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PACIFIC NORTHWEST LABORATORY ANNUAL REPORT FOR 1971 TO THE USAEC DIVISION OF BIOLOGY AND MEDICINE

VOLUME I LIFE SCIENCES

PART 2 ECOLOGICAL SCIENCES

Battelle
Pacific Northwest Laboratories
Richland, Washington 99352

DECEMBER 1972

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PACIFIC NORTHWEST LABORATORY
ANNUAL REPORT FOR 1971
TO THE
USAEC DIVISION OF BIOLOGY AND MEDICINE

VOLUME I LIFE SCIENCES
PART 2 ECOLOGICAL SCIENCES

By

Burton E. Vaughan, Manager
and
Staff Members of Ecosystems Department
Environmental and Life Sciences Division

December 1972

BATTELLE
PACIFIC NORTHWEST LABORATORIES
RICHLAND, WASHINGTON 99352

Volume I of this report to the USAEC Division of Biology and Medicine covers work in the Life Sciences and is issued as BNWL-1650 in two parts: Part 1, Biological Sciences and Part 2, Ecological Sciences. Volume II of this report is issued as BNWL-1651 also in two parts: Part 1, Atmospheric Sciences and Part 2, Radiological Sciences.

FOREWORD

This document is the fourth annual report of work in the ecological sciences, at Hanford, written for the AEC, Division of Biomedical and Environmental Research (DBER).[1] It reflects the principal efforts of Ecosystems Department and others contributing to departmental programs during the 1971 calendar year.

In many ways, 1971 was a decisive year for the Ecosystems Department--one involving our move to the new Life Sciences Laboratory, significant reorganization within the department, and major effort applied to AEC 30-program. At the time of this writing, our Department enters its sixth year as an independent research department, although the ecological sciences at Hanford have their origin over 20 years ago. Time, of course, has led to appropriate growth and change in the original research programs, but it is a tribute to our sponsors' foresight that broad-based ecological effort has continued. Without this continuity, we would not have had a base of scientists sufficiently informed to provide assistance in assessing the environmental impact of our developing high energy technology. Especially at a time of keen public interest in the environment, as reflected in passage of the National Environmental Protection Act and the creation of the Presidential Council on Environmental Protection, the wisdom of providing for such a scientific resource has been proven.

Our move to the Life Sciences Laboratory in January 1971, with our sister Biology Department, was long-awaited, and it is now permitting broadened programmatic responsiveness. Extensive flow-through aquatic facilities, computer terminals, the plutonium aerosol exposure systems, and walk-in plant growth chambers have especially facilitated ecosystems work in the newer AEC programs. The Laboratory was dedicated by Dr. John R. Totter, Director of AEC's former Division of Biology and Medicine, on September 27, 1971. Dr. Totter's remarks on that occasion are here included, as also are the remarks of Dr. Herbert M. Parker, former manager of Hanford Laboratories, and Dr. Harry A. Kornberg, former manager of Biology Operations (which included Biology and Ecosystems staffs).

In August 1971, the Department underwent reorganization. Six program groups, replacing the former, somewhat arbitrary grouping of programs in aquatic and terrestrial ecology sections, were formed. Dr. L. Lee Eberhardt was appointed at

Department level, as senior Research Associate, with general responsibility for biomathematical efforts throughout departmental programs. Mr. William L. Templeton had been earlier appointed to the newly created position of Associate Department Manager, and he continues with general responsibility for programs primarily concerned with environmental impact assessment. With this reorganization, cost centering has moved to the Department level, a system of planned program budgeting has been initiated, and the program leaders meet weekly on problems of mutual concern.

Ecology is a peculiar field of effort. Unlike other disciplines, it deliberately hybridizes with many other disciplines. Several kinds of effort usually need to be brought to bear on any given environmental problem, and over 12 classical disciplines are, in fact, represented by our present staff! The organizational changes were initiated by the staff, with support and concurrence of PNL management. We feel that the changes in the staffing chart at the end of this report will provide better integration of a diverse staff. We also look forward to continuing these administrative relationships.

In October, 1971, about one-third of our departmental staff were asked to provide immediate assistance to the Directorate of Licensing in connection with the AEC 30-program on environmental impact assessments. These efforts have impacted, in their own right, the on-going research program sponsored by DBER. On the other hand, they have also greatly stimulated our scientific staff. As a consequence of first-hand experience gained in reactor siting problems, I believe that we have been better able to orient towards and support some of the newer, programmatic responsibilities of the AEC. Since 30-program assistance commenced late in 1971, the effects of this effort will be considered more fully in our 1972 annual report.

Among the smaller complications of redirection of effort, mentioned above, has been a rather long delay in appearance of this annual report. As indicated, this report is the fourth annual report covering the 1971 calendar year. We anticipate publication of the fifth annual report, covering 1972, in about three months. In 1973, we plan to move the cut-off date from end of the calendar year to end of the Federal fiscal year, with publication, again, about three months later. Thus, you may be inconvenienced by three reports during 1973! While the calendar year has been a more suitable time for reporting, considering that ecological data must be obtained during natural growing seasons, we feel that shifting annual reporting to a fiscal year basis may provide information more timely with respect to budgetary planning cycles. We have also continued the practice of reporting fairly briefly in these annual reports. Full details, of course, will be available by requesting publications directly from the authors. We would appreciate also hearing directly from our readers as to suggestions for improving these reports.

A final comment is in order on the terrestrial ecology programs, to which a substantial portion of this report is allocated. In 1971, milestones for all supporting work had been attained or exceeded, as outlined for Program 1 of the 1968 "Master Plan for Bioenvironmental Research at Pacific Northwest Laboratory." We are now in the beginning ecosystems modeling phases, as scheduled in the Master Plan. Lest enthusiasm overtake us, we keep in mind, however, the caution of our biomathematicians, namely that in ecosystems analysis one year's collection of measurements is one datum point!

Burton E. Vaughan
Manager, Ecosystems Department

REMARKS AT THE DEDICATION OF THE
LIFE SCIENCES LABORATORY

BY

DR. JOHN R. TOTTER, DIRECTOR,
DIVISION OF BIOLOGY AND MEDICINE

It is no small responsibility to give the dedication address at these ceremonies for the new Life Sciences Laboratory. I feel it is appropriate today that I start my comments by briefly reviewing some of the outstanding research which has been conducted here at Hanford.

This may be a good time to invoke a bit of philosophy that is germane to my remarks. The philosopher, George Santayana, once said, "Those who cannot remember the past are condemned to repeat it." While it is of paramount importance in science to look ahead, it is often helpful to see where we have been, to evaluate what we think we know and to appreciate those things we don't know. I should like to continue in this retrospective-prospective tradition by directing my remarks towards both the past and the future.

As some of you in this audience know first hand, the Hanford Project began operation in 1944 with the assignment to supply plutonium for the Manhattan Project. Along with the awesome production reactors and chemical separations plants, there developed a fledgling monitoring and biological research project. It appears that the Biology Lab got its start when Herb Parker hired Harry Kornberg around 1947 to look into the possibility of identifying biochemical changes in blood that might be produced by exposure to radiation. Parker has been at Hanford since the start of operations as, I believe, Head of the Health Instruments Group. Incidentally, some interesting radioecology work, although probably not known as such at the time, was in progress in the late 1940's when Parker and colleagues monitored rabbit thyroid glands for ^{131}I.

During these early years, work was done on the oral uptake of ^{238}Pu and ^{239}Pu. Of historical interest is the fact that the ^{238}Pu was obtained from Berkeley, via Dr. Seaborg, and followed by only a few years the discovery of plutonium in 1941. Other studies were undertaken by Dick Foster, who had been working at the University of Washington's Fisheries Lab under Lauren Donaldson, to determine the possible effects of reactor effluent on fish.

I mentioned earlier the importance of occasionally looking back as we move ahead in science. This reminds me that things have a way of being rediscovered periodically; sometimes this must be pointed out to those who cannot remember the past. I am certain that those who have only recently discovered such things as reactor effluents - and tritium - could profit a great deal by looking at the development of the life sciences program here at Hanford.

In late 1945 and early 1946, trout were placed in troughs over which passed different concentrations of reactor effluent water. I wish I had time to develop for you the many interesting studies which have followed through the years in this area. Project ALE (Arid Lands Ecology) and the aquatic ecology studies conducted within the Ecosystems Department are evidence that serious thought has been given to future activities.

Around 1948, Kornberg and Parker formed a Biology Group and proposed a program which was presented the following year to the AEC's Advisory Committee for Biology and Medicine. This was indeed prospective in scope and probably marked the transition from the earlier emphasis on monitoring to a broader based concern for radiation effects, metabolism, and the use of radionuclides and radiations as tools in biological research. This was accomplished under the management of the General Electric Company. In 1965, the Battelle Memorial Institute assumed the management of research and development activities at Hanford.

The ACBM agreed with the proposed program and suggested that an existing building be converted to a temporary biology laboratory until a new one could be built. At that time AEC Commissioner Johnson was Manager of the General Electric Company at Hanford. To this end, a surplus building in the 100F Area was chosen - in part because of its proximity to the fish ponds. The biology group moved into the converted building in 1950 and produced an annual report in 1951.

This general period witnessed the organization of a Botany Group which initiated work on the absorption and translocation of radionuclides in plants. During the 1950-55 period, the animal farm additions developed. The AEC recognized the importance of life-time animal studies designed to study the late effects of radiation. One of the earliest, related to chronic exposure to reactor-produced ^{131}I, was initiated at Hanford in 1948 using sheep as the experimental animal. Concern about extrapolating these data to humans led to the development of the Hanford Miniature Pig as a research animal.

Another long-term study, begun in 1958, involved daily feeding of ^{90}Sr to pigs. This program spans three generations of animals - about a thousand - and still continues to provide useful data. Again, looking to the future, this effort has evolved into the exciting area of the leukemogenic process, per se. This is another example of an effort which is both mission oriented and basic in scope.

The early 1950's witnessed animal experimentation under the direction of Roy Thompson and colleagues. It is no surprise that this work was related to the development of the hydrogen weapon. What is a surprise to many scientists is that some people are rediscovering today things that Roy Thompson and coworkers found - and published - about 20 years ago. Some of this work represents the definitive experiments on the radiation biology of tritium in mammals.

In 1959, additional laboratories were added at the animal farm primarily for inhalation studies. Several years later a three-story addition provided new small animal quarters, a ^{60}Co irradiation facility, and the luxury of a conference room and library. The year 1964 marked the loss of the Aquatic Laboratory from fire. In 1967, anticipating the move to the 300 Area, dog and pig facilities were constructed adjacent to the chosen site.

Another example of far-reaching research here at Battelle is the inhalation program. The work on radioactive particles and pulmonary inhalation began in a peculiar fashion. Bill Bair, possibly one of the first Ph.D.'s in radiation biology, had just completed his work at Rochester under Newell Stannard. He came to Hanford to continue his work on yeast. It happened, however, that one of the chemical processing plants began to emit particles of ^{106}Ru; and in an effort to learn the effects of such particles, Bill Bair was asked to help out in a radioactive particle program. The particles were put on the skin and were fed. They were also instilled into the lung intratracheally, and finally an inhalation system was designed. From this start has grown the Lab's superb inhalation capability and its outstanding program on the transuranic elements.

Although emphasis has been on plutonium, the technology which resulted has a general application to our understanding of pulmonary deposition, retention, and translocation of inhaled particulates, that is, to the broad problem of airborne pollution. One particular study about 12 years old is of special significance as it has provided us with much information on the late effects of inhaled plutonium. This work has led to new studies, using even smaller initial lung depositions of plutonium, which will extend into the future.

Other work here at Battelle is related to uranium mining problems. More important, perhaps, is the fact that this work represents a serious effort to investigate the effects of radiation and other agents which may act additively or synergistically. Many people believe that we shall see much more of this kind of experimentation in the future.

Studies related to the artificial heart, which are now in progress, developed as an outgrowth of the proven competence in research on the implantation of thermal heaters in the thoracic aorta of miniature swine, performed for another agency.

If this quick review of the historical highlights has slighted anyone, I can assure you it was not intentional, except in the sense that it would take much too long to recite all of the significant achievements accomplished here.

I would also like to take this opportunity to discuss some of the more philosophical aspects of scientific research. Today we hear a great deal about the impact of technology on society and the failure of science to solve many contemporary problems. I suppose if I were asked what one factor had contributed more than any other to the so-called disenchantment with science that seems to be occurring, I would say communication. I should like to amplify for just a few moments my thoughts on this subject.

For a long time, it was my strong conviction that if one did good basic research, that would be ample justification for continued federal research support. However, in the past few years I have acquired much experience testifying before various Committees of Congress on the Atomic Energy Commission's biomedical and environmental research program. I think I now realize, as well as anyone here, that one must be prepared to explain to the Congress and to the public the significance of basic research in understandable terms. Just doing good work is not enough. We must be prepared to explain its value in competition with other demands. It is my view that most basic research can be presented to the public and the Congress in terms of broad national needs and goals. For example, if we are going to understand completely the effects of radiation on cells, we must first understand how the cell functions normally. Those of us speaking on behalf of science are doing our best to point out to the Congress both the immediate and long-term value of continued federal support of research. However, neither I nor other responsible federal officials can discuss this need with interested groups in all the local communities.

Just as you accept the opportunity to continue your research in this beautiful new facility we are dedicating here today, I hope you will endeavor at every opportunity to discuss with lay audiences the value of such research. I realize that this raises a special difficulty in terms of news media, newspaper, radio, television since the media may become impatient with the scientists' technical jargon and carefully chosen words. Occasionally, a reporter in the interest of dramatic effect or readability may render statements in a fashion which to the scientist would be considered unscientific. There are few who speak in public who have not been caught in such a difficulty. Rather than criticize the newsman for his failure to understand science, one might just as honestly criticize the scientist for his failure to make himself understood. The scientist has an obligation to attempt to explain his work to the nonscientist.

The Life Sciences Laboratory which we are dedicating is a multiple dicipline facility. Scientists can conduct work ranging from fundamental radiation biology at the cellular and molecular level to major studies in large animals from basic terrestrial and aquatic investigations to mathematical modeling of major ecological systems. Many of these studies might well be considered fundamental or basic research, but they are vital to developing a complete understanding of the effects of radiation on man and his environment. I believe such research is a coordinated long-term program which continues to contribute to our knowledge in this important area. We recognize, as I think you do, that each piece of research contributes in its own unique way to our overall understanding.

But something more is needed. It is important that the public understand this need. Such an understanding can, I believe, lead to a broader realization that the use of our natural resources, and here I would include our scientific talent and facilities, have been and are working for the betterment of our society. It has been said that last year's basic research is often this year's applied research. I think whether research is regarded as basic or applied depends on the time frame within which one views it.

Certainly our understanding of the fundamental life processes is still elementary and any advance in understanding is very likely to find applications rather quickly in medicine or in agriculture. Certainly the research which will be conducted in this new facility will have applications far beyond the immediate problems with which we are concerned.

While the results of your work will have direct application to the Atomic Energy Commission programs, some discoveries will also have application in the future in ways we could not foresee at present. It would be presumptious of me to attempt to predict specific contributions your researches might make to mankind many years in the future.

