Aspects of Research in Marine Biology[1]

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It is usual to begin a discourse by defining the terms to be used so that the author may assume that his readers will not be completely at sea. Of course it may surprise some to be informed that marine biology has yet to be defined to the satisfaction of many people. Some of those who would like marine biology defined are really asking if marine biology can be considered a separate field of science, if it has a different approach to its problems than terrestrial or non-marine biology, for example. The question might be academic if it were not that such a definition might be used for legislative purposes. It will be adequate for this discussion to consider marine biology as that part of biology concerned with marine life, and for most teachers not too far from the sea, this means the study of organisms that live on the seashore or in the bays. Such organisms may of course be isolated from their environment for experimental purposes, but that does not make them any less marine. Even the experimentalist who is utilizing marine material because it best suits his needs may also be concerned with the provenance of his material and may contribute to our knowledge of whatever he is using—be it sea urchin eggs or the nerves of polychaetes—as marine organisms. To that extent he is to be considered a marine biologist.

The term for which we must be most concerned with establishing a common ground of understanding is "research." This word is in danger of becoming meaningless. I would certainly not consider that looking up something in a dictionary or compiling a table of batting averages out of the almanac is research, but some people do. The older meaning of the word itself is not greatly different from this, however, and the Oxford Dictionary gives as it first definition of research: "The act of searching (closely or carefully) for or after a specified thing or person." This could include prospecting for gold or looking for one of the ten most wanted men, but it is also the general meaning understood by Charles Darwin when he called his first book "Journal of Researches into the natural history and geology of the countries visited during the voyage of H. M. S. Beagle. . . ." The second definition offered by the Oxford Dictionary is more descriptive of current ideas about research: "An investigation directed to the discovery of some fact by careful study of a subject; a course of critical or scientific inquiry."

According to the American College Dictionary, research is "diligent and systematic inquiry or investigation into a subject in order to discover facts or principles." This seems to be close to what we might call the average definition. That given in Webster is again different, and adds motive: "Studious inquiry; usually, critical and exhaustive investigation or experimentation having for its aim the revision of accepted conclusions, in the light of newly discovered facts."

All these definitions are in part adequate, although the tacit assumption in the last that *all* accepted conclusions may require revision is debatable. The most essential word in all of them is "inquiry." This means that someone has asked a question, and the alert and inquiring mind that understands the subject well enough to ask meaningful questions is the most essential part of research. Without the question—or some working hypothesis—we can have the sort of statistical compilation that passes for research in departments of education, and when the answer is already known we do not have research but a project. It is, however, neither possible nor advisable to draw a hard line between research and project. We should avoid the error of thinking that inquiries which do not involve experimentation in a laboratory are of a lower order—the humble observer of ants can be as much a research scientist as the daring improvisor of proteins who is flirting with the origins of life. As for projects, it is by no means rare to have a student turn up something unsuspected or unknown in the process of a standard laboratory assignment.

[1]From an address given at the Biologists Conference of NABT, at Diablo Valley College, Concord, California, March 11, 1961.

or experiment that may have been done thousands of times before, but the next step is the critical one. If this happens to an alert and inquiring mind, in the catalysing presence of an understanding teacher, some sort of research is inevitable. Indeed this is the way most research scientists have had their start: a student has been encouraged to follow through when his own curiosity has been aroused.

Research, of course, is not an exclusive property of science. One of the finest pieces of research that I know of—and one which had no small part in directing my inclinations toward systematic zoology and in demonstrating to me how a library could be used—is in the domain of English literature. This is that detailed and fascinating analysis of how Coleridge happened to dream of Xanadu and write the famous fragmentary poem that was interrupted by "that person on business from Porlock." This is research in the psychology of creation, inspired by the question: "How did this dream come to Coleridge?"[2]

