7

Behavior

Most people who have thought about the matter agree that even in the most advanced countries, fishing, as compared with other food-producing occupations, is still at a low level of development. Fishermen are like hunters and gatherers in primitive societies. Their techniques and apparatus—hook-and-line, traps, nets—are essentially the same as they have always been. This is not to say that they are as good as they could be. Fishing is everywhere a difficult occupation; and although fishermen in a few special situations are sometimes prosperous, most of them are perennially poor. The processes of fishing are slow and costly, with the consequence that fish is too expensive to solve protein deficiency problems. Thus fishing is less profitable than it should be, fish is more expensive than it need be. How could these conditions be improved? Experts generally agree that fishing could be made more economical if the techniques and apparatus were more effective than those now used. Perhaps entirely new methods need to be devised, radically different from anything that has ever been used. These are most likely to be achieved if based on principles of the behavior of marine animals. Research to discover those principles is fundamental to developing any science of sea fisheries. This chapter suggests questions which need to be studied, and examines various research techniques. It concludes that a special laboratory for studies in marine animal behavior should be established in an area where local conditions are favorable.

In the previous chapter it was suggested that one of the most valuable activities of an environmental laboratory would be the continuous systematic study of faunas. This would give information about the existence, abundance and oscillations of populations of organisms, including those having fishery potentialities. While this research was in progress, a fishery research agency (perhaps governmental) could test, by experimental fishing, the possibility of exploiting such potentially valuable stocks as were discovered, and later could determine appropriate harvesting rates by statistical analysis of fishermen's catches. Thus would come answers to the following questions about any environments that were studied: What is there? How much is there? How much can be taken each year?

There is another question that bears on the full utilization of the sea's biological resources: What is the most efficient and economical way to harvest a given environment? The approach to answering that one is to develop a science of the fishing process itself. As it is now, fishing all over the world is too cluttered with orthodoxies to be scientific. At best it is much more an art than a science, governed not so much by principles as by agglomerations of lore. True, much of this lore is sound, having evolved through centuries of observing the habits of fishes and trying various apparatus, tricks, times, and places to catch fish. Very little of this lore has been systematized, however. What fishermen usually do is draw conclusions and make generalizations from impressions rather than from organized facts; and thus they fall short of a useful degree of accuracy. There is a large element of luck in fishing; fishermen, like gamblers, tend more or less unconsciously to attach special significance to chance association between exceptionally good or bad fishing and quite unrelated events that happen to occur at the same time. Landsmen have many comparable notions, as, for example, that Friday the thirteenth, a black cat, a broken mirror, and an unfortunate arrangement of tea leaves in a cup are all inauspicious omens. Fancied associations like these are continually invented, and although most of them are short-lived, a few persist. Fishermen in many parts of the world go through various actions whose obscure purposes they themselves do not understand. They do these things simply because they were taught to do them. Some of these actions result from pure superstition and must have had their origin in episodes very far back in the past. A boy born into a fishing family grows up steeped in all such lore. It becomes part of him, like a language, so that by the time he is on his own it affects his response to every situation at sea.

Thus an aura of mystery has evolved about fishing, which sets it apart from the more prosaic activities of man. Moreover, it is much more hazardous than most occupations, financially as well as physically. Whether or not a fisherman makes a living at all depends very much on the success of his judgments, which in turn depends on his store of real knowledge. At best his income is unstable. Not only is he subject to the same economic ups and downs that affect people in other occupations, but he must contend with sharp fluctuations in fishing luck that range from glut to famine.

Fishing need not be so unstable. It need not be such a blind gamble, for the element of luck largely is proportional to the amount of ignorance. If fishing were completely scientific, a fisherman would know what species it would be most profitable for him to take at a particular time. He would know exactly where to find it and at what depth; he could herd not merely the species but the sizes he wanted, repelling those he wished to avoid; he would capture his quarry and get it aboard his vessel quickly and with a minimum of labor. All this would require very great improvement in the ways of fishing, including the invention of new apparatus and techniques. However, this should be attacked not by trial and error, which is a wasteful and unnecessarily slow way to advance, but by application of principles.

Perhaps the most fundamental subject of research to bring forth such principles is the psychology of marine organisms. That is to say, if we are to develop the most efficient ways to catch fish, we must first find out what they *do*. What are the strong and weak points in the patterns of their behavior? How can these be used to the advantage of fishermen?

For example, how do fishes feed? Do they detect food by sight or by smell, or by hearing? Do they go about actively seeking and selecting their food? Do they stalk their victims, or do they lie in ambush for them? Or do they behave like living plankton nets, sieving out of the water whatever food organisms happen to get caught in their mouths? Do they feed only when they are hungry, or whenever food is available? What are their enemies? How do they elude their enemies? How otherwise do they protect and defend themselves? What are their spawning habits? Do they exude their sex products into the water at random, or do they pair off and go through some kind of mating activity? Do the males and females ever gather into separate aggregations, and if so, under what circumstances? Do they sort themselves out by sizes to spawn in different areas? How do they distribute themselves and move in relation to each other? What do they perceive in the water? What attracts them? What repels them? What brings them together? How does an individual that has become isolated find its own species? What causes a school to disperse? To concentrate? What are the patterns of the diurnal rhythms in their behavior? How do they react when confronted with a situation new to their experience, like the sudden appearance of a net, the disturbance made by a propeller, bright lights at the surface of the water, or high-frequency sounds sent down by echo instruments? What compels them to migrate? How do they find their way over the courses of their migrations? How far can fish see? What shapes and sizes of objects and what colors can they discriminate? What part does motion play in their vision? What are the thresholds of light intensity that they can perceive?