A strong program in basic and applied research is necessary to the Atomic Energy Commission and, I think, to the nation. I hope I have convinced you to join with me in attempting at every opportunity to explain in an understandable fashion to the nonscientist why a strong and continuing program is necessary.

In closing, may I wish those of you who will have the opportunity to continue your work in this new facility every success.

Thank you.

REMARKS BY
H. M. PARKER, FORMER DIRECTOR
HANFORD LABORATORIES

Today is a day when all biologists should be looking to the future and what they can accomplish in the fine new Life Sciences Building that the AEC has prepared for them. Perhaps I can be excused for looking backward briefly to the origin of the biology program at Hanford. This program began in 1946 shortly after the General Electric Company took over the operating contract for the Hanford Works. It arose as a direct felt need of the radiation protection group at this location which in those days was known as the Health Instrument Division, commonly abbreviated as HI because "radiation" was a dirty classified word when Hanford started. It was conceived as a practical program in radiobiology to solve the problems that had arisen concerning hazards to man in the plant and the life forms in the environment.

Karl Herde, whom I hoped would be here today, was one of the first biologists to work on this program as was Dick Foster, who is still with us today. (Dick was indeed the first biologist working at Hanford, but originally he was in a separate division and it was only in September 1946 that we were able to seduce him into the HI Division.) In early 1947, I was able to acquire the services of Dr. Harry Kornberg as Manager of the Biochemistry Section of the biology activity. It was not long before Harry persuaded me that he should be manager of the biology program, a position that he filled with distinction for 20 years. Harry developed the original, wholly practical environmental and biology program into a good balance of applied work and enough basic research to keep our senior scientists from going insane, for the most part. Practically every one of his groups developed at least one long continuing program which has become a classic in radiobiology research in the United States. I have mentioned Dick Foster; his work on the Columbia River problem is such an illustration.

For brevity, I will single out only two more. One was that run by Leo Bustad, whom I am most happy to see with us today, in the classic program of radioiodine effects on sheep and later on other animals. Let me cite one other program which is still being conducted by the current staff, and that is the internationally recognized Inhalation Toxicology program of Bill Bair.

This country behaves as though it discovered the words "ecology" and "environment" about five years ago. Since that time, the AEC has been clobbered by its critics on all sides because it is said to have done a fairly respectable job of protecting workers in the atomic plants but has paid no attention whatsoever to ecology and the problems of radiation in the environment. The program that has been operating at Hanford for twenty years is a complete refutation of this which deserves to be better known. The principal programs that were started twenty years ago and have been maintained to the present time were in fact mainly concerned with the environmental problems.

Harry, will you please join me at the podium, and the two senior resident managers, Dr. Bill Bair of Biology and Dr. Burt Vaughan of Ecosystems, will you please join us? In recognition of this day, Harry and I have jointly drawn up plaques to wish you well in the new laboratory and to commemorate the origins in the HI Division. This plaque is based on the logo used by HI in the early days. The logo that you see, if you can see from the audience, represents a shield of radiation protection for people and the environment. HI is in the center and it is divided into three sections which represent, in the upper left, the biology program symbolized by the microscope. On the right hand side, the bio-physics program, symbolized rather insultingly by a voltmeter and below it, personnel monitoring, represented by the old CUTIE PIE instrument. It will be of interest to the biologists here to recall that it was actually Jerry Davis, who was a senior member of Dick Foster's team at that time, who drew this logo. That is why biology appears in the key position in the first place on the left. However, those of you familiar with British heraldry will also remember that the left hand side of the shield is the sinister side. Harry and I have great pleasure in presenting these plaques jointly to you, Bill and Burt; and we wish you the best in your programs in this building.

REMARKS BY
H. A. KORNBERG, FORMER MANAGER
BIOLOGY DEPARTMENT

As this building today is dedicated to research in the life sciences, we should recall that part of it serves to complement a physically much larger project--the Arid Lands Ecology Project. The 120 square miles along the northeast slope of Rattlesnake Mountain is one of this country's major ecology reserves, and the man who did most to bring it into being and into perpetuity is the previous speaker, Herb Parker. It was my privilege to have worked for and with him during the 20 years that life sciences research grew from a minor effort in biochemistry to one of this Nation's major laboratories in biology.

It is rare that a scientist has the opportunity and distinction to lead the building of a laboratory. Today I become one of the very few who have had that distinction twice. Herb Parker recalled some trials and successes during the 20 years when that occurred. A chapter he omitted, with no reluctance, I'm sure, concerns alligators. Eight years ago we were using them in our experimental program. We observed that alligators have two distinctive characteristics: they hiss at managers and laboratory directors and are great escape artists. To commemorate a year made especially eventful by those characteristics, one of the alligators was stuffed, mounted, and presented to me at Biology's 1963 Christmas party. This handsome little fellow has been my constant office companion ever since. And since we are here to dedicate a great new laboratory, I would like, in turn, to commemorate that event by bequeathing my little friend to the laboratory building. It is my pleasure to present him to the Building, care of its manager, Mr. Ray Hultman.

You who made this laboratory possible have my fondest wishes for continued success and for the satisfaction that achievement brings.

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AQUATIC ECOLOGY

Several problems are individually discussed in this section, such as "Physiological Behavioral Response to Thermal Stress," "Modeling of Thermal Death of Fish Passing Through a Thermal Discharge," "Effects of Thermal Discharge on Invertebrates," "Synergistic Effects of Temperature and Industrial and Agricultural Pollutants" and "Effects of Modifications on the Columbia River." One of our studies is designed to determine the threshhold levels of supersaturation causing lethality and to investigate the ability of fishes to endure supersaturation for short periods and recover when returned to air-equilibrated water. The primary intent for studying combined effects of temperature and chemical pollutants is the establishment and quantitative description of the combined stresses on fish to other aquatic organisms. Another study deals with the effects of Zow-Zevel acute and chronic radiation exposure of aquatic organisms. An additional facet of the program is the study of important aquatic problems associated with the nuclear power industry.

EFFECTS OF THERMAL DISCHARGE ON AQUATIC BIOTA

- PHYSIOLOGICAL BEHAVIORAL RESPONSE TO THERMAL STRESS
- MODELING OF THERMAL DEATH OF FISH PASSING THROUGH A THERMAL DISCHARGE
- EFFECTS OF THERMAL DISCHARGE ON INVERTEBRATES

Every cold-blooded organism has an optimum temperature for metabolism and development, based on efficient conversion of food to energy and energy to growth, but this optimum is unknown for the majority of species. Continuing studies at our laboratory are designed to quantify the ecological impact of thermal increments on various organisms inhabiting the Columbia River. Once known, thermal resistance patterns are useful and accurate methods of predicting the effect of various combinations of temperature rises that result from gross environmental modifications in an aquatic ecosystem or, more specifically, the sudden exposure to heated water discharged from modern thermo-electric power plants. Thermal resistance studies, based on determining the median times to death of an organism when transferred instantaneously from an acclimation to a lethal temperature, are an integral part of this program.

Temperature and Development of Aquatic Invertebrates

C. D. Becker

Poikilothermous animals in aquatic habitats maintain a body temperature essentially the same as the surrounding water and are highly temperature-dependent. The basic response of these "sold-blooded" organisms to a temperature increase is an increase in their metabolic rate, which may be accompanied by an increase in their rate of development. Ultimately, a point is reached near the critical thermal maximum where energy expended in metabolism will exceed the energy acquired by feeding and development is subsequently retarded.

Every cold-blooded organism has an optimum temperature for metabolism and development, based on efficient conversion of food to energy and energy to growth, but this optimum is unknown for the majority of species. Moderate thermal increments, such as may occur below outfalls of thermoelectric nuclear plants, tend to implement the development of aquatic invertebrates provided that sufficient supply of food is available. Our continuing studies with invertebrates occurring locally in the Columbia River support this generalized pattern.

For example, Figure 1 shows the effect of thermal increments at discrete 2.5°C stages on the development

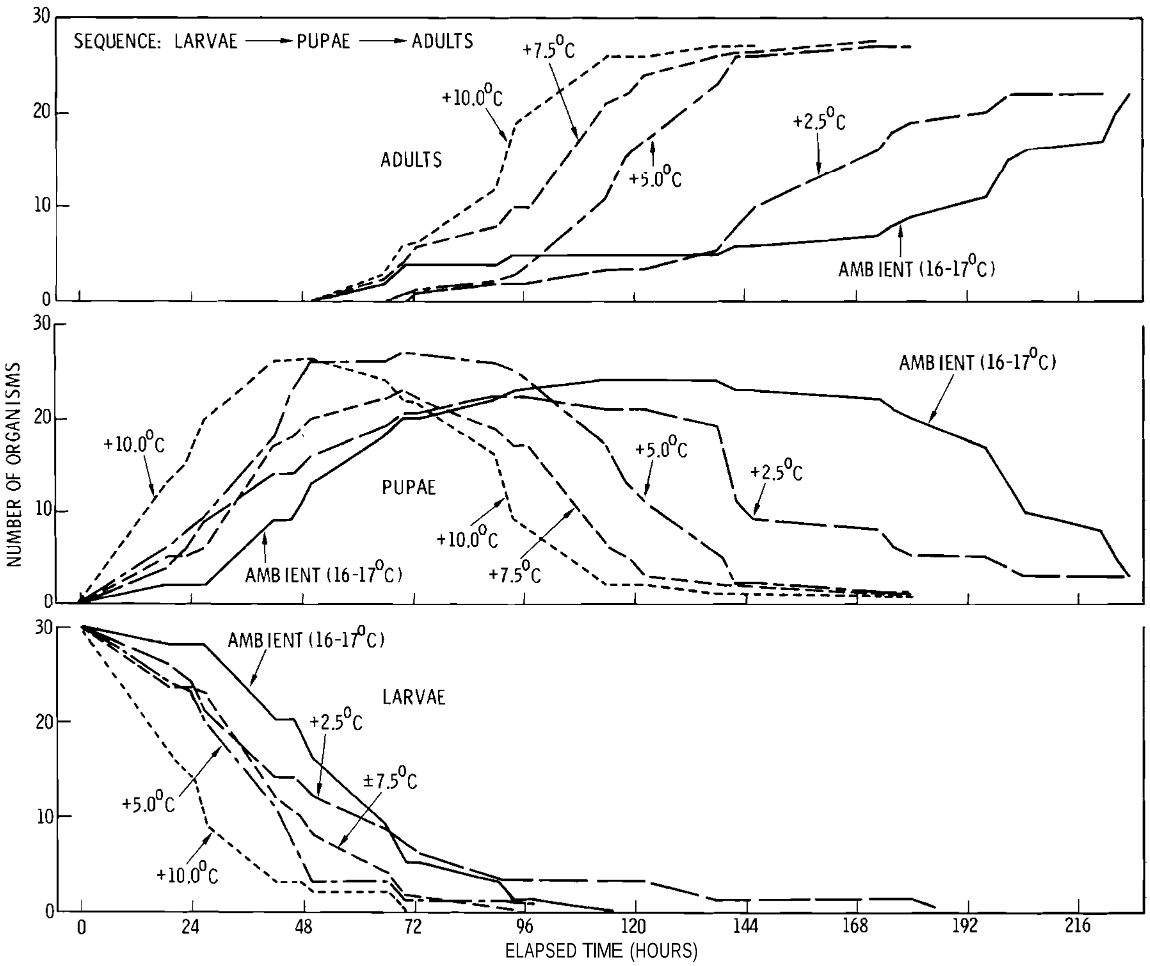

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FIGURE 1. Developmental Responses of the Blackfly, *Simulium vittatum* Zett., to Thermal Increments at 2.5°C Stages During the Fall (30 Larvae/Group).

of the multivoltine blackfly, Simulium vittatum Zett. (Diptera: Simuliidae), through metamorphosis from larvae to pupae and from pupae to emergent adult. The developmental rate increased in proportion to four thermal levels extending from a base river temperature of 17 to 27°C (in October). About one-half of the larvae transformed into adult blackflys in eight days at the ambient 17°C, whereas about one-half emerged as adults in four days at 27°C. Mortalities among all test groups were low and equal, indicating that a thermal increment of ΔT 10°C was within the range tolerated by this species in the river ecosystem during the fall.

Thermal Resistance of Aquatic Invertebrates

C. D. Becker

Discharges of waste heat associated with power production technology constitute an ecologically significant modification for cold-blooded invertebrate organisms in aquatic ecosystems. Continuing studies at our laboratory are designed to quantify the ecological impact of thermal increments on various invertebrates inhabiting the Columbia River. Thermal resistance studies, based on determining the median times to death of an organism when transferred instantaneously from an acclimation to a lethal temperature, are an integral part of this program.

We are investigating the thermal resistance of crayfish, Pacifasticus trowbridgii (Crustacea: Decapoda) as one aspect of our program. Acclimation temperatures approximated seasonal river temperatures and were set at 15, 20, 25 and 30°C for the tests. The linear relationship of the available 48 hr-TL_m's are illustrated in Figure 2. Subsequent tests will be conducted at 5 and 10°C acclimations.

It is well established that acclimation to a higher temperature both increases the length of time an organism can survive at an elevated temperature and increases the maximum temperature that the organism can survive for a given period of time. This principle is manifest in our data on P. trowbridgii by the slope and spacing of the regression lines. Although a rise in acclimation temperature increases thermal resistance, the increase becomes proportionately less as the acclimation level rises. The upper lethal limit for acclimation, and hence the natural occurrence of the species, is probably close to 32-33°C.

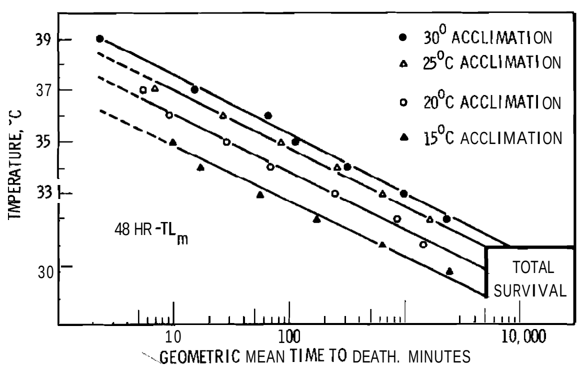

FIGURE 2. Geometric Mean Times to Death of Crayfish, Pacifasticus trowbridgii, at Acclimation Temperatures of 15, 20, 25 and 30°C (ten per test).

P. trowbridgii is relatively tolerant, among Columbia River invertebrates, to experimental temperature elevations. It can survive exposure to 29 or 31°C for 48 hr or more when acclimated to 15 and 25°C, respectively, but death occurs at 32°C within 48 hr even when acclimated to 30°C. Our preliminary work indicates that age (size) or sex has little effect on thermal tolerance of this species. However, instantaneous exposure to high but apparently sublethal test temperatures tends to stimulate molting, and the added stress sometimes results in premature death.

