FUNDAMENTAL PROBLEMS IN THE USE OF TELEMETRY IN ECOLOGICAL STUDIES

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Dwain W. Warner, Associate Professor of Zoology and Curator of Birds, Museum of Natural History, University of Minnesota obtained a B.A. degree from Carleton College in 1939 and the Ph.D. degree from Cornell University in 1947. He joined the staff at Minnesota in 1947. From 1943 to 1945 he was in military service in the South Pacific with a Navy Malaria and Epidemic Control Unit and in New Zealand with the Joint Purchasing Board. His primary interests have been in biogeography, systematics and ecology of sedentary, isolated populations of birds and in special adaptations of birds which make long migration flights. These have led to current studies of responses of wild birds and mammals to physical environmental as well as biological factors in the natural environment by attempting to combine the research resources of biology, physical science and engineering.

An appropriate beginning might be to restate what others have written before: that no technique can be used to full advantage until its possibilities and limitations are understood. I believe that our primary aim here is to explore biotelemetry in this light.

While there are usually several ways to explore any problem, it is my conviction, formulated several years ago and unchanged today, that the potential for telemetry in biological research will not be realized until the problems are approached on an integrated, interdisciplinary research basis between the several kinds of biologists, especially physiologists and ecologists, and physical scientists and engineers. Relegation of one or more groups to the level of a service unit has already resulted in strands projects aimed at telemetry in ecological studies.

In order to progress in research into the complex relationships of the numerous parameters of the natural environment the responsibility falls on the field biologist and ecologist to demonstrate to the physical scientist and engineer their research possibilities in ecosystem studies at a biological level. Without research participation by physical scientists and engineers advances in ecology will be slow and inadequate to the demands man is making on his environment.

The problems involved in space probes are far less than the enormity of those problems encompassed in the ultimate in understanding only a single ecosystem on Earth. But is a “crash” program in ecology an immediate need? Man has not yet adequately measured and defined his various environments. This inadequacy in human knowledge assumes grave proportions.
with the realization that the world population is increasing exponentially so that the present population of 2.5 billion is expected to increase to 5 billion in fifty years and 10 billion in 100 years.

In order to plan properly the utilization of natural resources to cope with the problems arising from this increased population, more extensive knowledge on the biological and physical factors of the natural environment is essential. The acquisition of this information at a sufficiently rapid pace commensurate with the time scale of the problem calls for bold and imaginative thinking and the utilization of modern research techniques in both the biological and physical sciences.

Fig. 1. Dr. Warner presented the first paper at the Conference. Chairman of the Session, Wesley Lanyon, is on his left.

One of the important problems confronting every biologist engaged in ecological research on the natural environment is obtaining continuous accurate and simultaneous measurements on a variety of factors. Much of the field biologists' data are obtained by sight and hearing; whereas the physical scientists and engineers have developed instrumentation for data
acquisition which is more sensitive and comprehensive than human senses. It is disappointing that the field biologist and ecologist have not exploited more fully these advances in data measuring and recording techniques made in recent years. As a result, the biologist often obtains information which is too discontinuous and incomplete for reliable statistical analyses. A possible improvement in this situation lies in the field of interdisciplinary research in which the engineers and physical and biological scientists apply their combined resources to obtain measurements of the natural environment.

INTERDISCIPLINARY BASIS OF ECOLOGY

Yet, ecology, the study of life in relation to its environment, is a science whose interdisciplinary aspects are not at all or only reluctantly pursued by many researchers. This was expressed more than thirty years ago by pioneer ecologist, Royal Chapman, (1929) who wrote, “Ecology is bound to become quantitative. Many of us are observing this inevitable tendency with regret. There is a feeling that the wonders of observational natural history are to be brushed aside by the cold dry calculations of a mechanistic mathematics....”

But he added that, “The urgent needs are, first, more accurate measurements of environmental factors and the populations which make up the natural associations, and, in the second place, better methods of evaluating the measurements of the factors.”