All these questions have to do with fishes. They are equally pertinent to any other marine animals of interest, from the largest mammals down to the smallest invertebrates. It adds enormously to the difficulty of this line of research that patterns of behavior differ so profoundly among species that knowledge concerning one cannot ordinarily be applied to another. Even for a single species, behavior patterns usually change seasonally, and therefore must be followed through the course of a year. They also change with age, as a result of experience, and must be followed through a complete life cycle. On this, E. S. Russell writes:

> . . . a very important characteristic of much behaviour, the significance of which is apt to escape the sophisticated observer, intent on analysis . . . is the fact that behaviour is often part of a long-range cycle of events, in which one action prepares for and leads on to the next until the end term is reached. Each stage in the chain or cycle is unintelligible to us except in its relation to what has gone before, and, more particularly, to what is yet to come. Such cycles have a temporal unity, extending often over months of time, just as a simple coactive action has unity of short temporal range.[1]

We agree, then, that it is worthwhile to study behavior of marine animals. How shall we proceed? The idea that comes immediately to mind is to experiment in aquaria. Subject captive fishes to various stimuli and observe how they respond. A few scientists have engaged in such research. However, they have used for subjects mostly animals that do well in small aquaria, like tide-pool fishes. These show such remarkably distinctive behavior patterns as to make one wonder what larger animals would do. There we run into an extremely difficult problem, for capturing large sea animals without injury and transporting them alive to a shore base poses a complex of formidable problems. Keeping them alive in a tank, even a very large one, and inducing them to feed and carry on their normal life habits without being conditioned by the artificial environment to the point of uselessness as experimental animals poses another set of problems. Russell makes the following comments.

One of the great practical difficulties about the study of animal behaviour is that it does not lend itself readily to laboratory work; it is necessary first of all to study the animal in its natural surroundings, to become acquainted with its normal mode of life. Without such knowledge we may easily go astray in our interpretation of behaviour in the unnatural conditions of a laboratory experiment; we may easily devise experiments which are meaningless, and, from the animal's point of view, stupid.

Work in the field then—good old-fashioned natural history observation—should precede experimental work in the laboratory. This is often a difficult task, requiring the expenditure of much time and energy.[2]

This statement represents an opinion that is widely held among biologists. It should be taken as a warning, not against attempting laboratory experiments, but against putting too much reliance in them.

There is a circle here. Field studies are needed to learn enough about the natural environment to reproduce it artificially. Experimental studies in the laboratory are needed to learn what elements of the environment are biologically critical. Ideally, the two should proceed together, each benefiting by advances of the other.

Scientists at the University of Hawaii have demonstrated that large, delicate, active, pelagic fishes like yellowfin tuna, dolphin, and jacks can be kept alive in large outdoor tanks.[3] Their experience is worth recounting to show the kinds of problems that are involved in such research. It was virtually impossible to transport skipjack tuna successfully; either they bled at the gills during their violent struggles on deck or they killed themselves by dashing against the sides of the live well. With other species the shock of capture and transportation killed from 40 to 99 per cent of the specimens and the subsequent mortality in the tanks was probably much higher than under normal, natural conditions in the sea. Even so, a few specimens did become adjusted to living there and survived long enough to permit several months of study.

P. B. van Weel conducted experiments on two specimens of yellowfin tuna (*Neothunnus macropterus*) and five of little tunny (*Euthynnus yaito*) in a concrete tank about 33 feet long.[4] His object was to determine whether these fish could detect food by smell or taste alone. To do this he tried several clear, colorless, and therefore invisible, extracts of supposedly attractant substances, introducing them carefully below the surface through a tube. The fish, cruising leisurely round and round the tank, would show a reaction by increasing speed and circling closer to the opening of the tube. The tests showed that both species responded strongly and positively to extracts of flesh of tuna and of marlin, but not at all to water in which bait fish had been living ("conditioned" water) or to extracts of bait fish or of squid. In general, the reactions of the tunny were more pronounced than those of the yellowfin. Further tests showed that it was the protein, rather than the fat, fraction of the tuna flesh extract which contained the attractant principle.

During the next two years Tester and others [5] continued these studies with much greater success in establishing yellowfin and little tunny both in the tank and in a large pond about 360 feet long, 75 feet wide, and averaging about 6 feet deep. Several of the fish survived for at least five months. Yellowfin loss was high, but this was ascribed to poachers who took advantage of the "tame" fish. Of the tunny, which were much less "friendly," two survived in the tank for about a year and two more lived in the pond for over two years. Tester attributes his success to the presence of these survivors, which acted as leaders of newly introduced fish. Eight of the little tunny survived at least five months; all of the yellowfin died within two months. The captive fish were fed squid, shrimp, and fish flesh, and their reactions to a large number of clear extracts of natural foods and suspensions of chemical materials were observed in a series of carefully conducted experiments. The fish responded positively to extracts of various kinds of fishes, squid, and shrimp, and not to any of the chemical substances. However, Tester could not evaluate the extent to which these results must have been influenced by conditioning, a factor which severely limits such tank experiments. The tuna became so accustomed to being fed dead material that they ignored the live bait in the pond to which they readily respond in live bait fishery. The cut-up food evidently gave off juices which were similar to some of the experimental extracts; consequently, the subjects associated the savor of these extracts with the act of feeding.

The first line of research which these results indicated was to test whether extract of tuna flesh could be effective in luring fish to a boat working in the open sea. The next would be to identify, isolate, and manufacture the essential principle into a bait. An artificial bait, if practical, could revolutionize tuna fishing by obviating the collecting of live bait, which requires days or weeks of each voyage before fishing for tuna can begin. The tests with extract of tuna flesh revealed that there was an intermediate problem. Whereas the attractant effect of the juices had been impressive in the tank, it was unappreciable in the sea. Evidently taste alone was not enough to attract and hold the fish. Perhaps what was required was a visual stimulus. Pieces of aluminum foil, strips of tin, and other such objects were suggested as possibilities. They shine like silvery fish. However, when tried they attracted tuna only momentarily.