Thermal Resistance of Columbia River Fishes

C. D. Becker

During the recent interagency Columbia River Thermal Effects Study program, considerable emphasis was placed on determining the resistance of salmonids to temperature elevations. Thermal resistance is essentially a dose response involving both temperature and time, so that the higher the temperature, the more rapidly mortality occurs at a lethal level. Thermal resistance patterns, once known, are useful and accurate methods of predicting the effect of various combinations of temperature rises that result either from gross environmental modifications in an aquatic ecosystem or, more specifically, the sudden exposure to heated water discharged from modern thermoelectric power plants.

Previously, thermal research on the Columbia River concentrated, although not exclusively, on salmonid fishes because of their economic importance and their relative sensitivity to thermal increments. For this reason, thermal resistance patterns for other resident fishes has required more intensive investigation. Each species has its own inherent range of thermal tolerance in nature, however, and understanding the total ecology of an aquatic habitat relative to temperature changes requires that thermal resistance patterns be known. Any species relatively tolerant of heat holds a more favorable environmental niche to resist long-term upward thermal alterations.

Presently, our program of thermal studies has been expanded to include fishes other than salmonids. Thermal resistance data for juvenile brown bullheads, Ictalurus nebulosus (Ictaluridae) are illustrated in Figure 3. This species is among the more tolerant of the common Columbia River fishes to experimental temperature elevations. It can survive exposures to 35, 31 and 26°C when acclimated to 25, 15-16, and 4-5°C, respectively, for more than 48 hr.

Fishes of the family Ictaluridae are not native, but were introduced to the Pacific Northwest prior to the present century. Comparison of our data with that available for I. nebulosus from eastern Canada indicates some small but significant differences in thermal resistance patterns. This difference may be attributed, in part, to over 70 years

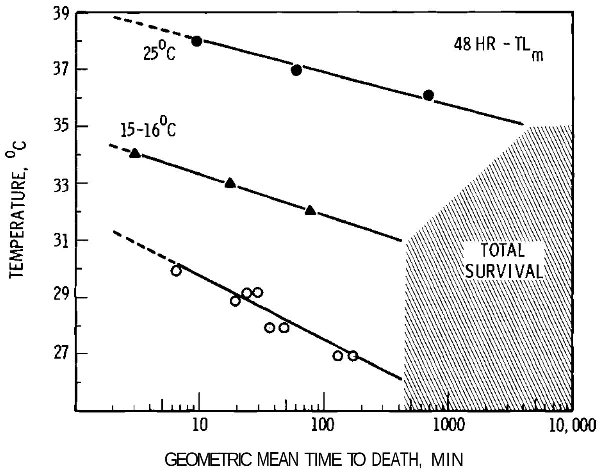

FIGURE 3. Geometric Mean Times to Death of Juvenile Brown Bullheads, Ictalurus nebulosus, at Acclimation Temperatures of 4-5, 15-16, and 25°C (Ten Per Test).

of genetic adaptation to the Columbia River environment. The differences are indicative of the potential heterogenicity in acquired thermal resistances for any given species living in isolated geographical areas.

Effect of Thermal History on the Resistance of Columbia River Steelhead Trout (Salmo gairdneri) to Thermal Stress

Mark J. Schneider

The numbers of steelhead trout in the rivers of the Pacific Northwest have diminished in recent years due to the impact of hydroelectric dam construction on spawning grounds and of gas supersaturated water on downstream migrants. Hatchery-reared steelhead have augmented the Columbia and Snake River populations. These hatchery stocks are cultured at numerous hatcheries and thus represent a variety of thermal histories. It is well established that past thermal experience has a significant effect on tolerance of fishes to thermal stress. The response of fish from different hatcheries to a thermal challenge (e.g., passage through a reactor discharge) may differ. The purpose of this study was to evaluate the effect of long-term thermal history on the resistance of steelhead to thermal stress.

A total of 240 steelhead were reared from fry to two-year old juveniles at accurately controlled temperatures; 60 fish at each of the following temperatures: ambient river temperature, 1.7°C(3°F), 2.2°C(4°F), and 2.7°C(5°F) above river temperatures. At two years of age, the average age of downstream migrants, the fish were tested for resistance to thermal shock. The index used to test thermal resistance was the time to loss of equilibrium and to death at three lethal warm temperatures, 25, 27 and 29°C. At the outset of the experiment, one-half of each of the four temperature classes was placed in a common tank and acclimated to 12°C; the ambient river temperature at the time was 4-5°C. After a three-week acclimation period, the fish were tested in like manner as the first half.

The geometric mean times to loss of equilibrium are presented in Figure 4. The data appear in two groups: Group I, the data for the four temperature classes tested; Group II, the data for the four temperature classes following acclimation to a common 12°C. No significant differences in time to loss

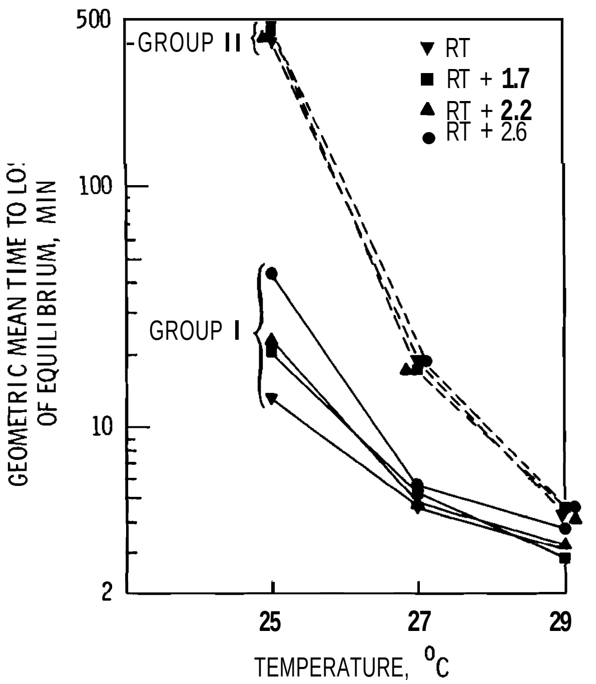

FIGURE 4. Geometric Mean Time to Loss of Equilibrium Adult Steelhead

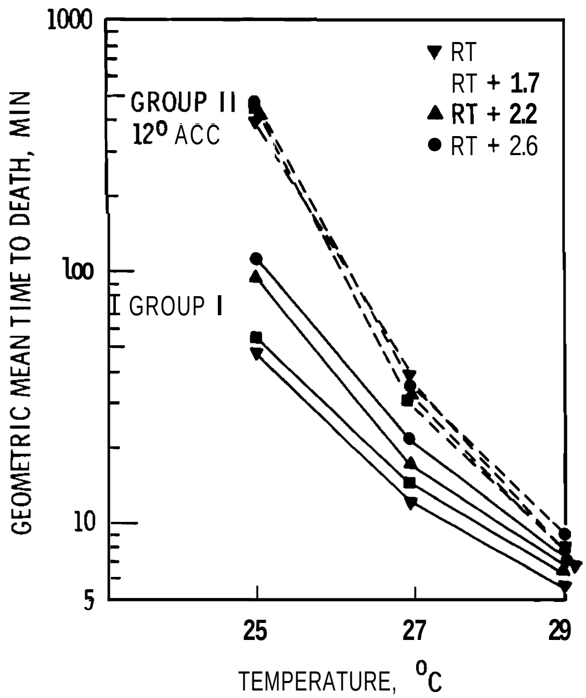

FIGURE 5. Geometric Times to Death of Adult Steelhead

of equilibrium were found between temperature class response to the three lethal temperatures. The effect of the 12°C acclimation period is clearly seen in the graph; i.e., the scatter in the data points is reduced.

The times to thermal death are presented in Figure 5 according to the same form as was used in Figure 4. Significant differences were found in temperature class response to thermal stress when time to death was used as the index. Fish reared at 2.2 and 2.6°C above ambient river temperature were significantly more resistant to thermal stress than fish from the other two temperature classes.

According to the data, a difference of 2.2°C in thermal history is sufficient to alter the response of steelhead trout to a thermal stress. A period of three weeks acclimation to a common temperature eliminated the differential sensitivity.

Publications

C. D. Becker, C. C. Coutant, and E. F. Prentice. "Ecological Evaluation: Migration of Juvenile Salmon in Relation to Heated Effluents in the Central Columbia River," in: Radionuclides in Ecosystems, Proc. 3rd Natl. Symposium on Radioecology, Oak Ridge, Tenn., May 1971. (In press).

C. C. Coutant, and C. D. Becker "Growth of the Columbia River Limpet, Fisherala nuttalli (Haldeman), in Normal and Reactor-warmed Water," in: Radionuclides in Ecosystems, Proc. 3rd Natl. Symposium on Radio-ecology, Oak Ridge, Tenn., May 1971. (In press).

C. D. Becker, C. C. Coutant, and E. F. Prentice. Experimental Drifts of Juvenile Salmonids Through Effluent Discharges at Hanford. Part II. 1969 Drifts and Conclusions, BNWL-1527, Battelle-Northwest, Richland, Wash., 1971.

C. D. Becker. Food and Feeding of Juvenile Chinook Salmon in the Central Columbia River in Relation to Thermal Discharges and Other Environmental Features. BNWL-1528. Battelle-Northwest, Richland, Washington, 1971.

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C. D. Becker, C. C. Coutant, and E. F. Prentice. "Ecological Evaluation: Migration of Juvenile Salmon in Relation to Heated Effluents in the Central Columbia River," Third National Symposium on Radioecology, Oak Ridge, Tenn., May 10 - 13, 1971.

C. C. Coutant and C. D. Becker. "Growth of the Columbia River Limpet, Fisherola metlalli (Haldeman), in Normal and Keactor-warmed Water," Third National Symposium on Radio-ecology, Oak Ridge, Tenn., May 10 - 13, 1971.

EFFECTS OF TRITIUM ON AQUATIC ENVIRONMENTS

- FIXATION AND ACCUMULATION OF TRITIUM
- EFFECTS OF SHORT RANGE PARTICLE IRRADIATION

A significant contribution to the radioactivity in the liquid effluent from nuclear power plants will be tritium. Limited data is available on the concentration in aquatic food webs. Chronic exposure experiments with an experimental aquatic ecosystem were carried out to determine the rates of accumulation under chronic exposure conditions and to determine whether enhanced accumulation occurs in tissues and selected subcellular fractions. In studies on "sublethal" effects of tritium as tritiated water, antibody synthesis against C. columnaris disease was used to investigate the results of tritium irradiation during embryogenesis on development of the immune process in juvenile and yearling rainbow trout.

Effect of Short-Range Particle Irradiation on Embryogenesis of Teleost Fish

J. A. Strand, M. P. Fujihara, W. L. Templeton and R. G. Genoway

As in previously reported experiments, eggs of rainbow trout, Salmo gairdneri, were immersed in 0.01, 0.1, 1.0 and 10.0 μCi/ml tritium (biological grade) contaminated spring water (essentially pathogen free). Rearing throughout embryogenesis, 28.5 days at 10.6 ± 0.5°C, was facilitated within a recirculating drip incubation system of 150-liter capacity.

The effects of each treatment were assessed in terms of the proportions of eggs hatching and the numbers of obviously abnormal larvae produced. Anomalies included major malformation of the eyes and body.

For those embryos used in previously reported accumulation and retention experiments (exposure to tritium for 20 days at levels of 0.01, 0.1, 1.0 and 10.0 μCi/ml), selected behavioral and physiological tests were applied to detect "sub-lethal" effect. The relative performance of tritium-treated (1.0 μCi/ml exposure for 20 days during embryogenesis) and untreated (control) juvenile fish to predation was determined using the method of Bams (1967). For other groups of tritium-stressed fish (1.0 μCi/ml exposure for 20 days during embryogenesis), equilibrium loss, thermal death time, and growth were determined. Antibody production in response to exposure to *Chondroccus columnaris* infection (naturally occurring in Columbia River) was employed to investigate the effect of tritium irradiation (1.0 and 10.0 μCi/ml for 20 days during embryogenesis) on development of immune response in both juvenile and yearling fish.

Radiation Effects

Results of exposures to the four concentrations of tritiated water as determined throughout embryogenesis are illustrated in Tables 1 and 2. In experiment No. 1, the 95% Confidence Limits for each treatment compared with the control indicate that under the described experimental conditions, a statistically significant

TABLE 1. Effect of Tritiated Water on Embryogenesis of *Salmo gairdneri*

Treatment	No. Eggs	% Hatch	95% Binomial Confidence Limits	No. Larvae Sampled	% Abnormal	95% Binomial Confidence Limits
Experiment No. 1						
Control	3743	79.2	77.5-80.4	2298	1.0	0.6-1.4
0.01 μCi/ml	7985	83.1	82.2-83.7	6240	5.5	4.9-6.1
0.1 μCi/ml	8123	81.9	81.2-82.8	6352	3.5	3.0-4.0
1.0 μCi/ml	4239	80.2	78.9-81.1	3338	1.8	1.4-2.3
Experiment No. 2						
Control	3182	89.6	88.9-91.0	2849	0.7	0.4-1.1
0.1 μCi/ml	6953	66.8	65.7-68.3	2882	1.6	1.2-2.1
1.0 μCi/ml	3434	57.0	55.4-58.5	1918	3.5	2.8-4.4
10.0 μCi/ml	4413	72.8	71.6-74.4	3203	0.5	0.3-0.8

TABLE 2. Effect of Tritiated Water on Embryogenesis of *Salmo gairdneri*

Experiment No. 2

Treatment	No. Fertile Eggs	No. Deaths Through 21 Days	% Mortality Through 25 Days	95% Binomial Confidence Limits
Control	3166	270	8.5	7.5-9.5
0.1 μCi/ml	6946	747	10.7	9.9-11.6
1.0 μCi/ml	3431	681	19.8	18.4-21.4
10.0 μCi/ml	4411	618	14.0	12.9-15.1

reduction in hatching percentage could not be demonstrated. In fact, a slight enhancement in hatching efficiency occurred in the 0.01 and 0.1 μCi/ml levels. No demonstrable delay in time of hatching for any of the three treatment levels as compared with the control was observed. A statistically significant increase in the incidence of abnormal larvae as compared with the control was encountered.

In experiment No. 2, the lack of rigid temperature control during the last week of development unavoidably resulted in terminating the tritium-treated lots before the greater proportion of the embryos had hatched. The control lot hatched under near normal experimental conditions. However, as in Table 2, if mortality is normalized to a period in development when environmental parameters were adequate (21 days), then a comparison between control and each treatment level is possible. In this case, a significant increase in moitality as compared with the control is encountered; which may be correlated to increasing exposure level. From Table 1, the embryos in the 0.1 and 1.0 μCi/ml levels produced significantly more abnormal larvae than the control.

Detection of "Sub-lethal Effects"

For those procedures applied to detect "sub-lethal" effect as a result of exposure during embryogenesis and including determinations of relative performance to predation, equilibrium loss, thermal death time and growth rate, no consistent statistically significant degree of impairment was demonstrated.

The percent distribution of C. columnaris antibody titers in juvenile and yearling rainbow trout is illustrated in Figure 6. All lots exposed to tritiated water showed an increase in titer magnitude during the test. The control lots, however, indicated that more fish demonstrated higher titers which suggests a suppression of the immune mechanisms in the tritium-irradiated rainbow trout.