Many of us in college and university science departments, fully aware of the great responsibility of the high school and junior college teachers—such teachers, whether they realize it or not, may stand at the critical parting of the ways in this process of mental development of their students—have become engaged in programs supported by the National Science Foundation designed to enhance the understanding of at least some of these teachers by making it possible for them to participate in active research programs. At Pacific Marine Station this takes the form of recruiting a summer research team to carry out some aspects of our long term program in the study of environmental changes and the composition of marine communities. Instructors from the first years have returned with selected groups of students to carry out phases of this work on week ends during the school year, and some of the instructors are working on their own research projects as a result of their experience with us. We do not expect that all our participants will become full blown research men because of this experience, but we hope that our participants will continue to develop modest lines of research that will not only enhance their own understanding of the research process but will also provide their students with an immediate demonstration of research in action. Research is not a mechanical process of hypothesis, testing the hypothesis and development of a theory, but an art—the art of asking meaningful questions. Demonstration by example is as essential a part of the process of research training as it is in music or painting. This implies education in its finest sense of "bringing forth" or "to bring out something latent," and is far removed from the didactic pedagogism of blackboard outlines and sterile analyses of great deeds of the past.[3]

Science fair projects may have their place in this process, and it may be like casting aspersions on Home and Mother to question their virtue, but they are hardly an unmixed blessing. Indeed I have heard of schools in which participation is compulsory or the program of the science class is designed specifically to produce science fair exhibits. Perhaps this was how one sad little exhibit turned up as an entry in biology at one science fair. This was designed to illustrate the achievements of great scientists— the science projects of the geniuses, I suppose. Orville Wright was represented by a battered toy airplane, Burbank by a potato or a daisy, I forget which, Marconi by a radio that looked suspiciously defunct, Edison by a Micky Mouse wind-up phonograph, and Pasteur by an empty milk carton whose label indicated that the contents had been pasteurized.[4] Some of the projects of more biological

[2]John Livingston Lowes: The Road to Xanadu. A study in the ways of the Imagination. Boston: Houghton Mifflin Co., Revised edition, 1930. One of my high school English teachers urged me to read this book, and I will always remain indebted to her for that stimulus although I must say that I remember practically nothing that went on in the class.

Reference to this was an extemporaneous digression from the talk as given at the meeting, and I remember to my horror that I made the not un-Coleridgean lapse of confusing the man from Porlock with Amos Cottle—a justly deserved fate for Mr. Cottle, perhaps, but nevertheless the matter should be set straight.

[3]Education, it seems to me, is too noble a word for educationists to debase. They should return to pedagogy.

[4]This was an eighth grade exhibit. It is of course heresy in some parts of California to question the scientific stature of Luther Burbank, but it should be obvious to the reader that Pasteur was the only subject in the exhibit described who has a place in the history of science. However, I am indebted

content were little better: something or another about a pet horse, a crudely drawn and labelled human skeleton, and the usual ant nests and series of chick embryos. Marine biology is usually represented by a collection of sea shells which seldom receives a second glance from the judges.

Good biology projects of any kind in science fairs are less in evidence than gadgety physics demonstrations. Perhaps biology is after all a more difficult science than physics, at least for young minds at the science fair stage. Or, it may mean that too many biology instructors are failing to demonstrate by precept and example, the scientific method in biology.[5] For better or worse, science fairs seem to have become an established part of our educational culture, and it is time that we gave more thought to them, not as status symbols for successful instructors and administrators, but as a privilege for those students who are doing things by themselves because they are interested in them for their own sake. They have always been such students, long before the days of science fairs, and while science fairs were started with the praiseworthy motive of bringing such young people to light, I wonder if some of the best students are not avoiding this light, while the glibly opportunistic win the prizes.