More recently, in the physical science field, veteran climatologist, Thornthwaite (1958), writes “It is worthwhile at this point, however, to remind ourselves that climatology is a geophysical science rather than an aspect of biology. However much we may use the plant as an indicator, or however vital we think the transpiration process, our concern is always ultimately with the exchanges of energy and moisture, rather than the life processes of the plant ....

“We must consider a warm-blooded animal or man himself in the same way that we would a boulder, a macadam road, or a bush or tree”.

In spite of the differences between these two disciplines of science, it is obvious that much of ecology requires quantitative data which may be obtained only through co-operative studies in biotechnology including the use of telemetry.

As an example of research in this field I may cite our basic concepts and direction of research effort at the University of Minesota. Our approach to these problems evolved on the basis of the following:

One of the most significant observations of an animal is its motility. Since the environment apparently furnishes or modifies the stimuli which trigger basic responses within an animal, the ability to follow an animal’s movements continuously and to attempt to correlate these movements with environmental factors seems essential to advances in ecology. Nearly
all the animals are at some time motile; and, since the causal factors of this motivation in the natural environment are not adequately understood, continuous recording of animal movements correlated with other events in the environment should be given major emphasis. Current advances in the field of instrumentation give hope for successes in this direction.

**NEED FOR IMPROVED MEASUREMENTS**

The works of Geiger (1950), Shelford (1952), Bodenheimer (1957), Macfadyen (1957), and others point to the need for obtaining more concise, accurate, and continuous measurements in ecological research. Many investigators (Birch 1958; Andreadhtha, and Birch, 1965; Shelford and Yeatter, 1955; and others) have presented data indicating a relationship between distribution and abundance of animal populations in relation to biotic and physical forces of the natural environment. Only a few quantitative studies on an individual animal’s motile responses to environmental factors have been attempted *under natural conditions* (Waterhouse, 1955; Platt, Collins and Witherspoon, 1957; Haufe and Burgess, 1956; and Platt, Love and Williams, 1958). Effects of animals on their immediate microclimate and the relation of these alterations of microclimate to the animal itself and to the habitat have been indicated by a number of authors but have been determined by accurate measurements in relatively few studies (Franklin, 1955; Uvarov, 1931; Wellington, 1950; Pimental, 1958; Sharp, 1958; and Hammel, 1956).

A precursor to field studies of animal responses to the physical environment is the need for more measurements fundamental to the definition of any field area. These include impinging, absorbed and reflected radiations, air and soil temperature, relative and absolute humidities, precipitation, local barometric pressures, wind and sound. Absorptivity and emissivity measurements of plants and plant covered surfaces and of animals are also necessary.

Although some current research techniques in climatology and microclimatology as applied to ecology utilize modern methods of measuring and recording, other do not. Instrumentation for following animal movements has received almost no attention (Marshall, Gullion and Schwab, 1962). Movement studies have been based almost entirely on visual observation, on recapture of previously trapped and marked individuals, and on appearance in study areas of species intermittently captured by various sampling methods. Data from these types of studies are the basis for a major part of current interpretations of: Response to environmental change, “home range”, territory, migration, dispersal, and for much interpretation of population structure and even systematics, evolution, and biogeography.

Under conditions of adversity an animal adjusts, moves or dies. Within an environment an animal or a population must maintain itself within
tolerable limits in its microclimate or, among larger animals, in its macroclimate. Maintenance within these limits is accomplished by:

(a) Physiological adjustment (change in rate of respiration, heart rate, peripheral circulation, etc.)
(b) Reorientation of body position within space and time in normal "home range" or territory.
(c) Alteration of microclimate by an individual or by a population.
(d) Migration, usually a seasonal movement, which may cover vast distances in all three of the earth's media.
(e) Dispersal, movement of individuals to find new places to live.