A Chi-square test of independence was used on the agglutinin data (Table 3) to determine if tritium-irradiation of the embryos significantly lowered immune capacity in juvenile and yearling trout. These results are illustrated in Table 4. Analysis of the data for juvenile control versus tritium-irradiated fish indicates a significant suppression of immune capacity during the last two sampling periods; however, no significant difference was observed between the 1 μCi and 10 μCi lots.

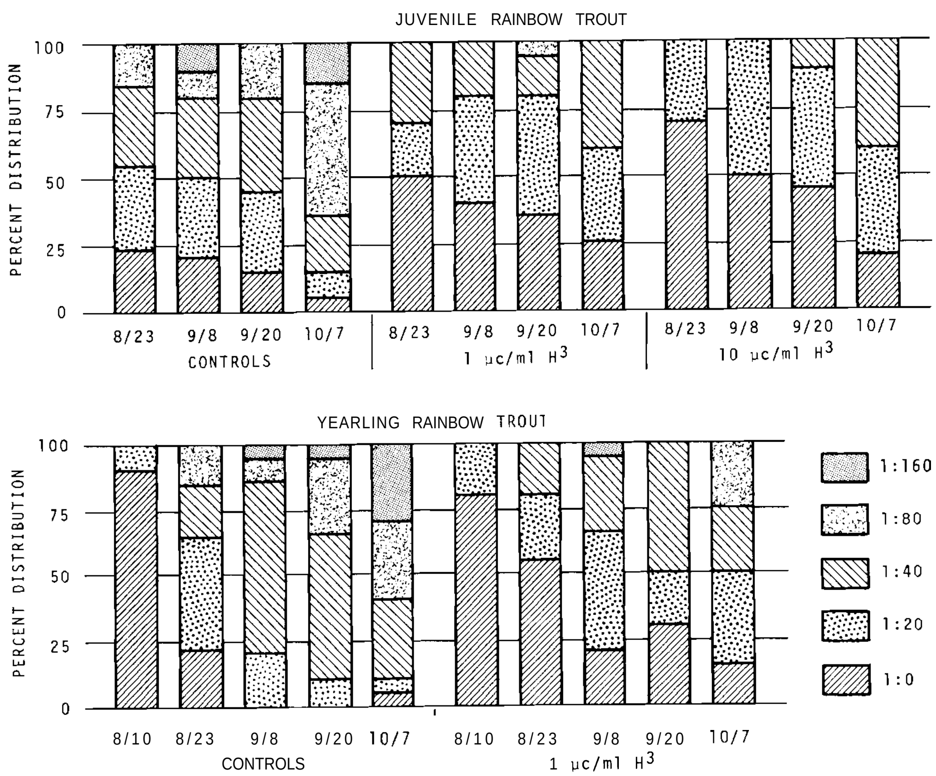

FIGURE 6. Percent Distribution of Juvenile and Yearling Rainbow Trout with S. columnaris Agglutinating Antibodies

TABLE 3. The Incidence of Chondrococcus Columnaris Exposure, Infection and Antibody Development in Juvenile and Yearling Rainbow Trout, 1971

Date	No. Fish[(a)]	Disease Incidence[(b)] Exposure, %	Infection, %	Titers, %	Range Pos. Titers	Date	Water Samples/ml[(c)]
Pond 4 (yearling controls)							
8/10	20	-	-	10	1:20	8/10	0.3
8/23	20	80	0	79	1:20-80	8/17	0.52
9/8	20	0	10	100	1:20-160	9/1	1.28
9/20	20	0	60	100	1:20-160	9/14	1.76
10/7	20	60	20	95	1:20-160	10/4	1.32
Pond 3 (yearling, 1 μCi/ml)							
8/10	20	-	-	20	1:20	8/10	0.1
8/23	20	0	20	45	1:20-40	8/17	0.4
9/8	20	20	0	80	1:20-160	9/1	1.04
9/20	20	40	0	70	1:20-160	9/14	2.56
10/7	20	0	40	85	1:20-80	10/4	3.0
Pond 5 (juvenile controls)							
8/10	20	25	10	-	-	8/10	0.4
8/23	20	15	0	77	1:20-80	8/17	0.4
9/8	20	0	0	80	1:20-160	9/1	0.12
9/20	20	5	0	85	1:20-80	9/14	0
10/7	20	10	0	95	1:20-160	10/4	0.04
Trough 1 (juvenile, 1 μCi/ml H^3)							
8/10	20	40	20	-	-	8/10	6.13
8/23	20	0	0	50	1:20-40	8/17	0.68
9/8	20	0	0	60	1:20-40	9/1	0
9/20	20	20	0	65	1:20-80	9/14	0.08
10/7	20	15	0	75	1:20-40	10/4	1.2
Trough 4 (juvenile, 10 Ci/ml H^3)							
8/10	20	25	10	-	-	8/10	0.67
8/23	20	15	0	30	1:20	8/17	0.64
9/8	20	5	0	50	1:20	9/1	0
9/20	20	10	10	55	1:20-40		
10/7	20	30	5	80	1:20-40	9/14	0.2

a. Ponds 4 and 3. Five yearling rainbow trout were sacrificed during each sampling period to determine exposure and infection; 15 additional fish were bled for agglutination studies and returned to the respective ponds.

b. Arbitrary definitions:
- 1 to 10 surface isolates/fish - exposed (not infected)
- >10 surface isolates/fish - infected
- 1 or more internal isolates/fish - infected

c. Ten separate water samples were drawn from the outlet of each pond or trough and four 0.25-ml aliquots were surface plated on solid growth medium.

TABLE 4. Comparison of Agglutinin Data Between Control Fish and Those Exposed to Tritium Utilizing Chi-Square Test of Independence on Titer Values Arranged in Contingency Tables

	Adults			Juveniles					
	Control vs 1 μCi			Control vs Tritium			1 μCi vs 10 μCi		
Sample Date	d.f.	χ^2	Level	d.f.	χ^2	Level	d.f.	χ^2	Level
8/10	1	2.06	NS	-	-	-	-	-	-
8/23	3	6.94	NS	3	6.46	NS	2	3.53	NS
9/8	4	10.50	(a)	4	7.11	NS	2	2.22	NS
9/20	4	13.71	(b)	3	11.66	(b)	3	1.43	NS
10/7	4	11.68	(a)	4	33.61	(b)	2	0.18	NS

NS - Nonsignificant Chi-square at 0.05 level indicating distribution of titer values was indepdent of treatment.
a. Significant Chi-square at 0.05 Zevel indicating the distribution of titer values was dependent on treatment.
b. Significant Chi-square at 0.01 level.

The yearling rainbow trout, exposed to tritiated water at 1 μCi/ml as embryos, showed a significant suppression of immune capacity during the last three sampling periods. The data indicate that there is a carry-over of agglutinins developed as juveniles, but more significantly a carry-over of the suppression mechanism.

To minimize excessive mortality from disease in general, both control and tritium exposed lots were given identical periodic prophylatic treatments. Agglutinin levels and concentration of organisms in water and fish were evaluated at intervals to assure that exposure and infection were occurring to establish a continuing development of antibodies against C. columnaris disease, Table 4. The data showed a sufficient incidence of C. columnaris exposure and infection which increased the percentage of fish with agglutinins as well as the magnititude of titers in all experimental lots during the two-month test period.

Fixation and Long-Term Accumulation of Tritium in an Experimental Aquatic Environment

J. A. Strand, W. L. Templeton and E. G. Tangen

Because of the effort spent on assessment of environmental impact of nuclear power plant siting, much of the work scheduled for this program during CY-1971 was unavoidably delayed.

Tritiated water at a concentration of 1.0 μCi/liter or 10 μCi/day was metered into the experimental ecosystem until March 15, 1971, a duration of nine months. To date, samples of biological material, invertebrates and fish, from the first six months of exposure, have been analyzed for volatile and nonvolatile or "bound" tritium. A rapid uptake of the isotope was demonstrated in all tissues analyzed. Equilibrium was achieved in approximately five days, followed during the ensuing period by maintenance of equilibrium levels. Samples taken over the first six months indicated that "bound" tritium accounted for approximately 20% of the total label.

After nine months of exposure, the system was maintained on nonradioactive replacement waters for an additional six months to determine the rate of elimination of tritium from the system. At appropriate intervals, samples of biological material, invertebrates, and fish were collected and subjected to analyses as before.

Statistical treatment of data derived from the last three months of exposure and the subsequent six months of depuration is nearing completion.

Bioenvironmental Effects of Effluent Discharge from Nuclear Power Plants to Coastal Waters

J. A. Lichatowich, J. A. Strand and W. L. Templeton

Preliminary studies have been completed to determine the range of lethal temperatures for juvenile and adult shiner perch, *Cymatogaster aggregata*, juvenile chum salmon, *Oncorhynchus keta*, and Dungeness crab, *Cancer magister*. Equilibrium loss and thermal death time have been employed as indices of thermal effect. Other studies have been initiated employing the eggs of a representative flatfish and the eggs and larvae of Dungeness crab. These latter studies are designed to evaluate thermal stress encountered during entrainment and employed an exposure regime of 2 to 5 min. and a temperature maximum of 10°C above ambient. Still other studies initiated during the reporting period have emphasized the potential interaction of elevated temperature, salinity, and selected toxicants. These studies are in preliminary stages; they will be reported on more fully in the subsequent year.

FACTORS AFFECTING BIOGEOCHEMICAL CYCLING

- ECOLOGICAL CHARACTERISTICS OF THE COLUMBIA RIVER
- EFFECTS OF MODIFICATIONS ON THE COLUMBIA RIVER
- RATES AND MECHANISMS OF BIOGEOCHEMICAL CYCLING PROCESS IN THE COLUMBIA RIVER
- FRESHWATER ECOLOGY OF RATTLESNAKE SPRINGS

Biogeochemical events will lead to detectable levels of trace metals in various biota. As the ecological characterization nears completion, emphasis in this group of programs is shifting towards establishing rates of movement of those elements from the abiotic to biotic compartments of the environment. Several studies reported here continuing efforts to build a baseline data base.

The heavy metal, mercury, is highly toxic and has been identified in some areas as a major pollutant in surface water and food fish. Relatively little information is available, however, on mercury concentrations in the river or the distribution of mercury in aquatic components. Data provided in this section documents the mercury levels determined for the Columbia River and its various confluences, as well as the effect of temperature on the direct uptake of mercury from water by fish.

Fall Chinook Salmon Population Studies

D. G. Watson

Aerial census of fall chinook salmon spawning in the Columbia River between Richland and Priest Rapids Dam were made during the period from October 18 to November 16. This is a continuation of a program initiated in 1947 to evaluate the effects of reactor effluents on this fish population. Although only one reactor is presently operating at

Hanford, this study is being continued to see if there is a noticeable change in salmon spawning population density following the closure of the production reactors.

Spawning started about the middle of October and reached a peak about the middle of November and was near completion on November 18. The peak of spawing was about one week later than usual. A total of 3600 salmon redds (nests) were observed. For the period of record, since 1947, this was the third highest number present, exceeded only by the 1969 and 1970 populations. The total estimated spawning population was approximately 25,000 salmon; or 36% of the fall run ascending McNary Dam, the nearest dam downstream; or 14% of the fish passing Bonneville Dam, the nearest dam to the river mouth.

At the start of spawning water temperatures were approximately 14.5°C, and had dropped to about 11.7°C at peak of spawning in November. These temperatures are within the recognized tolerance limits of chinook salmon.

<u>Uptake of Mercury-203 by Fish</u>

D. G. Watson

The heavy metal, mercury, is highly toxic and has been identified in some areas as a major pollutant in surface waters and food fish. Concentrations of this metal greater than that considered acceptable in human food have been detected in fish in several areas of the world including Sweden, Japan, Canada and the United States. The purpose of this study was to obtain information on the effect of temperature on the direct uptake of mercury from water by fish.

The juveniles of two species of fish, carp (<u>Cyprinus carpio</u>) and catfish (<u>Ictalurus nebulosus</u>), were maintained in a flow-through system containing ^{203}Hg at a concentration of 50 pCi/liter. The experimental temperatures were approximately 7 and 14°C and the fish were fed a standard moist hatchery diet. To establish the identity of the individual animals, each was tagged with colored glass beads attached to the dorsal fin. The body burden of ^{203}Hg in the fish was measured by live-counting the animals individually several times during the course of the study.

Some of the results are shown in Figure 7. After four weeks exposure to ^{203}Hg, both species of fish at the high temperature had body burdens greater than twice that of the fish held at low temperature. There was a marked difference between species, with the uptake of ^{203}Hg by carp more than 50% greater than that of catfish. This difference was approximately the same as the difference in average weight between the two species. The rate of uptake and loss of mercury was greatest in fish at the high temperature, reflecting the influence of this parameter on metabolic rate. Following the initial rapid loss of ^{203}Hg during the first two days after the introduction of the isotope was discontinued, the effective half-life was about 17 days and 26 days for carp in

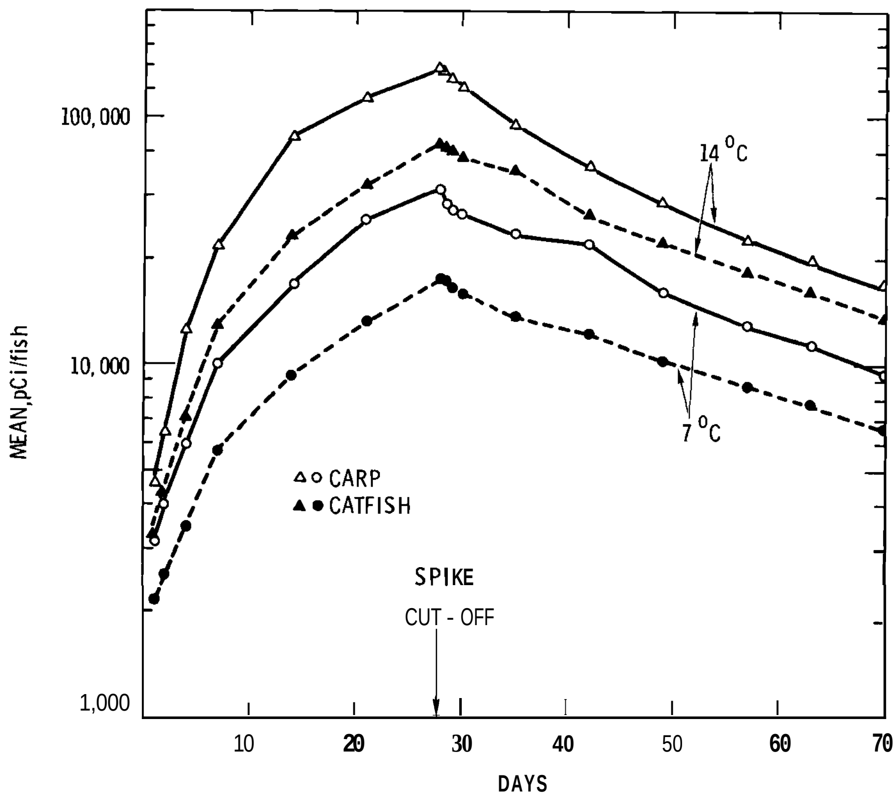

FIGURE 7. Uptake and Retention of ^{203}Hg by Fish

the high and low temperatures, respectively; and about 25 days and 31 days, respectively for catfish.