Enough of sermons and moralizing. After all, the subject of this contribution is supposed to be "aspects of research in marine biology." Aspect is a nice vague word which leaves the scope of the discussion to the speaker's discretion or inclination. I have chosen to take this as referring to the major problems of marine biology—the things we want to know, and which are being worked upon most actively at this time. If we put these in the form of questions, we can logically start with the most obvious one: "What organisms do we find in the sea?" While we know something about many of the creatures of the sea, there are still many incompletely known, and major discoveries yet to be made about them. And from time to time some strange and unsuspected creature is turned up, even an occasional "living fossil." Even if we knew all the organisms of the sea, this is still the first question anyone will ask, and it is the first question that brings class groups to the seashore on field trips. Much of the research inspired by the question falls into the domain of systematic biology, the process of classifying, naming, and studying the evolutionary relationships, of organisms. Up to perhaps a hundred years ago this was considered one of the major fields of research and no apology had to be given for the study of systematics or taxonomy. Science has its fashions, like any other human endeavor, and for a while this branch of biology was quite unfashionable. Yet we have come to realize that we need to know a great deal more about the systematics of the plants and animals of the sea, and that we will always need people who are curious enough to learn about them in such detail that they can be relied upon to provide accurate identifications of the vast numbers of specimens being taken by oceanographic expeditions and routine surveys. Indeed, in the expanded program of oceanography now being proposed in Congress specific consideration is being given to the need for training and supporting taxonomists, for it is realized that understanding many of the processes of the sea is directly dependent on how well we can keep up with the taxonomy—or systematics—of the organisms involved.[6] Al-

to this dismal exhibit for the stimulus to refresh myself about Pasteur's attainments by dipping into Gabriel and Fogel, "Great Experiments in Biology," Prentice Hall, 1955.

[5]Since making this comment I have seen the report by Lindsey R. Harmon, "High School Backgrounds of Science Doctorates" *Science*, 133 (3454), pp. 679-688; 1961. Biology is trailed only by education in the intelligence ranking and proportion of higher intelligence groups obtaining doctoral degrees, according to this report. The inference is directed squarely against the teachers: ". . . it is apparent that the fields of biology and education have not been able to attract their proportionate share of individuals of highest intelligence, as intelligence is judged from high school test scores. As the problems in these fields are certainly as challenging as those in the physical sciences or social sciences, it might be inferred that there is a failure somewhere, probably at the high school level or even earlier, to present these challenges adequately to the bright young people who eventually attain doctoral degrees." Of course, the differential in salary might have something to do with this also; according to Bentley Glass, in his little commercial offering for an insurance company the median wages of biology is $6,789. It is only fair to point out, however, that it has been the tradition for at least twenty-five years for high school counselors to advise students preparing for college to take physics and chemistry in preference to biology, and to advise weaker students to take biology as a high school science.

[6]For further details concerning the proposed ex-

though the systematics of many groups can be carried out with comparatively modest capital investments in equipment—microscopes, preservatives, and dissecting equipment, for example—critical systematic work does require the resources of a good library and an ability to handle several foreign languages. Nevertheless systematic work can be and has been carried out by high school and junior college instructors and more might be done by such people.

A corollary to the question that asks what are the organisms of the sea is the question where are they, or what is their distribution? This is the field of biogeography, and again there are many unanswered questions about the organisms of the sea. We are still not sure about the patterns of distribution of plankton on the high seas and have barely begun to get an idea of the distribution of those organisms that live somewhere between the surface and the bottom of the sea. This work requires expensive ships that swallow money at the rate of $1,000 a day and costly apparatus beyond the hope of most of us, but there are many problems of shore biogeography remaining to be investigated.

It is in this area of marine biology that field trips might make substantial contributions to our knowledge. Too often a field trip to the sea shore becomes a sort of picnic, especially if a long period of time has to be spent in travelling. The students have become restless and want to run around, and if the destination is a locality rich in marine life, there is too much to absorb in a short time. On all sides we are hearing expressions of regret and alarm about the attrition of our seashore life from excessive field tripping (principally the concentration by many school groups on limited areas) and increased public access. I am not too sure but that a richly populated shore is too much of a good thing, that it might not perhaps be better to take student groups to some less lushly populated spot, and to arrange to spend much more time there, accumulating information that might be stored against subsequent visits by classes in later years. We hear over and over again that things have changed, some of the animals seen last year are not there this year, or that newcomers seem to have turned up. This sort of information needs to be recorded in such a way that it can be of value, not simply experienced. Awarding students points according to the rarity of the specimens collected, however, reduces the field trip to the status of an Easter egg hunt. Long term study of the changes in the composition and abundance of marine organisms is incidentally one of the principal programs we have started at Pacific Marine Station. Our first phase concerns the bottom organisms of Tomales Bay, but we also hope to set up long term observation stations for intertidal organisms as well.