The addition of extract had no apparent effect, suggesting that vision plays a greater part in feeding than the sense of smell. Something else is needed besides appearance and savor; that something probably is the motion of a living animal such as a tuna is accustomed to eating. The desideratum now is to develop and produce in mass quantity a cheap artificial bait, with a fish-like shape and color, emitting an attractive flavor, and moving automatically in a lifelike fashion long enough to hold the interest of tuna and keep them at the surface where fishermen can catch them.[6] Whether such a contrivance is mechanically, economically, and biologically feasible has yet to be demonstrated.

The experiments to test the reactions of the captive tunas to food extracts were performed during the noon hour of the day. After dark, Sidney Hsiao observed the reactions of the same specimens to artificial light.[7] He illuminated the tank constantly with two 60 watt bulbs, and then cast additional light in a beam horizontally from one end of the tank to the other. In one series of experiments he used an arc lamp, in another, a projection lantern, and in a third, electric light bulbs. Both the yellowfin and the tunny were attracted to white or colored light of intensities ranging from 70 to 450 foot-candles. They did not react to weaker light, and they were repelled by stronger light. Systematic observations of this sort might lead in time to a more knowledgeable and effective use of lights in night fishing.

The tank studies revealed the kind of pitfalls to be watched for in laboratory experiments with large wild fish. The scientists had only one fish to work with at first, a yellowfin. When later they added another specimen of yellowfin and five tunny to the tank, the two species tended to swim in separate aggregations and to show different reaction patterns. When one of the two yellowfin died, its fellow joined the tunny, and although normally a slower swimmer than that species, it tried to keep up with those in the tank. Consequently its speed of reaction increased and was no longer comparable to what it had been earlier. Next, four of the five tunny died, and the survivor swam with the yellowfin, which took the lead; and reactions of the surviving tunny became slower than had been those of the school. These changes in behavior suggest that a great deal of work will have to be done before one can generalize about the reactions of schools or of individuals of these two species.

Captivity seems to increase susceptibility to disease, with consequent aberration of behavior. This is a problem which is very troublesome in aquaria, and which would always plague tank experiments. "Yellowfin number 1," the subject of most of van Weel's experiments, was brought into the tank on June 20, 1951. It started feeding twelve days later and remained in what appeared to be excellent health until the end of October. Then it took less and less food until it finally stopped feeding and its skin became whitish and distended. Late in December and early in January the fish regained its desire to feed, and although it would snap at food, it invariably missed its target. When it died in mid-January, its body puffy and swollen, it was found to be blind in one eye. The five tunny, introduced at the end of August, began to feed within one to three days, and remained in excellent condition until the end of October. Then they became listless, fed only occasionally, lost their bright color, and died during November and December. This experience probably results from the fish's being much more susceptible to disease in captivity than in their natural environment.

Large, circular tanks, 70 feet in diameter, 30 feet deep, more or less, have come to be a feature of several commercial establishments called oceanaria which have been built during the last few years in several places in the United States. The very size of these tanks makes it possible to approximate natural conditions in the sea so that if artificial intervention for the sake of showmanship were omitted, it might be possible for many species to behave as though they were in their normal environment. However, even as they are, with the crowds of people staring through the windows, and in spite of the spectacular acts that some of the animals have been taught to perform, and the unnecessary conditioning that has affected all the captives, the oceanaria are still useful for some kinds of scientific studies.

At the oceanarium in Marineland, visiting scientists have studied the noises which these animals make under water. The bottlenose dolphin, for example, produces sounds ranging from low growling or groaning, through barking noises, to shrill whistles. Since they make noises, can they also hear them, and if so how do they react to them? To study this question, W. N. Kellogg and Robert Kohler,[8] of Florida State University, subjected twelve specimens at Marineland (ten bottlenose dolphin, two long-snouted dolphin) to artificial sounds made with an oscillator having a frequency range of 20 to 200,000 cycles per second. The normal behavior of the captive animals was to cruise about the tank day and night in groups of two to six, generally in a clockwise direction against the current. They did react immediately to the sounds which the experimenter's instrument produced, by increasing the vertical movement of their horizontal tail and lunging forward with an increase in swimming speed. This burst of speed continued for several seconds after the end of the stimulus. Thus it transpired that these animals heard and responded to sounds ranging from 100 to close to 80,000 cycles per second. The lower tones, from 100 to 400 cycles per second, disturbed the animals much more than the higher ones, causing them to break up their swimming formation, at times to leap out of the water, and at other times to charge or attack the sound-making instrument. These studies demonstrated not merely that dolphins hear, but that they are sensitive to sounds far outside the range of man's hearing. This may mean that they can produce ultrasonic vibrations. Perhaps, like bats, they detect objects by the echoes of their own sound waves. Perhaps they locate food thus, and since they swim as fast as they do, navigating at night and in murky water, they might use this natural sonar, if they possess it, to avoid striking objects like submerged rocks.