Further analyses will be made on the uptake and retention of ^{203}Hg by the fish in each temperature group to describe the variation among the individual animals.

Mercury Levels in the Lower Columbia River Watershed

R. E. Wildung, R. L. Schmidt,
D. G. Watson and W. L. Templeton

Although agriculture and a number of municipal, industrial and government facilities utilize the Columbia River for a variety of purposes, relatively little information is available on mercury concentrations in the river or the distribution of mercury in aquatic components.

Total mercury levels were determined in water samples taken in September, 1971 from the Columbia River at Priest Rapids, McNary and Bonneville Dams (river miles from the mouth, 396, 292 and 148, respectively); the Yakima, Snake and Walla Walla rivers at their confluence with the Columbia River (river miles 335, 324 and 314, respectively) and the Ringold Esquatzel wasteways (river miles 354 and 344, respectively), which return irrigation water to the river. In addition, mercury levels in Columbia River sediments deposited behind the dams were also measured. Water samples were taken in September when the river flow was near the annual minimum and when irrigation waters were being returned to the river. Dilution of return waters was therefore likely at a minimum.

Mercury levels in all river and waste water samples were less than methodological sensitivity, i.e., 0.1 μg/liter (or 0.1 ppb). Sediments behind Priest Rapids, McNary, and Bonneville Dams on the Columbia River contained 0.115, 0.331 and 0.096 μg-mercury/g of sediment on a dry weight basis. Thus, McNary Dam sediments, situated below the confluences of the Yakima, Snake, and Walla Walla Rivers, contained significantly higher mercury levels than sediments behind Priest Rapids Dam, above the confluence of these rivers or Bonneville Dam, below McNary Dam. It is possible that the Yakima, Snake and Walla Walla river waters, which are generally of poorer quality than that of the Columbia, contribute mercury (perhaps bound to suspend particulate matter) to the sediments retained behind McNary Dam. It should be noted, however, that considerable industrial development also exists above the dam. The monitoring program will be expanded in the future to determine if seasonal differences in mercury levels exist and if mercury is transported in larger quantities during spring runoff when suspended sediment loads are at a maximum.

Activation Analysis of Caddis Larvae and Whitefish

C. E. Cushing and D. G. Watson

In November 1968, a program was initiated to collect basic ecological data on the Columbia River to provide baseline information for future work. During the first year, 1968-69, samples of water and phytoplankton were collected just below Priest Rapids Dam and analyzed by neutron activation analysis and conventional techniques for the concentrations of some 18 elements. These data, reported in previous annual reports, provided information on the first two links in the food-web; namely, the basic elemental composition of the water and the primary producers.

The next step in the program initiated similar studies of the subsequent links in the food-web. Activation analyses of the elemental composition of caddis fly larvae and whitefish flesh were initiated in 1970 and are in progress. The caddis larvae feed on the phytoplankton and other algae by straining them from the water or actively grazing on the surface of stones. Whitefish, in turn, are carnivorous and actively feed on the insect larvae, either by picking them off of the stones or taking them as drifting organisms which have become dislodged.

These samples, along with concurrent water samples, were to be 'collected at the same five times of the year as were the water and phytoplankton samples. These periods represented distinctive stages in the annual cycle of river conditions. The sampling program, however, was severely disrupted by unusual water conditions in 1971. The first sampling in November 1970 was successful and water, caddis, and whitefish were collected in February 1971, but high water levels prevented the collection of caddis larvae. These high water conditions, caused by manipulation of power dams, prevailed during the entire year and prevented further sampling of caddis larvae. Water and whitefish were again collected in April 1971, but fishing for whitefish was unsuccessful in July 1971 and no further sampling has been done. Data analyzed to date are shown in Table 5.

A comparison of the November 1970 data for caddis larvae and whitefish flesh reveals that only one element, K, was found in higher concentrations in the whitefish. All other elements found in both species either decreased (Na, Zn, Fe, As, Cs, Co, Cr, Sb, Sc, Ag, Au) in concentration in the fish or were relatively unchanged (Rb, Br, Se, and Hg). Seven elements present in caddis larvae were not found in the whitefish flesh.

Most elements showed only minor changes seasonally in whitefish flesh between November 1970 and February

TABLE 5. Elemental Concentration of Caddis Larvae and Whitefish Flesh, Dry Weight

Element	Whitefish, 11-16-70	Whitefish, 2-18-71	Caddis larvae, 11-16-70
Decreasing order of Concentration	(ppm)	(ppm)	(ppm)
K	20950	18200	12600
Na	1650	1200	3900
Fe	17	18	2000
Zn	13	11	260
Rb	17	12	18
Br	9.85	8.95	12
Sn	--	--	<12
Se	1.25	1.2	1.2
As	<0.82	<0.8	3.4
La	--	--	1.6
Hg	0.405	0.28	<1
Decreasing order of Concentration	(ppb)	(ppb)	(ppb)
Cr	<110	135	1800
Co	22	24	870
Th	--	--	660
Sc	0.261	<0.05	500
Hf	--	--	410
Cs	80	59	220
Sb	3.55	~0.7	110
Ta	--	--	68
Tb	--	--	66
Eu	--	--	56
Au	<5.7	<6.55	<16
Ag	~1.5	~1.0	39

1971, with the exception of mercury, cesium, and antimony which showed significant decreases. Scandium exhibited a questionable decrease and chromium a questionable increase.

Decline of Radioactivity in Biota Following Shutdown of Hanford Reactors

D. G. Watson and C. E. Cushing

The shutdown of the last plutonium production reactors which discharged significant amounts of radioactivity into the Columbia River occurred in 1971. This afforded the opportunity to follow the retention and/or elimination of the accumulated radionuclides in the biota of the river as the burden in the river dissipated.

To accomplish this in the most thorough manner, a cooperative study was initiated with the Radiological Sciences Department. It was agreed that the Radiological Sciences Department would be responsible for the collection of water and sediment samples and that they would count all of the samples on their equipment. The Ecosystems Department was charged with the collection of all biological samples. These were to include plankton, periphyton, invertebrates, and a carnivorous (squawfish) and herbivorous (sucker) fish species at each sampling location. The stations selected for monthly sampling were the White Bluffs area immediately below all the reactors (river mile 369), McNary Reservoir (river mile 294), and Bonneville Reservoir (river mile 152). Quarterly samples are collected in Priest Rapids Reservoir (river mile 398) above the Hanford Plant as background comparisons.

To date, although many of the samples have been counted, no completed analytical data are available.

Productivity of Rattlesnake Springs

E. G. Wolf and C. E. Cushing

Standing Crop

Water cress (*Rorippa nasturtium-aquatica*), the major autotrophic organisms in the spring-stream system, flourishes from late April until the annual winter flood in January. If there are no floods or major frost, it is possible for this plant to continue to grow until mid-summer of the next year. This producer organism has a rapid recovery and growth rate. Between April 23, 1970 and September 25, 1970, the total area of the stream covered by water cress increased from 2 to 85%. From September 25, 1970 until November 20, 1970, the total area covered increased by only 7%, but the total biomass of the water cress increased nearly 51% during the same time period. The standing crop on November 20, 1970 was 220,000 g ash-free organic matter for the 440 m segment of stream studies.

The invertebrate community increased from virtually a zero population shortly after the flood to 25,000 g ash-free organic matter on November 20, 1970. This community was dominated by an ostracod crustacean and a pulmonate mollusc.

The stream segment under study, therefore, contained a total community standing crop of 245,000 g ash-free organic matter on November 20, 1970.

Organic Input

A series of 12 traps were set along the edge of the stream to sample allochthonous material falling into the stream. From the total area of the stream and the segment sampled, the total input from the environment could be estimated. When the data were integrated for the entire year, based on changing stream area, the total allochthonous input was 246,000 g ash-free organic matter.

Allochthonous and autochthonous input from the stream segment above the study area was determined as particulate and dissolved fractions. Integrated values over the entire year for both dissolved and particulate organic matter was 462,000 and 3,797 g ash-free organic matter, respectively. Thus, there was a total input into the study area of approximately 712,000 g ash-free organic matter.

Organic Output

Organic output was collected and analyzed in a method similar to that used for the data of autochthonous and allochthonous input. Organic output is composed of allochthonous and autochthonous materials in excess of the community metabolic requirements of the stream segment studied. The dissolved and particulate components were 676,000 and 13,500 g ash-free organic matter, respectively.

In addition, the winter floods of January 1970 removed 60,000 and 2,000 g ash-free organic matter of water cress and invertebrates, respectively. These values represent the standing crop of the populations five days prior to the flood. Therefore, the total output from the study area was 751,500 g ash-free organic matter.

Net Production

If the total input (712,000 g ash-free organic matter) is subtracted from the total output (751,500 g ash-free organic matter), there was a net increase of 39,500 g ash-free organic matter. This, plus the addition of the standing crop (245,000 g ash-free organic matter) on November 20, 1970, indicates that the study area yields a net production of 284,500 g ash-free organic matter per year.

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SYNERGISTIC EFFECTS OF TEMPERATURE, POLLUTANTS, AND DISEASE IN AQUATIC ORGANISMS

- SYNERGISTIC EFFECTS OF TEMPERATURE AND INDUSTRIAL AND AGRICULTURAL POLLUTANTS

- THE RELATIONSHIPS OF INCREASES IN ENVIRONMENTAL TEMPERATURE TO INFECTION OF COARSEFISHES AND SALMONIDS TO DISEASE*

With constant temperature conditions, many of the common pollutants have been shown to disturb physiological processes in spite of their sublethal concentrations. The objectives of our field and laboratory studies are to determine the effect of seasonal and induced changes in river temperatures and other interacting factors on the development of specific diseases in selected aquatic organisms. During this reporting period, studies were initiated to determine which life stages are the most sensitive to these various interactions. The data obtained will provide a more meaningful ecological standard for the establishment of water quality criteria.

Monogenea of Juvenile Bass

C. D. Becker

A recent survey was made of the monogenetic gill parasites of juvenile largemouth bass, Micropterus salmoides, and smallmouth bass, M. dolomieui, from the Hanford area of the central Columbia River. The study was prompted by use of young bass as bioassay organisms in our laboratory, due to the possibility that the latent infestations might influence experimental physiological and toxicological parameters.

** Preliminary work initiated under Service Assessment funding; 189 submitted and funded for FY-73.*

Five species of Monogenea were recovered: Actinocleidus fusiformis (Mueller, 1934), Clavunculus unguis (Mizelle and Cronin, 1943), Urocleidus furcatus (Mueller, 1937), U. principalis (Mizelle, 1936), and U. helicis (Mueller, 1936). All five species were recovered from the gill structures of juvenile largemouth bass; A. fusiformis was the most common parasite, following in decreasing numerical order by U. furcatus, U. principalis, and rarely U. helicis and C. unguis (the last on the gill arches only). Only A. fusiformis, C. unguis, and U. furcatus were detected on the gills of juvenile smallmouth bass, and the infestations consisted of relatively few organisms compared to those on largemouth bass. Indeed, all largemouth were infested whereas many smallmouth were not.

Three factors point to the desirability of considering infestations of monogeneans in conducting routine bioassays with centrarchid fishes. First, Monogenea are apparently common gill parasites of juvenile centrarchids inhabiting various lotic and lentic aquatic environments throughout this continent. Second, centrarchids--such as various sunfish, bass, and crappie--are commonly used in monitoring the toxicity of various pesticides and industrial wastes. Third, gill tissues are sensitive to the action of pollutants and monogeneans cause histopathological damage by perforating the filaments with their haptoral hooks.

Few investigators have been aware of possible complications arising from latent gill infestations, which probably vary widely in incidence and intensity between populations of test fish, during bioassays. We hope to evaluate this effect in our future bioassay studies. However, the use of infested fish may actually be more harmonious with normal conditions (in most aquatic environments) than use of uninfested fish, or fish initially rendered uninfested by routine prophylactic treatment. However, the effects, if any, should be known.

C. columnaris Disease

M. P. Fujihara

Despite the prolonged and excess run-off and cooler river temperatures, C. columnaris field studies at the White Bluffs, Wenatchee and Keokuk sampling sites on the Columbia River during April, May and July, 1971 demonstrated an earlier incidence of exposure and infection, a larger percentage of coarsefishes with agglutinins and higher average titers than was observed during similar months in 1970 (Table 6). The data at the three sites suggest that C. columnaris disease conditions observed in 1970 had a direct bearing on the earlier incidence of exposure, infection and antibody development during 1971.

The earlier incidence (1-2 months) of C. columnaris exposure and infection of coarsefishes was probably due to a greater carry-over of pathogens from the unusually heavy infection rate observed during 1970. The higher percentage of coarsefishes with agglutinins and higher average titers was a result of a larger carry-over of fish with residual antibodies from

TABLE 6. A Comparison of Chondrococcus Columnaris Exposure, Infection and Antibody Development in Coarse-Fishes Sampled at White Bluffs, Wenatchee and Keokuk Sampling Sites on the Columbia River, April Through July, 1970 - 1971.[a]

Date	No. Fish	Temp., °C.	C. columnaris Incidence[b] % Exposure	C. columnaris Incidence[b] % Infection	% Titers	Av. Titers	Titer Range
White Bluffs							
3/24/70	60	6.1	0	0	30	1:18	1:20-160
5/1	50	8.4	2	0	30	19	320
5/25	50	12.2	4	0	40	28	320
7/30	44	20.2	31.8	4.5	45	55	320
4/16/71	38	8.0	5.3	2.6	68	1:62	1:20-640
5/12	15	11.2	27.0	7.0	87	47	160
7/9	46	15.5	34.8	13.0	82.6	98	640
Wenatchee							
4/8/70	51	4.5	0	0	43	1:27	1:20-160
5/6	50	8.9	0	0	22	12	160
6/2	24	12.2	0	0	--	--	--
7/13	42	18.9	35.7	42.9	71.4	46	320
4/15/71	40	5.6	10	2.5	85	1:106	1:20-320
5/13	40	10.5	20	5.0	92.5	108	640
7/8	29	13.4	27.6	13.8	89.6	222	640
Keokuk							
4/8/70	49	5.5-17.8	0	0	57	1:29	1:20-160
5/7	50	8.9-19.5	0	0	44	34	160
6/3	43	15.6-21.2	13.9	0	--	--	--
7/13	36	18.9-25.0	27.7	41.7	70	40	160
4/15/71	40	5.6-17.8	0	0	75	1:64	1:20-320
5/13	50	12.2-16.6	10	2.0	92	84	640
7/8	39	19.0-22.2	38.4	25.0	88	102	640

a. *Note that the percent of fish with titers and average agglutinating titers at all sites are higher during 1971, reflecting the larger infection rate and a larger carry-over of residual antibodies from 1970.*
b. *Arbitrary definitions.*
1-10 surface isolates/fish = exposed.
>10 surface isolates/fish or 1 or more internal isolates/fish = infected.