Closely related to the problem of the distribution of marine life in various parts of the sea is that of their ecological interrelationships; that is, how are marine organisms related to each other, how abundant or how scarce are populations, and how are these phenomena related to the environment? Biogeography, of course, assumes that we take into consideration some of the basic environmental factors, but such a problem as the interrelated populations of two species of barnacles that live at about the same place on the rocks is a problem of ecology. Research on such a problem requires counting and some concept of basic statistical procedures, and repeated observations and counts under the supervision of the same teacher over several years would provide an excellent basis for a field trip program that would demonstrate some of the method of ecology as well as provide exceedingly useful data for the oceanographers. We would understand a great deal more about the effects of the recent widely reported changes in ocean temperatures if we had had such counts from half a dozen long standing programs at various places along our coast.

An example of how this sort of thing has been accomplished is provided by the field trip program of a British school.

I am indebted to Mr. W. G. Fry for this description:

"Regularly every year certain boys from St. Paul's School, London, spend three weeks during the end of March and the beginning of April at the Scottish Marine Biological Association Laboratory at Millport. The exact period of time is chosen to coincide with good tides.

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pansion of our national effort in oceanography, marine biology, and aquatic biology generally, see the current version of the Magnuson Bill, 87th Congress, 1st Session, S 901. This is an outgrowth of the "NASCO report" (*Oceanography*, 1960-1970, A report by the Committee on Oceanography, National Academy of Sciences—National Research Council).

"Attendance at the course is optional, but the number of places available is limited, and so only the better students are selected. In addition, those students are preferred who would be able to attend three of these annual trips.

"The school pays a fee covering laboratory space, use of chemicals and darkroom, and supervised use of the library. In addition one of the station boats can be used at certain specified times.

"During the first year's trip, when a student would be 15 or 16 years old, the entire period is spent in class study of the neighboring marine environments, and in becoming familiar with the fauna. In addition, a simple class study of a population of littoral lamellibranchs is carried out. This study has been repeated yearly since the 1930's.

"The second year's stay consists of a small supervised project, worked upon by one or more students, as well as a rounding out of knowledge of the local fauna.

"During the third visit the whole period is devoted to a more advanced project. This is deliberately less closely supervised than the second year project, to find out the student's ability to design and carry through a small research program. At this stage the student would be 17 or 18 years old.

"Results from such projects can be used in the oral examinations on Biology of the Advanced Level of the General Certificate of Education, a public examination taken by all students hoping to attend University."

I do not wish it thought that I am trying to discourage the general, one-shot type of field trip, but too much faith has been placed in them at times, as if the mere act of field tripping was virtuous in itself. Some years ago I participated in a curious interview in which the president of a certain institution interviewed several of us for a position and sermonized us to the effect that he was looking for a field trip man, one who would lead his classes from the low tide line to the mountain tops. "What we need," he said, "is field trips. Dissection killed high school biology, gentlemen, and we must get away from looking at animals in bottles." Since this gentleman told us in the next breath that there would be no time for research in his institution it was obvious that he had no idea how field trips might contribute to research, or, I almost suspect, to education for that matter. General field trips, to look at what is there and get some impressions of seashore life are a necessary preliminary to what we might call research trips, and I hope that more of the latter can be encouraged. Like research itself, they require as a final step some sort of publication, even if only in the form of students reporting on phases of the trip to each other after their return to the classroom.