Other kinds of marine animals may also depend heavily on hearing for their perception of the environment. People had long thought of the sea as a great world of silence. Now we know it is nothing of the sort. The intensity of sound is reduced by a factor of 1,000 to 1 at the interface between air and water in passing from one medium into the other. Consequently, all but the loudest of undersea noises are inaudible to us. People acquired the means of observing them only after the hydrophone was developed. With this instrument, Marie Fish, of the Narragansett Marine Laboratory, has tested many fishes of the western North Atlantic. Among sixty species studied, all but six made sounds which the hydrophone detected. Fishes have several sound-making mechanisms. The most important of these is the gas bladder, which is caused to vibrate and thus to produce sounds that are usually "low pitched, guttural, vibrant and drum-like . . . variously described as thumps, grunts, groans, growls, knocks, thuds, clicks, boops or barks." [9] Some fishes make rasping, scraping, scratching, or whining noises, by scraping their teeth together, vibrating bones, or rubbing the pectoral fins against the body. Among crustaceans tested were six snapping shrimps, one squilla, three spiny lobsters, a crab, and the white shrimp of the Gulf of Mexico. These all make stridulatory (high-pitched, creaking) noises. Barnacles are reported to make weak cracklings.

Probably many if not most of these sounds have some biological significance. Some attract members of the same species or serve to keep members of a community together. Others repel enemies. Croakers engage in choruses during their spawning migrations. One sound which the toadfish makes appears to serve as a mating call;

another is a threatening growl which tends to drive intruders away from the spawning nest. Hiyama [10] has recorded noises associated with all sort of activities of marine animals, some to repel enemies, others to attract their own kind, and still others made incidental to swimming, feeding, breathing (by mammals), and struggling (against being caught).

Here is a great subject for research. What are the functions of all these noises? How would marine animals respond to reproductions of their own sounds? Research on this aspect of behavior might lead to using sounds for inducing certain species to congregate in places where it is most convenient to catch them, and for driving others away.

Primitive fishermen in various parts of the world apparently use such a principle. In Indonesia, a boy clinging to a bamboo float, his head close to the water, cries out a long monotonous wail over the surface. This noise attracts a certain kind of fish, the black pomfret, which gathers around the singer, where other fishermen are waiting with a net. In the Natoena Islands fishermen attract sharks by making a noise with a rattle. In some Oriental countries, tuna fishermen heighten the frenzy of feeding fish by spraying drops of water on the surface of the sea. Skipjack fishermen of Hawaii do the same thing.

Perhaps fishes hear—perhaps identify—the low frequency sounds which swimming motions of other fishes generate, and from these they may locate their prey. Perhaps too, they somehow orient themselves by using sound. Donald Griffin, working at the Woods Hole Oceanographic Institution, analyzed sounds that had been recorded at sea. In the course of these studies, he observed a loud noise which an unidentified animal had made, followed by a fainter repetition of the noise. Griffin concluded that the second sound was an echo, which was probably audible to the animal producing the original sound. He writes:

> It is thus plausible to infer that at least one abyssal fish estimates its distance above the ocean floor by echo sounding. But we cannot pass beyond the level of speculation without further data concerning the occurrence of such sounds, their correlation with the presence of fish or other marine animals, and the quantitative sensitivity of their hearing.[11]

C. M. Breder has made many studies on fishes in aquaria and tanks. At the Lerner Marine Laboratory at Bimini, Bahamas, he studied the structure and behavior of schools of the small fish, *Jenkinsia,* in a circular pond 12 feet in diameter. At the same time he observed schools of wild fish from the laboratory dock, and so was able to integrate experimental work with natural history observations. *Jenkinsia* may never become a commercially valuable species, and the patterns of its mass psychology may be very different from those of such fishes as herring and mackerel. Yet Breder's studies demonstrate that schools can live in a tank—he had as many as 1,000 individuals at once. They demonstrated further that a great deal can be learned about behavior of a captive school and that there are distinctive mass reactions to stimuli. For instance, schools of *Jenkinsia* always form clear spaces around dark objects. They will not approach solid objects closer than a certain distance. They go nearer to light objects than to dark ones. The temperature of the water in fractions of a degree determined the location of the school in the tank.

> Certain temperature gradients acted to confine these fish as well as would a solid wall. No amount of frightening caused them to pass this temperature barrier.
>
> As the water entering the circular pool was naturally cooler than that near the outlet of the pool, because of the heating effect of the sunshine on the shallow basin of water, a nice gradient occurred across the tank. The critical temperature appears to be about 30°C., the fish consistently refusing to enter water of this temperature. . . . They simply could not be driven by nets or shadows from the area of tolerance.[12]

Concerning the behavior of individuals in the captive schools Breder writes:

> A second-to-second check shows that there is a considerable variation in the behavior of any one individual fish. It is as though any given fish were acting individually, but because of the large numbers of others present, each with its sphere of influence, that individual is continually thrown back from what would have been an independent course of action, giving the whole group the appearance of unit action. The spacing of individuals is also not so regular as might be supposed. . . .[13]

Kenneth Norris, Director of the California Oceanarium, finds that it is not possible to get an accurate conception of the shape of a school by observing from above; it is necessary to observe them frontally also; and this can be done effectively through the windows of his deep tank.

Large open tanks permit the captive animals a good deal of swimming space and thus to some extent simulate natural conditions. At the same time the animals are subjected to such complexes of influences, some natural, others not, that it is difficult to isolate one of them in order to determine its contribution to the sum of effects. This, of course, is a problem that good experimenters continually keep in mind.

An entirely different technique of studying behavior in an aquarium is practiced by H. O. Bull, who experiments on conditioned reflexes of marine fishes under very close confinement in a small laboratory, to learn how they respond to individual stimuli. His work, carried on at the Dove Marine Laboratory, Cullercoats, England, necessitates a specially constructed, sound-insulated building, with tanks designed to preclude all extraneous stimuli from affecting the subject under observation. In a personal communication, Bull writes:

> This special building enabled me to concentrate on factors which are important from the fisheries' standpoint. Emphasis was shifted from academic problems to such purely technical ones as keeping fishes (especially the major food fishes) alive and healthy in confined spaces for long periods, and of isolating the particular stimulus being investigated. None of these was complicated in the sense that a radar set is complicated, but to ensure the purity of the stimuli was not easy.