1970 and an earlier re-challenge of these fish by the pathogen.

It is anticipated that the incidence of C. columnaris exposure and antibody development in coarsefish species in the middle and upper Columbia River will continue to increase, but the peak infection rates during the summer and fall months may be lower than observed in 1970 because of the development of high agglutinins and resistance to the disease. Consequently, the infection of anadromous salmonids should be lower this year because of fewer infected coarsefishes.

Gas Bubble Disease of Salmoid Fishes
M. J. Schneider

Research of the effects of gas-supersaturated water on aquatic organisms requires an accurate and rapid means of analyzing the dissolved gas levels of water. The major portion of the effort during the last year was devoted to the further refinement of the analytical techniques. The final result is a rapid gas chromatographic procedure which produces a digital output. These data are then used to computer-calculate parts per million dissolved gas and percent saturation for each water sample. Total analysis time, including computer terminal time, is less than 5 min. per sample. The accuracy of the method has been determined as 0.2 ppm.

The refined system for dissolved gas analysis was demonstrated in a series of multiple water samplings that were conducted at Priest Rapids Dam. A total of 29 water samples were taken each sampling day at nine selected stations above and below the dam. At each station, surface samples were taken. The total field sampling time averaged 90 min. Upon return to the laboratory, each water sample was analyzed and the data reduced. Total analysis time was 2 hr. 20 min.

Surveillance of the dissolved gas levels was continued in the stretch of the Columbia River from Priest Rapids Dam to the White Bluffs area. Sampling was started in April and continued until September. The sample stations remained the same as last year with the exception that the slough areas were deleted. Sample stations were: above Priest Rapids Dam, the spillway and powerhouse discharges water, Vernita Bridge, B-C reactor site, and White Bluffs. For these routine samples, only surface water is taken. The results of the 1971 season surveillance appears in Figure 8. For simplicity, only the nitrogen levels (percent saturation) are shown and three representative stations were selected: Priest Rapids Dam forebay, stilling basin, and Vernita. Two features of Figure 8 are apparent, the dissolved gas level of the river was supersaturated from late May until early September and there is considerable variation in dissolved gas levels from station to station on a given day.

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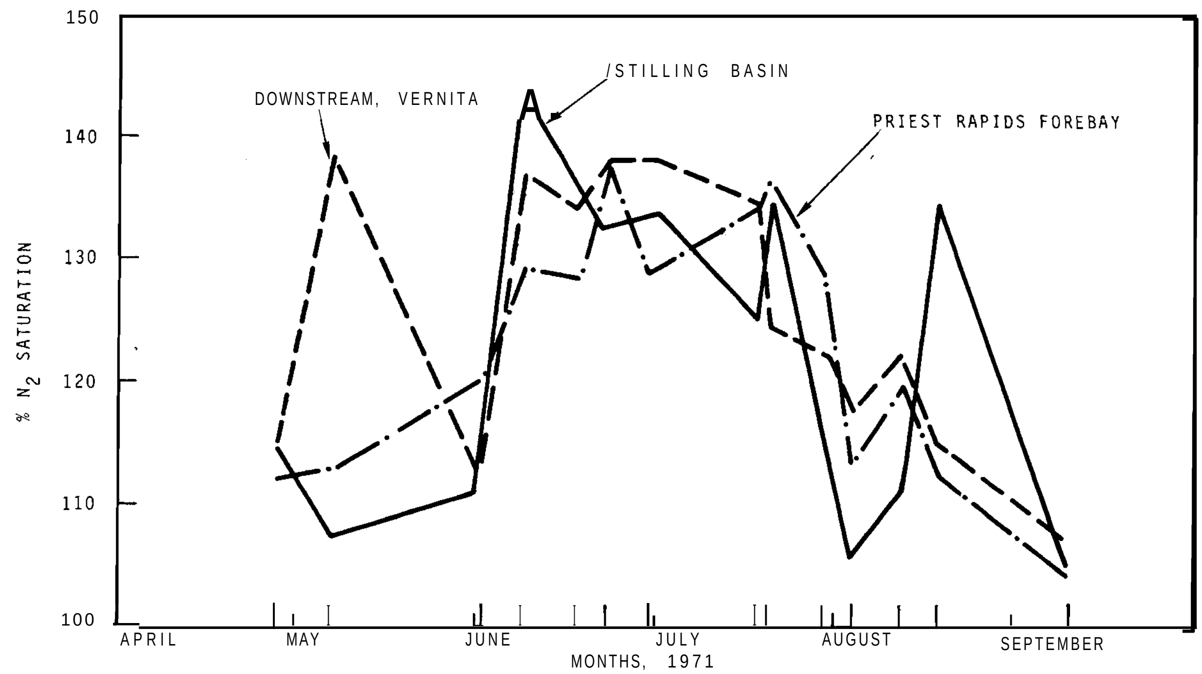

FIGURE 8. Nitrogen Levels (percent saturation) for Three Representative Stations

TERRESTRIAL ANIMAL ECOLOGY

The major objective of the terrestrial animal ecology project is to characterize the functional roles of the important animal species, both vertebrates and invertebrates, of the ALE Reserve shrub-steppe ecosystems. Major emphasis is placed on elucidating the relationships between perturbed environments, irradiation effects, population dynamics and reproductive habits, environmental quality and the fate and effects of fallout radionuclides and their element counterparts in northern Alaska environments. The animal program is dependent upon the studies of soils microclimatology, and herbage dynamics for data on environmental parameters that directly effect the responses of the animals. This project contributes to important information on the Terrestrial Plant Ecology Program, a focal point of the ecology studies.

TERRESTRIAL ANIMAL ECOLOGY

A. PERTURBED ENVIRONMENTS

B. IRRADIATION EFFECTS

C. POPULATION DYNAMICS AND KEPRODUCTIVE HABITS

D. ENVIRONMENTAL QUALITY

E. ALASKA

A. PERTURBED ENVIRONMENTS

It is known that the quality and quantity of food alters the reproductive performance of wild and domestic animals. It was the purpose of our continuing studies to determine the effect of such variables on the population densities and species composition of small animal life. Wildfire and other environmental conditions will further affect wildlife. Also, as large grazing animals remove a portion of the annual productivity of grasslands, they indirectly affect populations of other primary consumers such as small animals. A major objective of the ALE grassland study is to measure possible changes in the numbers and species composition of small mammals on grazed or ungrazed study areas. The data obtained from these programs during this reporting are presented in the following papers.

Population of Pocket Mice, *Perognathus parvus*, on the ALE Reserve

T. P. O'Farrell, J. D. Hedlund,
R. A. Gies, H. A. Sweany,
R. J. Olson* and R. O. Gilbert*

Populations of pocket mice, *Perognathus parvus*, have been followed for the past five years and estimates of numbers have been derived from trapping data using Jolly's stochastic model (Figure 9). Over 35,000 trap-nights have been logged, and approximately 1700 individual pocket mice have been identified and captured over 15,000 times.

Population fluctuations during 1967-1970 were summarized in earlier annual reports. Briefly, 1967 and 1970 were "average" years with regard to plant production and rodent reproductive success. In 1968, which had the lowest plant biomass production, there was virtually no small mammal breeding. But 1969 saw the greatest yield of winter annuals, and the greatest reproductive activity of small mammals: juvenile as well as adult females produced litters in 1969.

* *Mathematics and Physics Research Department.*

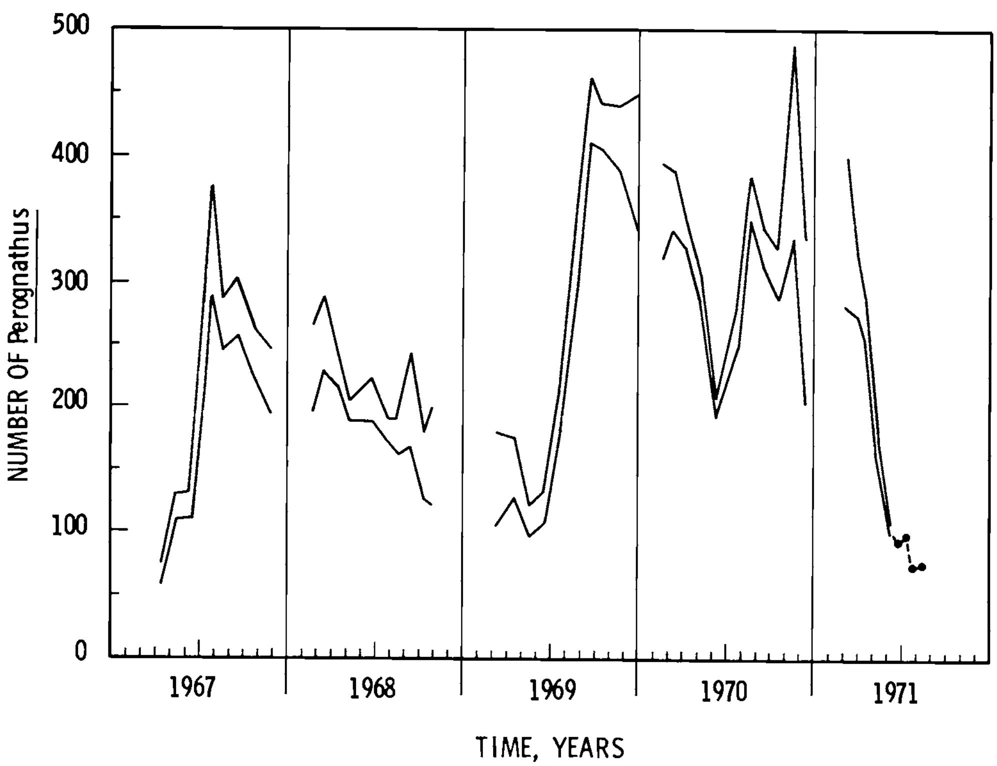

FIGURE 9. Population sizes of *Perognathus parvus* Estimated from Trapping Data Using Jolly's Stochastic Model. Band widths indicate the 0.95 confidence intervals.

Precipitation during the winter of 1970-1971 was almost half that of the previous two winters and the yield of winter annuals was reduced. For the second year in a row only adult mice bred, producing 1-2 litters per female. The downward trend of the population, which began at the end of the 1969 breeding peak, was continued through 1971. There were few new juvenile animals entering the population to offset the decline in population size caused by mortality of adults and the beginning of estivation-hibernation. In 1971 the adults ceased their aboveground activities at least one month early. The period of torpor may have been induced by the unusually cool soil and air temperatures during September.

An examination of the trapping data for this important primary consumer has led to posing the hypothesis that productivity of winter annuals, particularly the magnitude of the seed crop, is largely responsible for alterations in the indigenous reproductive rhythm of the species. This is certainly not a unique observation since it is known that the quality and quantity of food alters the reproductive performance of other wild and domestic animals. The task now will be to quantify the relationship and to determine the other variables, particularly population density, which would further modify the reproductive performance of pocket mice given varied levels of their natural food supply.

Population Dynamics of *Perognathus parvus* on Manipulated Shrub-Steppe Ecosystems

T. P. O'Farrell, J. D. Hedlund
and R. A. Gies

During the past five years, a population of pocket mice (*Perognathus parvus*) was sampled and observed in an effort to determine what environmental factors are responsible for perturbations in the annual cycle of abundance. After examining such variables as precipitation, photoperiod, soil temperatures, and plant productivity, it appeared that the amount of winter annual production was largely responsible for the variability in reproductive performance exhibited by the pocket mouse. The seeds of winter annuals, particularly cheatgrass (*Bromus tectorum*), are the most important single food item of *Perognathus* in this region.

During years of low production, such as occurred in 1968, few litters are conceived; in average years, such as 1967 and 1970, adult females have 1-2 litters each; and in years of extremely high winter annual production, such as 1969, the adults have 1-2 litters and a high proportion of the juvenile females also have litters, swelling the population in only a few months. The productivity of winter annuals is in turn dependent upon the amount and timing of winter precipitation, and the magnitude of drying conditions during the spring growth period.

To test the hypothesis that plant production alters the breeding behavior of pocket mice, field manipulations were commenced in 1970-1971. Three 5.75 hectare study areas were established in shrub-steppe vegetation typically used by Perognathus. The first site was irrigated with an overhead sprinkler system to simulate a year of high natural precipitation. An herbicide, IPC-Chemhoe, which selectively kills annual grasses, was applied to the second area to simulate a year of little to no winter annual production. The third area was unaltered and represented the response of the vegetation to environmental conditions during 1970-1971. A total of 100 trapping sites were located on 10 x 10 grids with 10-meter centers in the middle of each plot. The traps were operated on a biweekly schedule and individual animals were marked, weighed, and examined for reproductive and general condition before release.

Data on trapping success on the three study areas are presented in Figure 10. After pocket mice emerged from hibernation in March-April, population densities on the three

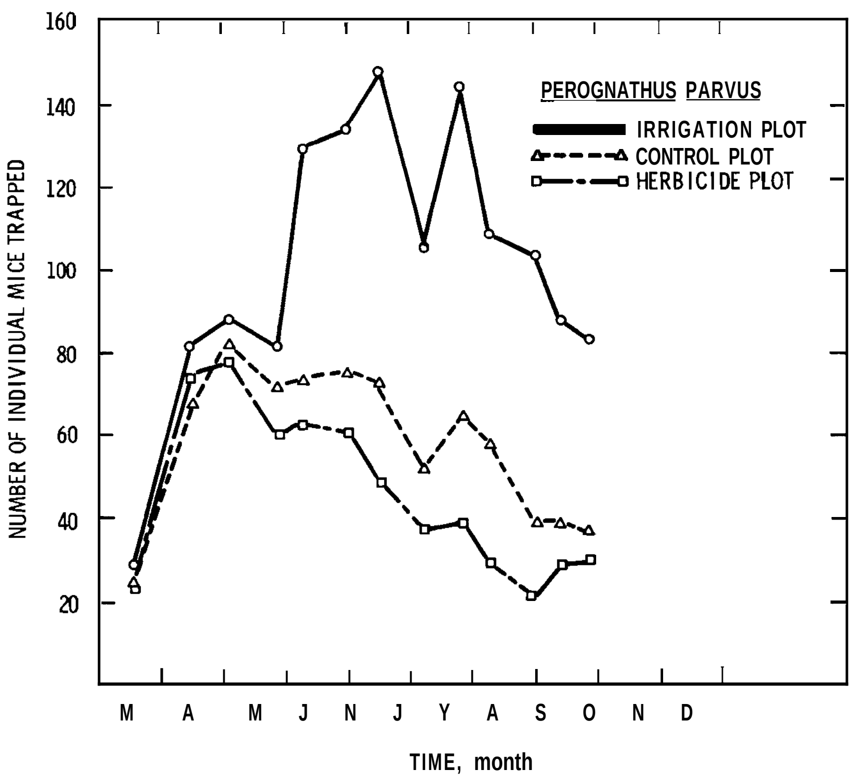

FIGURE 10. Number of Individual Pocket Mice, Perognathus parvus, Trapped on Manipulation Study Areas in 1971. The number of traps on irrigated site was doubled from June on to compensate for the change in animal density.

study areas were identical. The effects of the modulations on mouse densities began to appear in late May when the population on the irrigated site began to increase dramatically and the density on the herbicide plot dropped below the density on the control grid. This order of decreasing trapping success, irrigation, control, herbicide, did not change for the remainder of the year. The highest densities of Perognathus on the control and herbicide plots were reached in April-May, the onset of the breeding season, and numbers then declined at approximately the same rate on both plots. The population dynamics of these two sites were identical to those recorded for the same species on the grasslands study site and on the five-year study area near Rattlesnake Springs. It appears that 1971 was a poor year for pocket mice, much like 1968. Few adults bred, and the annual recruitment was less than the loss of animals from the trapping cohort either through mortality or commencement of estivation.