As for ecological questions, most of those concerning marine organisms remain to be answered and indeed some are still unasked. Research in ecology, in one phase or another, from matters of no direct commercial application to problems involving fisheries and destruction of docks by shipworms and gribbles, is the major activity of many of our marine stations here and abroad, and of fisheries commissions. To this we have added in recent years the tremendous problem of radioactive isotopes. How are such isotopes accumulated by plants, and how are they transferred from one organism to another through the food chain, and how may they effect the organism directly? We have just begun to realize the scope of this problem, and in the years to come this aspect of marine biology will be one of the major fields of research. Understanding this problem will require much more critical information than we now have on feeding habits of all sorts of animals, the actual chemical makeup of the organisms themselves, and how this chemical composition may bear on the accumulation of particular isotopes, and so on. These matters bear upon what might be called the question of ecological physiology of marine organisms. Feeding habits and rates of feeding are almost unknown for the great majority of marine animals, and teachers who are handy at making sea water aquaria go can make genuine contributions to this almost unlimited field.

On the seashore one of the most obvious ecological phenomena is that of zonation. The way in which tidal fluctuations, wave action, and populations of shore organisms interact to result in some of the sharp boundaries that can be observed is still obscure. Here is a field in which we need some new questions, or approaches. At least one ecologist of my acquaintance has been so bold as to say there is no problem here. "Why, the emperor has no clothes!" so to speak. This at least prompts us to ask the question again: "Does zonation really exist" and to go forth and re-examine with much more critical standards this apparent phenomenon. Here again we stand in need of series of continuous observations, re-assessments, and remeasurements. As one who has read almost a five foot shelf of papers on this subject, I can say that one of the most unsatisfactory things about this most obvious feature of seashore life is the lack of good solid quantitative data of actual numbers or weights of the organisms involved. This is a complex ecological problem, involving not only the relations of individual species to the physical environment, but of their populations to other populations, to communities, which we can regard as mixtures or combinations of populations. Many of the problems to be solved here call for knowledge of the physiology of the organisms concerned.

The problem of communities, that is whether there are patterns of combinations of organisms that are there because they are interrelated to each other or whether such groupings are merely the response of different organisms to a similar set of environmental factors, is one of the central problems of ecology, whether on land or sea. Our work in Tomales Bay is in part a program of researches into this question, both from the viewpoint of the present groupings as well as their possible continuity in time. Although the problem of the nature and structures of ecological communities is not peculiar to the sea, marine communities are more three dimensional in nature than terrestrial ones, which makes their study more interesting as well as more complex. Involved in this study are considerations of life cycles, possible interlocking or overlapping periods of feeding, and reproduction by predators and prey, and possible substances that may repel or attract associated organisms. Only recently we have begun to realize that the behavior of marine organisms may play a large part in these interrelationships. Behavior of shrimps and small fish in relation to large fish, with elaborate patterns of symbiotic cleaning or eating of parasites from the gills and surfaces of large fish, may play an essential role in the apparently natural groupings of marine organisms in certain localities. This sort of thing is best observed within the water by divers. Incidentally we are often asked by divers if there is anything they can do for us. Our local waters are too often dark and too murky for good observation of the fine details of behavior, but this is an activity which has become so popular that we can expect some excellent and valuable observers among divers, and in time such people will make substantial contributions to our knowledge of life in the sea, not only of behavior but of communities. It is difficult to gain a good idea of the arrangement of clam burrows and worm holes from the jumbled haul of a bottom grab, and diving in shallow water will become an essential tool for such studies. However there are problems of safety and liability which make it necessary to proceed with caution. Perhaps good courses for adults in their spare time will be the answer to making the best use of our diving talent.

One of the basic questions we ask of the sea, or of its creatures, is that of productivity. Usually the specialists in this field talk of primary productivity, the activity of plants in fixing carbon in the process of photosynthesis. Upon this depends all the life of the sea, as does that of land. The still unanswered question is: which is more productive in this matter of fixing carbon in usable form, the sea or the land? Ingenious methods to study this, some using isotopes, have been devised and symposia of active workers in this branch of inquiry are held almost annually. More is involved here than simply the rate of fixation or the overturn on a seasonal or yearly basis by the plants. The nature of photosynthesis itself still has its mysteries. While studies of photosynthesis and research involving isotopes require facilities beyond the means of most schools, information about the seasonal abundance of phythoplankton is needed from every environment, from the sloughs of the delta as well as the ocean itself. Such studies ought to be accompanied by analyses of some factors of the physical environment—temperature, oxygen, salinity, and nutrients. But even where all these analyses cannot be easily managed, good series of observations, adequately recorded and supported by reference samples, will have their value.