He first conditions his subjects to associate the presence of food with a change in a single element of the environment—say temperature. Then he determines what degree of change the subject feels and responds to by the threshold at which it performs a complex task to get food. Thus a cod is conditioned to associate food with a change of temperature. It is kept in a specially constructed tank with floor inclined so that one end is deep enough to provide an inhabitable living space and the other extends out of the water. The food is introduced into a chamber at the upper end of the inclined floor of the tank. Gradually, over the many days that the conditioning process goes on, the subject cod learns that food is in the chamber when the temperature of the water increases. As this association becomes more and more firmly established, the subject fish becomes conditioned to move up the inclined plane. At the same time the food chamber is gradually moved upward, day by day, ever farther out of the water. At last the fish learns to go quite out of the water, to wriggle into the food chamber, and to wait there practically high and dry until food is given, which it then seizes sharply and splashes and swims back to its normal position. There is no mistaking the response. If the cod detects a change of temperature, it goes through this remarkable performance; otherwise, it does not.

With such experiments, Bull has demonstrated that under some circumstances sea fishes react purposefully to changes in temperature of 0.03°C., and in salinity of 0.2‰. These figures are close to the limits of accuracy of hydrographic instruments. This fact must be taken into account in designing programs to bring out relations between oceanographic conditions and biological effects; and observations at sea, such as readings of instruments, must be made with much more attention to precision than is generally realized.

Experiments with these conditioned-response techniques are probably the only way to determine sensory thresholds of fishes. They must be planned and controlled with extreme care, however, to avoid conditioning the subjects to the wrong stimulus. This precaution has been very much neglected in the past. Between 1887 and 1920, at least thirty papers were published describing results proving or disproving that fishes discriminate colors. Most of these were meaningless because their authors had failed to control brightness in the experiments.

Many of the troubles that plagued earlier scientists experimenting with these techniques have at last been overcome by improved measuring instruments. Useful as these experiments are, however, they are no magic key to understanding all the mysteries of animal behavior. They tell us about sensory capacity but nothing more. For example, we might train a fish to respond to very low concentrations of various chemical substances in the water. From these studies we could conclude that the olfactory apparatus is functioning well, and we might even establish a measurement of its sensitivity. But we cannot tell how the subject uses smell in analyzing its environment. This problem might best be attacked with a different type of experiment, based essentially on unconditioned rather than conditioned responses and designed to mimic natural situations as closely as possible. But this is exceedingly difficult.

Many kinds of marine organisms seem to have exacting and mysterious environmental requirements which we do not yet understand and therefore cannot yet duplicate. A deep-water species, such as some of the rockfishes (*Sebastes*), might never prosper in artificial enclosures, no matter how large the tanks. And even if, by very clever effort, a few specimens were acclimated to live in an aquarium, it seems doubtful that much could be learned about their normal behavior in so abnormal an environment. However, if we cannot have them in the laboratory, we can at least try to study them in their native environment. So long as we do so systematically with clearly formulated questions in mind, and not just to accumulate more anecdotes about behaviorisms, we can learn a good deal in the field, especially since there are now new instruments which make it possible to penetrate the marine environment with our senses of hearing and sight. Echo sounders, sonar, underwater cameras, television, and bathyscaphe are new and still in the developmental process. Consequently biologists have hardly begun to use them, and have yet to learn how to give full scope to their potentialities. When they do, such instruments will probably be the means of revolutionizing both marine biological research and fishing.

Although the echo sounder is older than the other instruments, it is only in recent years that scientists have begun to adopt it as a research tool. This instrument was invented to measure the depth of the water automatically and continuously as the ship plows ahead at full speed. It sends a beam of high frequency sound waves into the water, receives the rebounding echoes, translates the intervening time into fathoms, and with a stylus draws on a moving strip of paper a graphic picture of the sea bottom. Recently developed instruments are built to send the beam horizontally as well as vertically, and can detect objects as far away as 2,200 feet. They record not only the bottom, however, but anything that can deflect the sound and send back echoes, which means anything whose density is in contrast to that of the surrounding medium. Fishermen have been using echo sounders for several years to locate fish, and so have saved themselves untold time over the older method of blind scouting. They are even learning to identify the fish below from the characteristics of the traces on the bathygram.

Fishermen locate schools with the echo sounder, but scientists, whose skill it is to arrange and collate data so as to bring out otherwise obscure patterns, can make much more from the records than just that. One example of a fishery biologist's studies of bathygrams will suffice to illustrate the point:

By continuous use of the echo sounder, I. D. Richardson, of the British Ministry of Agriculture and Fisheries was able to keep a research vessel over a school of sprats in the Thames Estuary from mid-afternoon of one day until mid-morning of the next.[14] In the afternoon, the school was in shallow water, packed in a dense mass close to the bottom. About an hour before sunset, it started to rise. By 4:55 p.m. it had reached eighteen feet from the surface, and in the next twenty minutes as the light of the sun left the sky, it rose until the noise of the fish breaking the water could be heard. The school moved about, into areas that were deeper, but stayed near the surface until dawn, when it descended again towards the sea floor.

He went on further to observe the diurnal movements of herring schools off North Shields, off the Yorkshire coast, off East Anglia, and off Cape Gris-Nez on the French coast. Herring evidently behave differently in different places. The echo tracings showed that in the North Shields area they formed less tightly packed schools than off Yorkshire or East Anglia, perhaps because in the one region they were schooling for feeding, while at the other two they were gathering before spawning. Although there was a good deal of irregularity about their vertical movements, the schools of herring tended to be nearer the surface of the sea during hours of darkness and farther down during the day. Off North Shields the schools came to within about five fathoms of the surface at midnight, on the average, whereas off Yorkshire they never got closer than ten fathoms, and at Cape Gris-Nez six or seven fathoms.