On the irrigation plot, adults disappeared at a rate similar to the other two sites, but the population density increased due to a high rate of reproduction. As in 1969, both adults and juvenile females produced litters, causing the second peak in numbers during late August.

The results indicate that the production of winter annuals, between the extremes of low to maximum productivity, can influence the breeding characteristics of small mammal populations in the shrub-steppe. One unanswered question is how much population densities at the onset of the breeding influence the rate of reproduction. The field manipulations will be repeated in 1972 to examine this question.

Effects of Wildfire on Native Rodent Populations

T. P. O'Farrell, J. D. Hedlund, R. A. Gies and H. A. Sweany

Immediately following the 1970 wildfire, an investigation was initiated to document the effects of the burn on the small mammal populations which were so numerous before the holocast. The major objective of the study was to estimate the species composition and relative abundance of small mammals during successional stages over the next few years.

Four live-trapping areas were established, three in the burn and one outside but in a similar vegetation type. Each plot was 0.25 hectare and had 25 live traps in a 5 x 5 grid with 10-meter centers. The traps were operated for 100 trap-nights each on four occasions: immediately after the burn; four months later at the onset of hibernation; at the beginning of the 1971 breeding season; and on the first anniversary of the fire. The trapping data are presented in Table 7.

In August, 1970, more pocket mice were captured in the control area than in any of the burned plots: the decline in numbers was about 20%. Additional traps were operated in November, 1970, to describe population levels prior to hibernation, but

TABLE 7. Trapping Success of Pocket Mice, *Perognathus parvus*, Following the 1970 Wildfire

	Burned Plots 17	Burned Plots 18	Burned Plots 19	Control 20
8/4 to 8/7/70				
Total captures[a]	48	31	41	61
Range/night	9-15	7-9	8-12	12-18
Mean captures/night	12	7.8	10.3	15.3
11/10 to 11/13/70				
Total captures	6	0	4	4
Range/night	1-2	0	1	1
Mean captures/night	1.5	0	1	1
3/30 to 4/2/71				
Total captures	53	24	39	64
Range/night	11-15	2-9	9-11	15-17
Mean captures/night	13.3	6	9.8	16
8/10 to 8/13/71				
Total captures	10	5	28	39
Range/night	2-4	1-2	6-8	9-11
Mean captures/night	2.5	1.2	7	9.8

a. Total of 100 traps at risk

most of the mice had already become torpid. The few active animals did not show any preference for the burned or unburned sites.

The most critical season for the small mammals was the spring of 1971. Laboratory tests indicated that many of the annual plant seeds were destroyed in the intense heat of the fire. The few plants that did germinate were literally sandblasted down, leaving little food for emerging animals. Nevertheless, the pocket mice did enter the traps in good numbers during late March. More mice were trapped in the control plot, and plot 18 continued to have the lowest success.

One year after the fire, the numbers of small mammals appeared to be lower in the control as well as the burned sites. This depression in numbers reflected the general low level of small mammal populations over the entire Hanford Reservation during 1971. More pocket mice were taken on the control plot once again. During the first and third trapping sessions more mice were trapped on plots 17, 19 and 18, in that order; but in August, 1971, plot 19 had more mice than plot 17. Vegetation studies revealed that more species of plants had become established in plot 19 than on any other burned plot. Plot 18, which was the most severely burned, still maintained the lowest numbers of rodents.

Trapping efforts on the burn will be postponed for at least two to three years to allow seral succession to proceed to the next stage. The paucity of vegetation indicated that succession will not proceed rapidly enough to justify trapping annually until more food items are available.

Small Mammal Populations on a Grazed Grassland

T. P. O'Farrell, J. D. Hedlund, R. A. Gies and H. A. Sweany

One of the major objectives of the International Biological Program (IBP) is to examine the productivity of the grasslands of North America and to determine the effects of grazing on this biome. As a part of this Program, a cooperative study was established under joint sponsorship of the USAEC and the National Science Foundation. The study takes advantage of the unique characteristics of the ALE Reserve, particularly the lack of prior disturbances, and the availability of a true multidisciplinary team of ecologists who are experienced in conducting field research. The availability of personnel with the necessary expertise and background data to plan field studies using modern design techniques permitted the initiation of controlled grazing as an environmental manipulation during the first year of the program. The grazing could, therefore, take place while measurements of the productivity of the ecosystem were being monitored at most trophic levels.

As large grazing animals remove a portion of the annual productivity of grasslands, they indirectly affect populations of other primary consumers such as small mammals. This is particularly true in the cold grasslands where small mammals are the most important mammalian consumers, owing to the lack of large, indigenous ungulates of numerous lagamorphs. A major objective of the ALE grassland study was to measure possible changes in the numbers, species composition, or biomass of small mammals on grazed and ungrazed study areas.

Two small mammal trapping grids were established, one in a grazed pasture, and one in an ungrazed control site. A total of 144 trap sites were located on a 12 x 12 grid on 15-meter centers. Two live traps were placed at each site and all were operated for five consecutive days once each month beginning in March, 1971. Trapped animals were toe-clipped for individual identification and released after weighing and examination for reproductive and general condition.

Seven species of small animals were trapped on the grids during 1971, including pocket mice (Perognathus parvus), deer mice (Peromyscus maniculatus), grasshopper mice (Onychomys leucogaster), sagebrush voles (Lagurus curtatus), Townsend's ground squirrel (Spermophilus townsendii), harvest mice (Reithrodontomys megalotis), and the Norway rat (Rattus norvegicus). This is a remarkable species diversity which has not been equalled anywhere else on the ALE Reserve. The most numerous mammals were pocket mice and deer mice, but during some months of the spring, ground squirrels equalled or exceeded the biomass of these most numerous species. The definition of which is the most "important" species of small mammal is further confused by the dynamic changes in numbers, size, growth rates, and periods of activity above ground.

On an annual basis, however, the most consistent contributor to energy turnover in the mammalian-trophic level is the ubiquitous pocket mouse. The data in Figure 11 demonstrate the

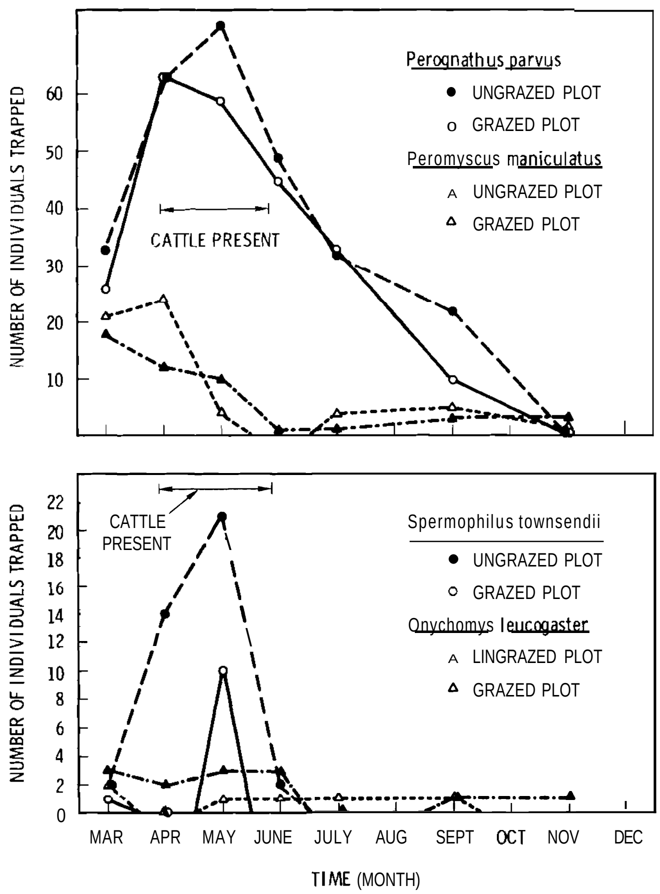

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FIGURE 11. Number of Individuals Trapped on Grazed and Ungrazed Grasslands of Project ALE During 1971. A total of 288 traps were at risk nightly on each plot during the five-day trapping sessions. Cattle were present on the grazing plot from April 14 until June 10, 1971.

changes in the numbers of pocket mice on the two plots and the similarity in data for the control and grazed sites. The peak population size occurred in April-May which is the beginning of the breeding season. The numbers immediately began to drop and there was no marked rise during the summer that could be attributed to recruitment of juvenile animals. The food crop in both grids was poor in 1971, breeding was curtailed, and the adults appeared to enter estivation early. This response of the pocket mice to low food supplies duplicated the response exhibited by populations elsewhere on ALE during 1971. This was not a good year for small mammals.

The poor productivity precluded making conclusions regarding the effects of cattle on small mammals. A change in population density of small mammals might be expected in a year when large seed crops were produced in control plots while cattle were consuming grasses and forbs before they set seed on grazed sites. In years of poor food production, grazing does not appear to be as critical to population changes as the normal responses of the species to low forage supplies.

Cattle Grazing on a Pristine Grassland

T. P. O'Farrell and Ecosystems Department Staff

A major objective of the ALE grasslands investigation was to examine the impact of man's agricultural or animal husbandry activities on the productivity and recovery of the ecosystem after use. Without irrigation, the most practical economic use of the grassland would be cattle grazing. This would be a marginal grazing site since stock could not be maintained on native forage throughout the year, and because of the cattle industry evolution from open-range grazing to feed lots as a method of raising beef.

Two 22-acre connected pastures were fenced in 1971. A watering trough was installed and salt blocks were made available. On April 14, 1971, 15 yearling steers were introduced into one of the pastures (Figure 12). At weekly intervals the stock were rotated between the pastures to allow some recovery of the forage, and also to allow the research team to make measurements of the various natural trophic levels. On June 10, 1971, the cattle were removed since it was the end of the grazing season and the vegetation was beginning to show signs of degradation.

The cattle weighed in at a total of 6615 pounds, and 58 days later they weighed 7970 pounds. The net individual gain per animal per day was 1.6 pounds, which is an excellent rate of increase for range cattle on most native grasslands in North America. The effect of the cattle grazing on the natural system, particularly the productivity of the perennial grasses, is discussed in other sections of this report.

Neg TPO 7113-6

FIGURE 12. Cattle Being Introduced onto the ALE Reserve in 1971 for Studies of the Impact of Grazing on the Grassland Ecosystem

Publications

W. H. Rickard. "Observations on the Distribution of *Eleodes Hispilabris* (Say) (Coleoptera:Tenebrionidae) in Relation to Elevation and Temperature in the Rattlesnake Hills," *Am. Mid. Nat.*, vol. 85 (Part 2), pp. 521-526, 1971.

T.P. O'Farrell and V. K. Christensen *A Bibliography of Environmental Research: Ecosystems Department*, BNWL-1549, Battelle-Northwest, Richland, Washington, 1971.

B. IRRADIATION EFFECTS

A radiation study of pocket mice was conducted, both in the field and the laboratory, to determine whether the animals might be more resistant to radiation because they were in a familiar environment or, conversely, whether they might exhibit a lowered resistance due to the synergistic effects of radiation and natural predation stresses.

Radiation Effects in Free-Ranging Pocket Mice

T. P. O'Farrell, J. D. Hedlund, R. A. Gies, R. O. Gilbert* and R. J. Olson*

In 1967, a population of pocket mice, Perognathus parvus, was subjected to the stress of acute ionizing radiation at doses spanning the median lethal response of the species. The objective of the field experiment was to compare the responses of free-ranging pocket mice with similar information gathered in the laboratory. We wanted to see if animals might be more resistant to radiation because they were in a familiar environment or, conversely, whether they might exhibit a lowered resistance due to the synergistic effects of radiation and environmental stresses.

The laboratory drived $LD_{50/30} \pm SD$ was 858 ± 27 rad, and the value for unconfined mice was 834 ± 32 rad. There was no evidence to suggest differences between the median lethal values for pocket mice irradiated in the laboratory as compared with free-ranging mice.

Median longevity was 12 months or less for all animals, although some unconfined mice lived three years postirradiation. Mice exposed to 900 rad lived less than three months. Median longevity appeared to be inversely related to absorbed dose.

Controls showed evidence of breeding behavior up to three years after the study began. Radiation-induced sterility was not evident in free-ranging males, but none of the exposed females showed evidence of reproductive activity during three subsequent breeding seasons.

Unconfined mice survived secondary effects including: swelling and eversion of cheek pockets essential for carrying food; hair loss including total depilation; and a change in coat color from tan to white. The white pelage did not appear to make the irradiated mice more vulnerable to predation.

During 1971, laboratory and field irradiations were repeated to obtain some measure of the variability of such experiments, and also to stress the free-ranging population during the onset of the breeding season. In 1967, the field exposures took place at the end of the breeding season as the adults were entering hibernation.

* *Mathematics and Physics Research Department.*

The treated animals included both juveniles as well as adults, but in 1971 only adults were exposed.

The laboratory derived $LD_{50/30}$ was 880 ± 14 rad, which is not significantly different from the 1967 statistic, and the value for unconfined mice was 780 ± 27 rad (Figure 13). Both the median lethal doses and the slopes of the survivorship curves were significantly different. There was evidence of a higher rate of mortality in the free-ranging pocket mice, Since these results reverse the conclusion posited after the 1967 field exposure, we must assume that some seasonal or annual variation was operative. It is known that the beginning of the breeding season is a period of behavioral and physiological stress in small mammals, and perhaps there was a synergism between the radiation and environmental stress in 1971.

Our ability to trap all but one of the 19 control animals 28-30 days postirradiation was encouraging since it supported our assumption that we can recover virtually every animal still living on the study area. These data helped minimize the correction for natural mortality which must be made in the data prior to probit analysis and comparison of the survivorship curves.