The need to know an animal's diel (24 hr), seasonal and annual movements and the physical as well as biological stimuli responsible for these movements has become paramount in many fields of science both pure and applied. Throughout the evolutionary history of man, he has had need of knowledge of animal movements for direct hunting for food; but hunting cultures have all but disappeared. Today, the fields of medicine, agriculture, game management and conservation of our renewable resources at the local, national and international levels have increased the demand for information in this field to the point where it requires major attention by the fields of technology and biology. Aside from a desire to know more about the earth's environments and its flora and fauna, man must be able to predict occurrences in the ecological world if he is going to manage and control it (Haufe and Burgess, loc. cit.).

ECOLOGY STUDIES AT U. MINNESOTA

These considerations were brought together for study and evaluation by a group of persons representing the fields of biology, biophysics, physics, meteorology, and engineering at the University of Minnesota. From these seminars evolved our research program, the study of motile responses of animals to radiation fields and to other physical and biotic factors in the natural environment. These discussions covered a period of two years.

This study, now in its third year of active research, includes five rather different fields of investigation. These are:

1. Basic ecologic survey by biologists of the field area selected for future environmental and animal instrumentation. This survey included measurements of the surface contour, vegetation and plant forms, seasonal phenology and observations on cottontail rabbit behavior and use of the area. (The cottontail rabbit was selected as our study animal for a number of reasons not given here.) Results of this study are in press.
2. Radiation measurements related to biological systems. These measurements have been made by the Heat Transfer Laboratory in the Department of Mechanical Engineering. It was concluded early in planning
that infra-red and visible spectrum radiations may be of primary importance to animal motility. Measurements have been obtained to date on: (1) thermal properties of animal integuments, (2) infra-red emissivity of a number of animals, (3) effective radiation temperatures of fur as a function of air temperature and wind velocity, (4) the total energy emitted by animal surfaces for various environmental conditions, and (5) absorptivity and reflectivity characteristics of animal integuments to solar radiation.

3. Development of animal tracking system. This research is being carried out as part of the function of the Bioelectronics Laboratory of the Museum of Natural History.

4. Development of instrumentation for measuring physical environmental parameters and some physiologic functions of the animals being tracked is another phase of study in our Bioelectronics Laboratory.

5. Investigations into energy conversion systems of potential use in telemetry in ecological studies. This phase of research is being carried on by staff in the Department of Mechanical Engineering.

FACTORS INHIBITING BIOTELEMETRY

Our own interdisciplinary diversity is cited only to present a basis for critical evaluation of some of the obstacles to be overcome if telemetry and modern data reduction and analytical procedures are to be used successfully in ecological studies. From our own experiences and from those of other researchers in this field, abortive efforts, confusion and failures in research toward the use of telemetry in ecology have been the result of the following six factors:

1. Lack of adequate communication and basic differences in terminology between biological and physical sciences and engineering in defining ecological problems and direction of research effort.

2. The often blind acceptance by biologists of the engineers’ over confident statement that instrumentation for telemetry in ecosystem studies is “on the shelf”. This is indeed a most elusive shelf which, even with our combined efforts, we have been unable to find.

3. The handyman biologist’s “do it yourself” programs in such technical and rapidly advancing fields as electronics. This is one of the most wasteful pursuits in time, energy and money in ecology today. Telemetry and instrumentation for tracking systems and programming belong to physical science, engineering and mathematics. The biologist could better spend his time in improving his base line observations which will be necessary for future ecological studies as conceived at this meeting. He can, by learning some of the technology and the terminology of
the technological fields, explain better what needs to be measured and the significance these measurements may have to the total problem.

4. The pressure by industry for production contracts premature to a project. In my opinion it would be to industry's ultimate advantage to assist and support openly basic research in environmental studies now rather than to contract to build instruments which are kept under wraps so that they cannot even be adequately field tested.

5. Isolating mechanisms in relationships between industry and the biologist. Current isolating mechanisms have two bases: (1) a history of almost no association between biologists and industry, and (2) unidirectional flow toward industry of information on subjects of mutual interest in ecology. Through his own isolation, often self imposed, the biologist tends to perpetuate this condition.

6. The naïveté of the biologist on cost of research in the use of telemetry. Compared to cost of programming, computer service, a data reduction system, a complete tracking and telemetry system and the personnel involved on even a small scale over a short period of time, the standard items for most ecological studies today are indeed of another magnitude.