At East Anglia herring seem to rise suddenly and rapidly from the depths. These episodes, which fishermen call "swims," generally occur at night, though occasionally also during the day. After a swim, the schools remain near the surface for a very short while, and then descend to deeper water. Swims are very important to East Anglian fishermen, for it is then that schools strike the drift nets suddenly and fill them with bumper catches. On analyzing a large number of echo tracings, Richardson was not able to adduce any evidence to support fishermen's long-standing belief that a swim results from a fast, sudden vertical movement. When he statistically analyzed the tracings from all places where echo soundings had recorded herring, it transpired that the level which schools take is determined by the intensity of light; and that varies from place to place and time to time, depending on the quality of daylight and the turbidity of the water. A rapid swim certainly does occur at East Anglia, for fishermen's nets do on occasion fill up suddenly and fast, but it has yet to be explained.

Why herring seem to respond to light as they do also has yet to be explained. The logical first supposition is that the fish rise or descend not because the light intensity changes, but because they are pursuing food organisms which migrate diurnally. But it can hardly be that, since herring make the same vertical migrations during periods when they are fasting as when they are feeding.

Richardson performed some interesting experiments with an electric searchlight which he directed vertically over the side of the ship. As soon as he switched on the light over where the echo sounder had recorded a school of herring, the fish descended to deeper levels, and remained there until he switched off the light. Then they rose again to their normal level. Pilchard, on the other hand, reacted differently. When the light was switched on, they descended just like the herring. But after a minute and a half, they rose towards the light, a few specimens even breaking at the surface.

They remained there until the light was switched off and then returned to their former level.

Scientists on board ships have performed other light experiments which demonstrate how changing some quality of a stimulus can alter the response. Although sunrise and a bright searchlight repel herring, causing them to move to deeper levels, people often use lights to attract them. The difference in intensity between a 100 watt bulb and a 200 watt bulb hung over the side of the ship is enough to reverse the reaction; that is, herring rise toward the surface when the weaker light is turned on, but move downward in response to the stronger. It thus appears that a certain light intensity exists above which herring are photonegative and below which they are photopositive. In the afterglow after sunset, they rise and move westward. In the pre-dawn glow they move eastward. At sunrise when the light becomes bright they descend.

Studies on the responses of marine animals to artificial stimuli in their natural environment obviously have important practical application in fishing. They can go farther, however, when they are backed by fundamental research into the microscopic anatomy and the physiology of the sense organs. This is a field of research that has been very much neglected by marine scientists and should be a starting point in any serious effort to build up a science of behavior.

It is an old story to fishermen that commercially useful demersal animals like flounders, rockfishes, lobsters, and crabs are not scattered randomly over continental shelves, but are concentrated in rather definite areas. The locations of these areas shift about with a certain amout of regularity, but also with enough irregularity to make them undependable. To understand such vagaries in distribution, it would be useful to know the habits of all the other creatures that share the environment with the commercially valuable species. How do the animals space themselves in relation to their own kind and to other species? What are the geological characteristics of the ground which they occupy? Until lately, scientists could answer such questions only by sampling the bottom with dredges and mechanical grabs, then analyzing the composition of the collections. That was the only means they had. Qualitatively it was not very satisfactory, and quantitatively it was worthless because there was no way of knowing what had escaped from such gear, and no sure way of reconstructing from the heaps of intermingled specimens, rocks and mud, the arrangement in which these organisms existed in the bottom communities from which they were taken. That need no longer be a troublesome problem, because the bottom can at last be photographed, and its ecology examined as it actually exists.

An automatic undersea camera was introduced in 1940, which can be operated down to depths of over 2,000 feet and can take pictures which show the organisms clearly enough to permit identification and counting.[15] It is a superb, relatively inexpensive instrument for systematic ecological studies on an area like a bank, but so far its use for that purpose has not been fully exploited. Henry Vevers, of the Marine Biological Laboratory at Plymouth, England, has given a fair sample of the kind of information the camera can yield.[16] He took a large number of photographs each of a square meter of ground, along transects over the bottom off Plymouth, following sampling methods used in surveying land vegetation. Just as expected he found patchiness in the bottom fauna. In some places there were very few animals, in others clumps of bryozoans, which served as shelter for crabs and mollusks. Most astonishing, though, were the masses of brittle starfish which he found concentrated in some areas, completely covering the bottom and piled on top of one another. He counted as many as 500 on a square meter, and estimated that over large areas of the sea bottom in that part of the ocean, there were 250 million brittle stars to the square mile. He thought they might concentrate thus only during a certain season of the year, perhaps for spawning. But no, continued observations proved that they remain so all year round, packed together even when there is apparently vacant space nearby.

A laboratory study has shed much light on the reasons for this behavior. W. C. Allee,[17] working at Woods Hole on *Ophioderma,* a related inshore species, found that this brittle star would form just such aggregations in glass aquaria but not in their normal summer habitat which is among the leaves of eel grass. Aggregated animals consumed more oxygen than isolated ones, and their survival was better. This effect persisted when Allee substituted twisted glass rods in the aquarium for some of the starfish. The starfish would then twine themselves amongst the rods, not forming the typical clusters found in otherwise empty aquaria.

Do fishes avoid these grounds that are so infested because brittle stars are not very nourishing, or in response to some other mechanism? In any case, such grounds are useless for fishing. It might be worthwhile to trawl out the starfish in order to make room for something more valuable. That brings up the question of whether fishes would actually move in to take up the space thus vacated, and whether the job would cost more than the return.

