handled. Thus we have available weight-frequencies for each month consisting of large, well distributed samples of the tuna population available to the long-line fishery. Mr. Harvey Moore of the POFI staff is engaged in the detailed analysis of these data, which he has assembled from the records of the market in question. The figures presented here were prepared by him as part of a detailed study which will be completed and published later this year. In figures 1 and 2 are plotted the frequency distribution by sizes of each month's catch of yellowfin tuna, on a percentage basis, with the average curve for the year superimposed on it. Positive deviations of the month's curve from the average are shaded to make the modes easily followed. It is easily seen that a group of fish appears in the fishery in December and January at a weight of 70 or 80 pounds and can be followed through month by month until by the time they are a year older the modal weight is in the neighbourhood of 130 pounds. This mode is more clearly brought out in figure 3 where the yellowfin tuna data for both years are combined and plotted as deviations of the frequency curve for each month from the average of all data. There can be no doubt that this mode represents an age group of fish growing in one year from an average weight of about 75 pounds (at a length of 120 cm.) to a weight of about 135 pounds (at a length of 148 cm.). The length scale at the bottom of these graphs represents the lengths in centimeters corresponding to the weights in pounds on the scale above according to the relationship

$$\log L = 1.45660 + 0.33290 \log W$$

obtained from a sample of 200 fish representing the range of sizes encountered in the Hawaiian region both in the flag-line and live bait fisheries.

These data confirm the previous conjecture that the yellowfin tuna are very rapid growing. If the hypothesis, based on my previous Costa Rican data, is correct that this species at one year old is about 60 cm. in length and at 2 years old is about 85 cm. in length, and Hawaiian fish grow at about the same rate during these years, the fish of the age group making up the mode in question are probably either in their third year or fourth year of life. In any case, with respect to yellowfin tuna we seem quite safe in concluding at this stage of our research that (1) they are very rapidly growing fish, (2) the tuna that are taken in the live bait fishery (fish up to 100 pounds in weight) are very young fish, and (3) both the surface fishery by live bait for the very young tuna and the flag-line fishery for older fish are dependent at any one time on only a few age classes which make up the fishable stock.

Current studies, by Mr. Vernon Brock of the Territorial Division of Fish and Game, which I hope will see publication in the very near future, indicate that the skipjack are likewise young, fast growing tunas and that in Hawaiian waters two age classes constitute the bulk of the stock during a given fishing season.

The fact that a tuna stock is composed of only a few age groups has the important implication that if the recruitment fluctuates very widely the stock may also be expected to exhibit large fluctuations since there is lacking the "buffer" action of many other age classes to dampen out the effect of variations in recruitment. This becomes more important economically to the fishery the more intense the fishing becomes, because at high levels of fishing the catch cannot be greatly increased by simply stepping up the fishing effort in a poor season.

SPAWNING HABITS.

The likelihood of fluctuations in recruitment depends to a large degree on the spawning habits of the tunas. If a single population of tuna spawns over a wide area and a long season, fluctuations in environmental conditions are much less likely to give rise to large variations in survival and be reflected in the recruitment than if spawning takes place only on one spawning ground during a short season.

The spawning habits of the Pacific tunas have been quite obscure until very recently. Yellowfin, skipjack and black skipjack (*Euthynnus lineatus*) as well as frigate mackerel (*Auxis thazard*) were found in 1947 to spawn during the early spring off Costa Rica and Panama (Schaefer and Marr 1948a, 1948b). Marr (1948) also demonstrated that both the yellowfin and skipjack spawn in the region of the Marshall Islands during the summer. As I noted in another paper (Schaefer 1948) there are references by several authors to evidence of tuna spawning near Japan, Hawaii, Palau, and the Solomon Islands. Juvenile specimens of *E. yaito* and *Auxis* sp. were noted also from material collected by A. W. Herre at Celebes. Papers by De Jong (1940), Delsman (1931), and Delsman and Hardenburg (1934) describe eggs and larvae of *Euthynnus alleteratus, Neothunnus rarus*, and *Thunnus thunnina* from the Java Sea. Papers in Japanese, recently translated by POFI translators, such as Kishinouye (1919) and Hatai et al (1941) give evidence of several species of tuna spawning both in the waters adjacent to Japan and in the waters in the region of the Pacific Trust Territories (former Japanese Mandated Islands). Juvenile skipjack captured near the Hawaiian Islands have recently been described by Eckles (1949). Other, smaller specimens of this species have since been captured by scientists of the Territory of Hawaii Division of Fish and Game. Occurrence of females of *K. pelamis, N. macropterus* and *P. sibi* in advanced stages of maturity in Hawaiian waters during the spring and summer months, and the collection last year of a running ripe female *K. pelamis* and a very nearly running ripe female *N. macropterus* from these waters by scientists of our staff prove conclusively that these species spawn in these waters, and it seems likely from the evidence of gonad examinations that the spawning season of each is fairly extended here. Wade (1949) has recently described juvenile *Auxis* from Philippine waters, and has advised us in personal communications of the capture by tow nets of about 2000 specimens of larval stages of various tunas and tuna-like fishes.