We have learned through some experience that a team of specialists, representing the biological and physical sciences and engineering, working together in experimental research in telemetry in ecology avoids some of these problems, but recruitment of personnel, availability of consultant service, academic sophistication and financial limitations remain as additional critical obstacles. None of these problems will deter for long progress toward use of new techniques in ecology.

Experiences in the recent International Geophysical Year have shown the tremendous advantages of a world-wide program of measurements. An equal factor in the success of this effort, however, has been the utilization of modern measurement techniques, many of which have been developed during the past twenty-five years. If the biological sciences, ecology in particular, are ever to participate in such a program, they must also be prepared to use advanced instrumentation whenever possible. A logical outcome of the perfection of instrumentation for continuous recording of physical and biological data in one environment would be the organization of an International Biophysical Year. In such an endeavor it would be possible to measure and record systematically related data in all major biotic units on the earth from arctic tundra to desert to tropical rain forest.

Finally, in answer to Royal Chapman who sounded a pessimistic note on ecology, I wish to emphasize that observational natural history, rather than being replaced or downgraded as it has been in many colleges and universities, must be greatly encouraged and expanded to permit the establishment of adequate direction for quantitative studies in ecology, many of which will surely utilize telemetry as well as other instrumentation.
REFERENCES


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DISCUSSION

GRIFFIN: Perhaps Dr. Warner would care to define a little more closely what he would like in terms of a consultant service. It seems to me that the need for a service of this sort has been often mentioned by other people.

WARNER: Ordinarily, my concept of consultant service, as a biologist, is one which can assist in defining a problem. In terms of biology there would be a need to define the problem in terms of what kinds of measurements to make, and how to make them in ecological studies. For example, we find in biology that we use terms which are incompatible with those used in many of the physical sciences, especially in engineering. Hence, as far as my own desires and needs are concerned, we have to go to people to learn first how to define in engineering terms some of our own biological problems. We have had need, actually, of learning each other's terminology and sometimes my desire for a consultant service is just to listen to other people try to interpret what our basic problems really are in engineering and physical science terminology.

GRIFFIN: Would you prefer that this were a sort of a body sponsored by National Science Foundation or something of that sort? Would you prefer a private consulting service which you could hire as needed?

WARNER: I don't believe I thought of committees for this. I think a single consultant is much more free as an individual than as a part of a group.

SCHMITT: Could I say that consultant service, as Dr. Warner defines it here, has a very definite threshold that should be kept in mind. If the function of such a consultant is to help define the problem for him, it would require insight into the problem, not just technical fact. This requires months, perhaps, or a year of a substantial amount of time in learning what his problem is, and clearly doing a piece of his research for him.

I'd like to point out that this can be done in one or two ways. Either have this man participate on an extensive basis, and, incidentally, this would be an expensive basis. Or else have him already briefed and serving several people. But if you want to have a reservoir of such people nationally available to people likely to become concerned with similar problems, this approach might be more feasible. Or if your problem is not big enough you may want to invite into your research somebody who becomes partly an ecologist, partly a biologist, just as you are eventually going to have to become partly a bio-physicist, and partly an engineer. This, of course, is the other way of doing it. But we can't go out and buy two hours of consultant service that is going to give us anything except just a specification for an instrument and very often it will lead us down the garden path of doing something desperately wrong because we are doing something that is engineered.

GRIFFIN: I would like to take issue with Dr. Warner here in that I think that perhaps inadvertently he expressed an idea which I find hard to accept, and that is that biologists need to turn to physicists to help define their problems. I reject this idea categorically. I think that if we are interested in biological problems, it will take biologists to define them. We are very desperately in need of better tools and instrumentation and that is the area in which I think the physicists can most effectively participate. I throw this out possibly as a challenge. Perhaps I'm alone in this feeling.

WARNER: No. I agree with this. Your point is a good clarification.