Automatic cameras can provide answers to many questions, but their use is a blind operation and they do not afford continuous observation. For that, a television camera, adapted for underwater research, is ideal. After several years of development the apparatus is still expensive, good equipment costing in the neighborhood of $20,000. Less sensitive yet very useful equipment can be bought for around $5,000. Underwater observation with television has been shown to be a wonderfully effective instrument for studying the deep sea environment and its occupants.

H. Barnes, one of the pioneers in developing this equipment and in using it for undersea studies,[18] has demonstrated its effectiveness in bottom surveys for estimating sizes and numbers of sedentary and slow-moving animals. He watched for several hours at a time the behavior of lobsters and crabs with traps. He observed that most crabs entered the traps through the opening on the side facing down tide. Evidently they were reacting to material carried down current from the bait. Once inside the trap the crabs made straight for the bait, sometimes fought rivals for a piece of bait, fed vigorously for about twenty minutes, then retired to a corner and remained inactive for a while. Then they moved around to explore the trap, sometimes escaping through the top netting. Barnes also observed and identified plankton organisms and even counted those passing before the lens at different levels.

He points out several disadvantages. For one thing, the biological material is only seen, not brought up for examination. Therefore, television cannot be used quite independently of classical techniques of zoology and botany. On the other hand, information gained through television should be helpful in making collections. Another disadvantage of television at its present stage of development is that it is costly to operate as well as to buy, for it is necessary to have a full-time technician to service it. No doubt further improvement of the apparatus will bring about considerable simplification. Clarity of water is a limiting factor; in turbid water the haze resulting from light scattering reduces the quality of the image. When artificial light is used, animals do not behave normally, a fact which the observer must take into account in assessing the results.

Barnes also points out the advantages of underwater television in undersea studies. It yields information on the bottom fauna and the relations of one set of organisms to another. The observer can watch a scene continuously on the viewing screen, making records all the while. He can adjust the apparatus by remote control mechanisms so as to get the best view and focus of a given scene. With television biologists can safely and comfortably study ecology at great depths. In discussing the results of his studies, Barnes writes:

> We have had many hours' viewing and it is neither necessary nor desirable to describe in detail the many things which have already been seen. Rather we must attempt to assess the potentialities. The instrument is undoubtedly of importance for the study of the epifauna both biologically and in its relation to the physical environment. If the species present in an area are known, it is not difficult, after practice, to distinguish between them—and if in doubt animals can be lowered with the camera for practice recognition. Dense colonies of Ophiuroids, *Luidia ciliaris* preying on them and seeming to sweep whole areas clean, have been observed. The behavior of animals can be watched—the fighting of crabs, the behavior of bottom-living creatures in relation to their burrows—all come within this category. Physical features of the bottom—aggregation of shells of fixed orientation, sand ripples, traces left by animals dragging over mud surfaces—have all been investigated.
>
> All these are stationary or sluggish subjects. With fast moving animals such as fish the technical difficulties become greater. When close up and easily recognizable they are quickly out of the field of view and when far away they are recognized only with difficulty.

Already a good many of the disadvantages described by Barnes have been overcome by recent advances in underwater television development. A group of fishing gear experts at the United States Fish and Wildlife Service laboratory at Coral Gables have developed a small, compact vidicon television chain. This equipment has proved effective in studying fishing gear in operation in the clear waters of Florida. Observers have studied a moving trawl by lowering the television camera from a following boat and towing it in various positions around the net. Remote controls enable the operator to direct the camera toward the particular parts of the net under investigation. The great possibilities for the use of television in gear improvement work are apparent.

The advantages of vidicon equipment in simplicity and compactness are offset to a considerable degree by lack of sensitivity. This shortcoming may be of little importance in clear tropical waters, but can reduce the usefulness of television greatly in the turbid waters of more northerly seas.

Biologists at the United States Fish and Wildlife Service laboratory at Woods Hole, Massachusetts, have recently developed a television chain which combines compactness and high sensitivity. The image-orthicon equipment used is sensitive enough to produce a usable image with only one foot-candle of light. This television chain requires, in addition to the underwater camera, deck gear in the form of a power supply unit and a camera control unit, each about the size of a living room television set. These units are connected to the camera by a 28 conductor, ¾ inch, water-proof cable.

The camera unit is housed in a streamlined cylindrical case, 10 inches in diameter and slightly over 5 feet long, which contains sufficient air space to afford neutral buoyancy. This housing can withstand pressures to 1,000 feet of depth. Controls on the deck units permit the operator to change focus, select one of three lenses and adjust the iris opening. Signalling systems warn of leaks in housing or cable and of excessive heat in the camera unit.

The remarkable sensitivity of the image-orthicon equipment permits viewing in depths of over 120 feet in the normally turbid waters off the New England coast. Thus relatively deep-water species can be studied in their natural environment without affecting their behavior, for artificial illumination is unnecessary. Although it is still not possible to observe closely the activities of fast-moving, wild fishes on the underwater plains over which they range, many exciting possibilities suggest themselves.

The Woods Hole biologists have been able to secure the camera inside a trawl which they have dragged at 3.5 to 4 knots over the bottom. Thus they have been able to prove that small fish of many species really do escape through the distended meshes of the cod end (thereby refuting fishermen's assertions to the contrary), and they have watched the impounded larger fish swimming along in the same direction as the net was dragged, evidently not panicked by the surrounding webbing.