It begins to appear that the Pacific tunas spawn in many parts of the Pacific, indeed it seems they may spawn throughout much of their range. The next step is to find out how extensive in time and space is the spawning in a single region. This we are undertaking to do in the region of the Hawaiian Islands by means of systematic study of gonads of females in the commercial catch and by tow net collection of eggs and larvae. During the spawning season this spring and summer we shall attempt to find out about the vertical distribution and the rate of development of the eggs and larvae. If this attempt is successful we shall then be in a position to conduct quantitative spawning surveys by means of tow net sampling in subsequent years.

Compared to our knowledge of many of the commercially important species of the northern seas, the halibut, cod, plaice, salmon, herring, haddock, etc., our store of knowledge of the Pacific tunas as indeed pitifully small. The efforts that have recently been expended towards rectifying this have, however, met with at least initial success. The cooperative efforts to fishery scientists throughout the Pacific promise to provide an early solution to many of the mysteries of long standing regarding the basic biology of the Pacific tunas.

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4

BACTERIA IN MARINE ENVIRONMENTS

by

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ABSTRACT

The main difficulty of marine bacteriology is to explain the way in which the small number of bacteria which can be detected in the open sea brings about the transformations usually ascribed to it. Even in muds this difficulty occurs. It is suggested in this paper that the bacteria do not act directly as much as by producing catalysts or by creating the conditions for reactions which catalysts already present may carry out. The bacteriological work of the Division of Fisheries is testing these hypotheses.

Studies on marine bacteria are numerous, early work being concerned with their numbers, and later work with their taxonomy and function. Zo Bell and Feltham (1934) consider that there are specific marine bacteria which differ from land bacteria in their ability to thrive in seawater. They contend that sea water is bactericidal to land forms, but Waksman and Hotchkiss (1937) have shown that it is also bactericidal to marine forms. I consider, from my own quite extensive work, that the existence of true marine forms is extremely doubtful, and believe that one can trace a gradation from soil forms through the estuarine flora, which also has something in common with the flora of fish spoilage, to the gram-negative marine flora recorded by Zo Bell and his co-workers. The change from gram positive soil types to the gram-negative flora which normally pre-ponderates in fresh water is analogous with the transition from the largely gram-positive mud flora of estuaries to the gram-negative flora characteristic of the sea. There are times in each case where a mixture of types occurs, and except far from land, this is usual. I have found also that many soil forms will grow or can be trained to grow on sea-water media while oceanic forms usually adapt themselves to freshwater media. In terms of genera, the genus *Bacillus* which is common in soils, is also common in estuarine muds, but rare in the sea itself. The genus *Corynebacterium* is frequent in soils and *C. globiforme*, etc., are common in the sea. Many of the gram-negative marine forms seem to belong to the genus *Mycoplana* described by Gray and Thornton (1928) from soil, and to the ubiquitous genus *Pseudomonas*. *Micrococcus* occurs in both environments as does *Sarcina*. The unique *Sporosarcina ureae* recorded by Gibson (1935) in soil has been found by me in the sea ten miles offshore. I should say that the truly marine bacterial flora is an adapted flora rather than a distinct one. To clinch this point, we are now studying the flora of the continental shelf, but the recent loss of our research vessel has prevented me from having this final piece of evidence to discuss at this Meeting, although we have found the usual marine *Mycoplana* in muds of the Australian continental shelf. In addition to the heterotrophic flora, the autotrophic flora is common to both environments, e.g., the purple bacteria, *Azotobacter*, *Clostridium pasteurianum*, etc.

The question of numbers of bacteria in the sea is an awkward one; most observers find only a few bacteria in the sea except near land and in plankton swarms, but these observations have been made by cultural methods. Cultural methods usually reveal only a small fraction of the total bacteria present in a given sample, and we have been trying to find some relationship between the number found by these methods and by direct counting. A further difficulty is that, even in freshwater, the distribution of bacteria does not follow the theoretical Poisson series, and duplicate samples can give a wide variation. So far we have not succeeded in finding a relationship, and I think we may safely conclude

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