The next step beyond researches in productivity is the problem of the economy of the sea, of the energy budget of what we call the ecosystem. This is a problem that many investigators are now interested in, since a good estimate of the capacity of the sea to support its populations—of the energy needed to make the system go—is necessary before we can turn to what is often considered mankind's best hope for future food, the resources of the sea. Some knowledge of this energy flux, if we wish to call it that, is also necessary in estimating how much radioactive waste we may safely deposit in the sea. Some thoughtful people believe that we should put none of this stuff in the ocean, because we know so little about this aspect of the ocean ecosystem. Others, equally thoughtful, believe that we can dispose, within limits, of radioactive material. What we do not know about this aspect of marine biology is our greatest gap. It involves all these problems of the identity as well as the individual physiology of marine organisms, their feeding rates, their migrations, both up and down (as in the scattering layers), and to and fro with current systems and less regular patterns of oceanic water movements, and of the structure of communities. There is indeed much to be done, and many ways in which enlightened teachers can contribute, both through their own activity and in inspiring able students. The essential aspect of all research is to limit the scope of the problem to be tackled so that it does not exceed either the material or intellectual resources of the researcher. Thus we are back to our definition of research as the art of asking meaningful questions. It is true that many of the problems of marine biology are beyond the simple resources available to most of us, but even the greatest problems have simple aspects. No single person can expect to know the identity of all the creatures in the sea, and for the individual this question may take some such form as "What sea slugs can be found on the California coast," to name as an example one recently published report.[7] As for more complex questions, we can remind ourselves of the example of spontaneous generation. This remained one of the great questions of biology through the centuries until Pasteur designed his ingeniously simple experiment to demonstrate the fallacy of this hypothesis some ninety-nine years ago.

Geniuses with such simple minds are rare, however, and philosopher's stones and magic talismans are even rarer. In the meanwhile there is work to be done, and ample opportunity for all who go to the seashore with an inquiring and informed mind to make useful and essential contributions to knowledge. Chance, as Pasteur said, favors the prepared mind, and conversely, chance may be wasted on an unprepared mind. There are many chances along the seashore as well as out in the deep ocean, and the moral need not be labored further.

[7]Marcus, E. 1961. Opisthobranch molluscs from California. *The Veliger*, Vol. 3, Supplement.

Bionics

Scientists and engineers in their search to understand the world about them and make that knowledge useful turn constantly to nature for clues. At the second annual Bionics Symposium, sponsored by Cornell University and the General Electric Company some 300 scientists and engineers heard reports on studies of such organisms as baby chicks, leaves, and frogs, and how they may be applied to man-made systems such as radar.

An experimental machine, described by A. J. Cote, Jr., of the Applied Physics Laboratory of Johns Hospkins University employs processes patterned after those used by a frog in spotting and capturing insects and has demonstrated the ability to distinguish targets on a radar screen from background noise. Mr. Cote revealed how studies of the visual processes of a frog provide the basis for developing machines capable of fully interpreting radar displays.

Research Institute

A Basic Health Research Institute has been established in Tucson, Arizona, where qualified scientists may conduct basic research on problems of their own choosing. Inquiries should be addressed to Dr. Beatrice Gelber, Basic Health Research Institute, 509 N. Santa Rita Avenue, Tucson, Arizona.

NSTA Meeting

San Francisco is the site for the March 9-14, 1962, meeting of the NSTA. The convention will develop a series of "policy" resolutions for NSTA. A curriculum center under the direction of Prof. Paul DeHurd of Stanford will be a feature attraction. Major speakers include Dr. Ralph Tyler of the Center for Advanced Study in the Behavioral Sciences; Emilio Segre, Nobel winner in physics; and Vice-President Robert MacVicar of Oklahoma State University.