TOBACH: I was wondering whether the difficulty about the formulation of communication is not at the basis of the exchange between Dr. Griffin and Dr. Warner. In my own very limited experience with engineers, to whom I went for help in setting up equipment, I found that the problem was very clear on the psychological or behavioral level. The real task was to define the problem in terms of the available techniques and concepts that the engineer has. It was a question of translation and communication, and we found that in the course of this relationship a collaborative venture did arise because what we required was not in existence. So the engineer had to begin to develop new ways of looking at the problem from his viewpoint and developing new techniques which had not existed before that moment.

MCCULLOCH: I might say in the Research Laboratory on Electronics, there are three groups of biologists working on the nervous system. The first of these is bio-physics communication; the second is our group in neuro-physiology, and the third is Larry Stark's group is neurology. Affairs between us have gone on very happily and, I would say, very profitably on a bona fide symbiosis. We learn, inevitably, what the engineer and the physicist
are doing next to us and he learns what our problems are and I would say in the daily give
and take of the youngsters between groups, we find the greatest profit.

Corson: I think some of these problems could be solved if either the National Institutes
of Health or the National Science Foundation would organize an Institute for Biophysical
Instrumentation. I know the Russians have done this and have come up with a great many
things in a very short time without any extensive background of technology such as we have.
And I think a good many of us are trying to solve problems on our own scale simultaneously
that could probably best be solved, in its major aspects, by founding a National Institute
of Biophysical Instrumentation.

Galler: I would like to suggest that before we start worrying about solving the problem,
we had better define the problem. I would like to state that in my opinion, Dr. Warner has
presented one of the most lucid descriptions of many of the facets of the problem confronting
us. But I sense that we are beginning to run into a danger of grouping two things together
as one. One is the possibility of interpreting biological phenomenology in terms of physical
principles, which, I believe, might be considered as part of bio-physics. And the other is
to provide the biologist with physical tools and techniques. Quantitatively, they may be
considerably different in terms of problems.

For example, we have sensed that biologists, some of them at least, are quite willing to
become more familiar with the principles of physics and mathematics, in order to advance
their own research and in order to be able to communicate with physicists and mathematicians
and collaborate with them. There is not this enthusiasm, however, for sitting down with
an engineer and educating him in biology to the point where the engineers can play a useful
role in the development of tools for the biologist.

In other words, we have found that some biologists at least, are quite willing to take on
physicists and mathematicians as research collaborators, but following this stated symbiosis,
they are not quite willing to spend the time and effort to sit down with engineers and educate
the engineer to the point where he can play a useful role in developing new tools and tech-
niques. They are less patient with this matter; they would much rather pick up the phone
call the consultant, if one is available, or go to an instrument organization and say,
"Build me a black box" which may turn out to be a magnificent piece of engineering but
be inadequate for the biologist. So I think we will have two separate problems here.

Schmitt: In response to that, I’d like to point out that we’ve had a little bit of difficulty
in “educating” engineers in that this costs money. When one goes to industry and begins
to discuss a problem, industry becomes interested if you are going to pay them money to
solve this problem. The engineer does not want to sit down with you for a day or two and
talk about this problem. At least in many cases this is true.

Secondly, going to an engineer on the university faculty, frequently results in the same
sort of response. He doesn’t have a day or two to spend with you talking about your prob-
lems and, as you say, unless he becomes interested enough to integrate with the problem
and be a part of the project all the way through, there seems to be some difficulty in reaching
this level of understanding with him. If you can hire an engineer, put him on your staff
and have him work with you, then you can reach this agreement.

Galler: I hope I’m not spending too much time here, but I think perhaps I have placed
you under a misapprehension. As Dr. Schmitt points out, consultation can mean anything
from a couple of hours to a full time collaboration. In using the term “training” of engineers
I would do so not in the sense of bringing them in for a couple of hours—which I think is
one of the difficulties right now—but would be willing to take them on for six months or a
year to give them enough background in basic biology so that they can play a more useful
role. I agree that this costs money, but as Dr. Warner pointed out, I think it is about time
that the biologist faced up to this problem more realistically and included such items as
part of their costs for research.