A direct and inexpensive way for the field observer to get into the same environment with marine animals is by free diving equipped with a scuba (self-contained, underwater breathing apparatus), consisting of a face mask, compressed air apparatus to permit underwater breathing, and skin covering for protection against cold. Free diving is the best means of studying marine life and the reactions of animals to various stimuli, for the animals seem generally indifferent to the presence of a human being. Occasionally a curious fish approaches to investigate him but most animals ignore him. Thus he is able to observe their normal behavior in their own environment. He can peer into caves, dig in the bottom, collect specimens of particular interest, and can experiment with lights, sounds, chemicals, and objects. These things cannot be done by the operator of a television camera or a biologist sitting in a bathyscaphe. On the other hand, a Scuba diver is severely restricted by depth, air supply, and other limiting factors.

An excellent instrument for observing at deeper levels is a steel diving chamber. The first of these was the bathysphere, which Otis Barton invented more than twenty years ago, and in which he and William Beebe went down 3,028 feet into the deep water off

Bermuda. Through the fused quartz windows, 3 inches thick, they peered at such wonders as had never been caught in net or on lines, and so had not been seen by anyone else. Beebe wrote, "Every descent and ascent of the bathysphere showed a fauna rich beyond what the summary of all our 1,500 nets would lead us to expect. Bermuda is in the Sargasso Sea, which is accounted an arid place for oceanic life, but my observations predicate at least an unsuspected abundance of unknown forms." Other such craft have been built since. In 1953, Auguste Piccard and his son descended into the Tyrrhenian Sea almost two miles in a "bathyscaphe." This diving vessel was lowered a short distance by a cable, then freed, sinking with the help of two steel balls held in place magnetically. Two small electric motors permitted navigation. The vessel was raised by cutting the magnetic field which allowed the steel balls to drop off. Thus the diving vessel was free to cruise about independent of the surface tender. The first descent of the bathyscaphe established a record for depth. The observers saw plankton, looking like "the milky way during a beautiful summer night." [19] At 1,200 feet they saw shrimp, jelly-like blobs, small medusae, and a number of kinds of fishes, including some that looked like anchovies, and small eels. At 3,300 feet the abundance of organisms increased considerably. There were shrimp, squid, unidentifiable creatures, and many sharks. The bottom at 4,040 feet was "blistered with innumerable big mounds pierced by small holes." Animals burrowing into the bottom indicated an intense underground life. A bathyscaphe would be superbly useful for studying life on the slopes of continental shelves and in canyons where the ordinary gear of fishermen does not reach, for learning the direction of migrations, and for locating stocks that have moved out of the range of a fishery (i.e., become "unavailable").

A research submarine chamber has recently been built in Japan. It is 3.15 meters high, 3.7 meters long; the observation chamber is 2.2 meters high and 1.48 meters in its outside diameter. It has one window in front which is 150 millimeters in diameter, besides three on the sides and rear and one on the bottom, all 100 millimeters in diameter. Lights required for photography and illumination, including a strobe flashlight, although outside, can be controlled from within the observation chamber. The apparatus carries two people; it can descend to 200 meters and stay there for ten hours. In case of emergency, it can be raised immediately by manipulating a special device, or if this should fail, by casting off weights attached to the lowering platform, and thus increasing buoyancy. An advertisement says of this instrument:

With this we can study the spawning grounds in deep sea areas, the ecology of fishing grounds, the characteristics of the bottom on which fishes live. We can observe fishing gear in actual operation. We are now carrying on a survey of coastal resources, which we consider a most important undertaking. We are firmly convinced that this is really an epoch-making research enterprise.

I have emphasized in this chapter the difficulties inherent in laboratory studies. Bringing the animals from their native habitat to a laboratory subjects them to a severe trauma. They are given too little space and are frightened; they become malnourished, diseased, and they die. If we could take the laboratory to the animals, as we could with a diving vessel, these technical problems could be solved. There would be other problems, of course, but we would at last surely be studying natural behavior. Biologists using this instrument would have the chance to answer many questions that have been puzzling us. For example, how do bottom-living fish behave? What are the diurnal rhythms of animals? What stimuli trigger their responses? How do animals space themselves in relation to each other? How do predators attack their prey? How do the various species protect themselves against each other? How do they cooperate? In short, what do animals *do* in their own environment? People to whom the behavior of land animals is commonplace knowledge because they have seen it with their eyes, do not realize the vastness of our ignorance about behavior of marine animals. The original bathysphere still exists, others have been built in France and in Japan, and one is being planned in the U.S.S.R. Unfortunately, these are costly to buy as well as to operate; they are cumbersome and they can accommodate few observers at a time. For these reasons the chief hope of making a submarine observation vessel generally available to biologists in a region would be for several neighboring laboratories to join forces to acquire one and keep it in continual operation.

In the main, it is not lack of techniques and instruments which hinders research into the psychology of marine animals, but lack of interested scientists. How can research on behavior of marine animals be encouraged? To begin with, it is necessary to seek scientists who are more interested in that subject than in anything else and who have prepared themselves for it by a suitably broad education. Research must always begin there, with men who are excited by a particular mystery in nature, and are driven by an irresistible will to explore it. To study behavior effectively, these men need something more than a pair of rubber boots, a bucket, and a portable glass aquarium. They must have a proper place to work, including large, deep tanks with facilities for underwater observation and laboratory rooms especially constructed for perfect control of experimental conditions. There must be equipment for free diving, for undersea photography and television, and, if possible, a submarine such as a bathysphere or bathyscaphe. For behavior studies, the characteristics and equipment of the base of operations are more important than for most other kinds of laboratory marine research. The base of operations must be in a place where the surrounding water is clear enough for field observation and where there is a good supply and variety of marine forms for study. It might be in such a place as Bermuda, the Gulf of California, the Mediterranean, or Hawaii. It should be part of an environmental laboratory attached to an established research institution, providing the obvious advantages of a good library and a staff of scientists working in related fields.