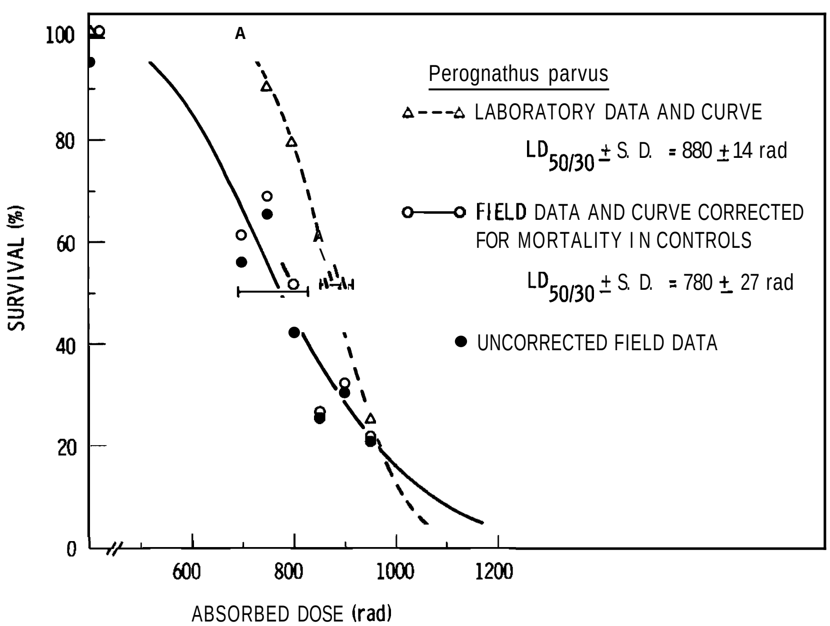

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FIGURE 13. Survivorship Curves of Captive and Free-Ranging *Perognathus parvus* Obtained by Probit Transformations of Mortality Data Following Exposures to Acute Radiation. Data for unconfined pocket mice have been corrected for mortality in controls, and the median lethal doses are bracketed by the 95% fiducial limits.

Publications

T. P. O'Farrell, J. D. Hedlund, R. J. Olson and R. O. Gilbert. "Effects of Acute Ionizing Radiation on Survival, Longevity, and Reproduction in Free-Ranging Pocket Mice, Perognathus parvus," Rad. Res. vol. 49, pp. 611-623, 1972.

T. P. O'Farrell. "Effects of Acute Radiation in Captive and Free-Ranging Pocket Mice, Perognathus parvus," D. J. Nelson fed.), Third National Symposium on Radioecology, CFSTI, Natl. Bur. Stds., Springfield, Va., 1972. (In Press.)

C. POPULATION DYNAMICS AND REPRODUCTIVE HABITS

Continuing efforts in the mule deer tagging operation were made to determine the location, numbers, composition of individual herds and the proportion of fawns carrying ear tags. A few white-tailed deer have been sighted interspersed among mule deer herds, although there is some speculation as to their survival if they are forced to seek food away from the river. Continued observations will be made of both species.

Attempts to quantify the distribution and abundance of pocket mice (Perognathus parvus) and deer mice (Peromyscus maniculatus) as a function of altitude and season progressed during the year. These are the two most important species of mammal on the ALE Reserve. Although the grasshopper mouse (Onychomys leucogaster) has the same reproductive potential as the other species found on the reserve, there is a discrepancy between this potential and the low numbers found in the field. Accumulated data for the year is documented herein.

Tagging Hanford Deer, *Odocoileus hemionus*

J. D. Hedlund, R. A. Gies and T. P. O'Farrell

In 1969 a tagging operation was initiated to establish known-age individuals in the deer herds of the Hanford Project lands. A total of 24 fawns was sighted from a helicopter, pursued on foot, and tagged with metal ear tags. One of these animals was later killed by a car, making it the first data point in the population study.

It became apparent that a limited amount of data could be obtained from incidental deaths and recovery of the small metal ear tags. In 1970 large, white plastic ear tags were also placed in the ears of 51 fawns. These larger ear tags allow the collection of movement data by observing animals from a distance without disturbing them.

During the winter of 1970-71 attempts were made to observe the ratio between tagged and untagged fawns as an index to total numbers. The observations were also used to define movements of the fawns from the fawning areas. Approximately 35% of the fawns observed had tags. Either many deer are missed during the tagging operation in June or the wintering population is diluted by deer migrating in from other areas.

During the 1971 deer tagging, large yellow plastic ear tags were used to facilitate identification of age classes in the field. A total of 52 fawns were captured and tagged with individual numbers. As part of a cooperative program with the State of Washington, Fish and Game Department tags were placed in the other ear of each fawn. Hunters should now have less difficulty deciding who to contact regarding information on tagged deer.

Sighting and recovery information from previous years' tagging operations has begun to yield valuable data. Sightings have been reported by local sportsmen as well as Game Department agents. A tag placed on a fawn in 1970 was recovered when the 15-month old deer was killed by a car 8-1/2 miles from where it was born, and over 3 miles beyond the boundary of Hanford Reservation. On opening day of the hunting season, three bucks tagged in 1970 were shot. Two of the deer were taken less than 5 miles from their initial tagging location, but one buck was shot 20 miles away. Tags, mandibles, and measurements of antlers were collected from these known-age deer. As each year passes, a higher proportion of the older deer will have tags and more information on movements should come from local sportsmen who hunt in the proximity of the Hanford Project.

White-Tailed Deer, *Odocoileus virginianus*, Range Extension in South-Central Washington

T. P. O'Farrell and J. D. Hedlund

During the 1970 deer tagging operation on the Hanford Reservation, a white-tailed doe (*Odocoileus virginianus*) was sighted on Locke Island. When the doe was first spotted she was running through dense vegetation near the central portion of the island. She mixed with a band of mule deer does which allowed investigators to make side-by-side species comparisons for key characteristics. The obvious differences between their tails confirmed the initial species identification.

In January, 1971, two observers were sent on a ground survey of the habitats used by mule deer for winter feeding. Their objective was to determine the location, numbers, and composition of individual herds, and the proportion of fawns carrying conspicuous plastic ear tags. No mention was made of possible white-tailed deer on the reservation. However, when the technicians returned they reported seeing two antlerless white-tailed deer mixed in with mule deer. The first white-tail was seen on the mainland with a band of five mule deer 3-1/2 miles NNW of the 100F reactor area, approximately 1 mile west of Locke Island (Fig. 14). The second white-tail was observed with 23 mule deer 1 mile NNE of the 100D reactor area, approximately 3-1/2 miles WSW of Locke Island (Fig. 14).

The closest resident populations of white-tailed deer are in the Blue Mountains about 100 miles ESE of Locke Island. Herds in northeastern Washington come as close as Pullman, 110 miles E of Locke Island. State game biologists have reports of white-tailed deer moving down the Columbia River from Okanogan County in the past few years. These observations support the belief that the white-tailed deer is making a range extension along the Columbia River into southcentral Washington. What is significant is that except for eight large islands in this stretch of the Columbia River, the riparian cover, normally used by white-tailed deer,

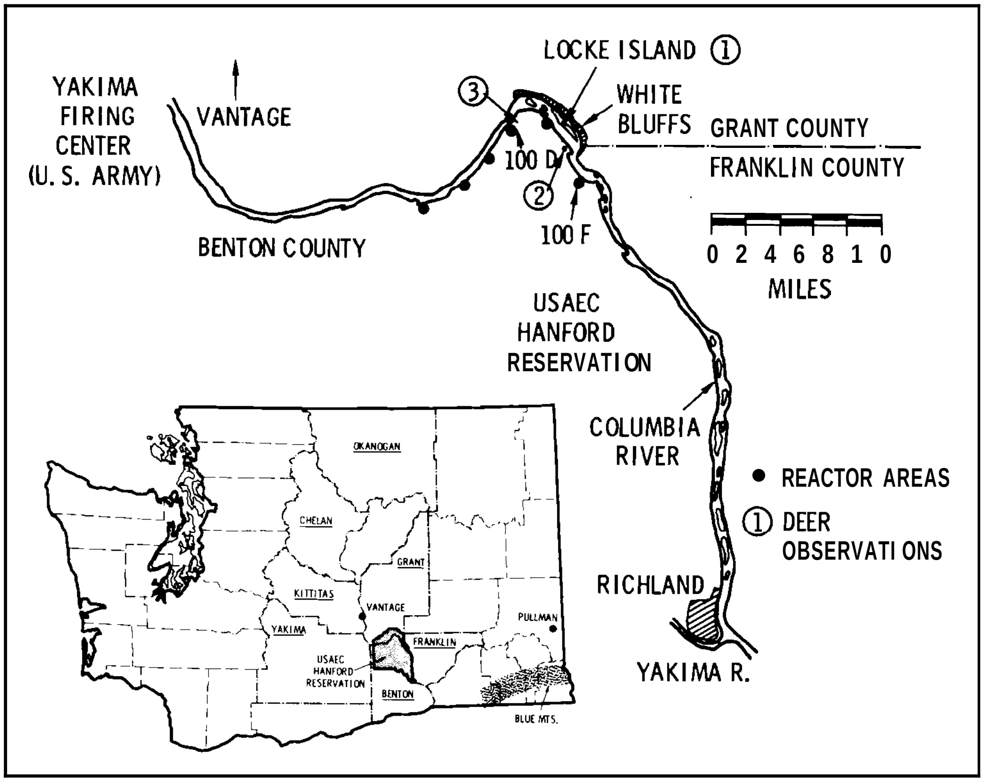

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FIGURE 14. Location of the U. S. Atomic Energy Commission's Hanford Reservation in Southcentral Washington. White-tailed deer have been observed at the three locations indicated by numbers in open circles.

is exceedingly scarce. There is some question as to how well the species will survive if it is forced to seek food away from the river in the shrub-steppe vegetation.

Distribution and Abundance of Small Mammals on Rattlesnake Mountain

T. P. O'Farrell and J. D. Hedlund

This program was initiated in April, 1969, to quantify the distribution and abundance of pocket mice (Perognathus parvus) and deer mice (Permomyscus maniculatus) as a function of altitude and season. These are the two most important species of mammal on the ALE Reserve. The results help guide extrapolations of population dynamics data gathered from the intensive study sites to other habitats on ALE.

Trapping information was gathered on 1.5 acre quadrats at four elevations, 500, 1500, 2500 and 3500 ft above sea level, using 50 live-traps per site. Figure 15 contains the data obtained in two years of effort on

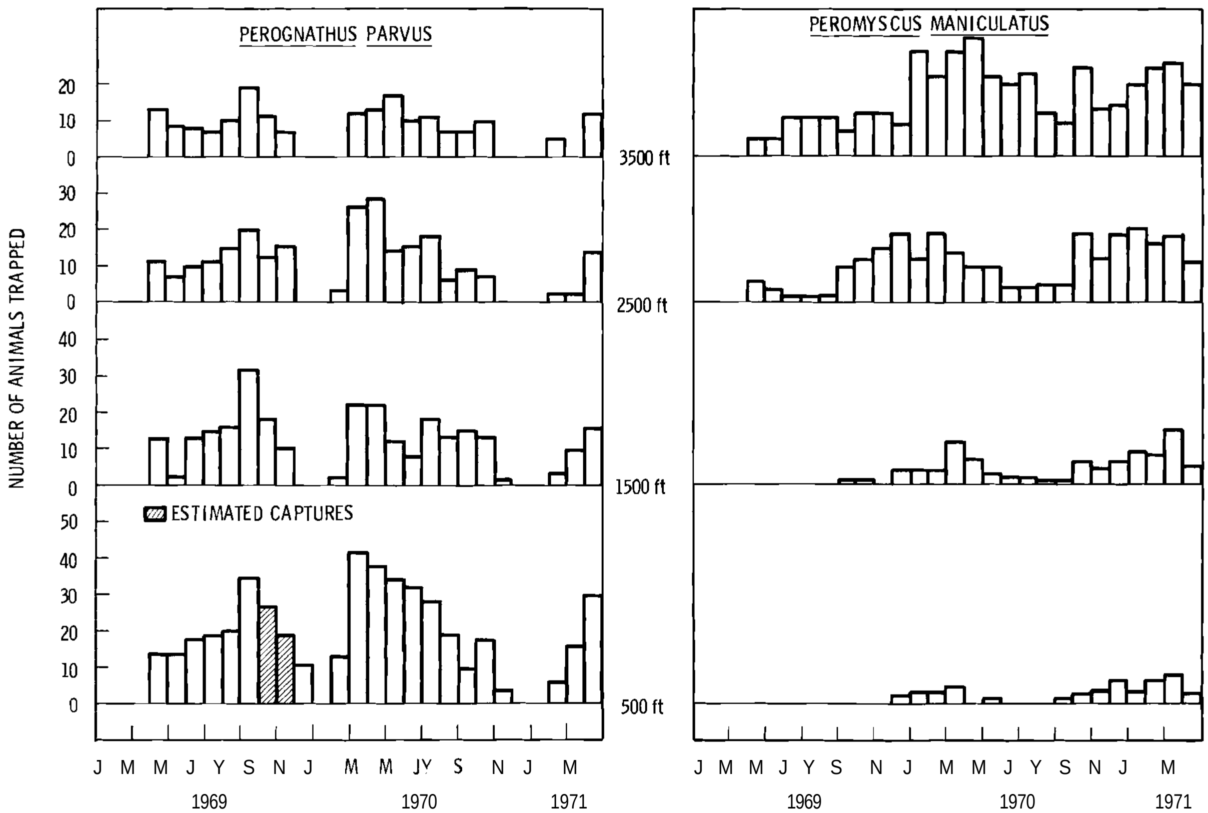

FIGURE 15. Relative Population Sizes of Deer Mice (Peromyscus maniculatus) and Pocket Mice (Perognathus parvus) as Determined by Live-trapping in 1.5 Acre Quadrats (50 Traps/Night).

the elevational transect. Populations of Peromyscus were directly proportional to altitude, while Perognathus reached highest densities at low elevations. Deer mice were most abundant during the late fall to early spring, while pocket mice reached population peaks in spring or summer.

The overwintering populations of Perognathus, indicated by total captures during January-April, were comparable for all three years at the four elevations. The numbers of deer mice were quite low following the severe winter of 1968-1969, when no Peromyscus were taken at the two lowest elevations. During the fall and winter of 1969, the populations increased to peak levels which were reached in early 1970. In 1970-1971 this pattern of breeding was repeated. Populations were sustained even at the 500-ft elevation during the winter of 1970-1971.

The significant aspect of these data is the lack of symmetry in the histograms of trapping data gathered from 1969 to 1971. There was a great deal of variability in trapping success, peak numbers of each species captured, and chronology of peaks and troughs in population curves. This variability proscribed any but descriptive comparisons between the sets of information, but it does demonstrate the need for caution in making broad generalizations concerning small mammal population dynamics.

Reproductive Behavior of the Northern Grasshopper Mouse, Onvchomvs leucogaster fuscogriseus

T. P. O'Farrell, J. D. Hedlund and R. A. Gies

The grasshopper mouse, Onychomys leucogaster, is one of the small mammals most sensitive to acute ionizing radiation. Throughout its range, the grasshopper mouse is one of the least numerous rodents, and relatively little is known of its ecological life history and reproductive potential. Our earlier reports indicated that in the laboratory Onychomys has a reproductive potential that is comparable with other more numerous small mammals. The remarkable discrepancy between this potential and the low numbers encountered in the field still remains unanswered. An experiment was started in March, 1969, to test the published hypothesis that female grasshopper mice undergo reproductive senility at one year of age.

The previous annual report presented data for the first year and one-half of the experiment which indicated that grasshopper mice were reproductively active into the third year of life. Results for the last 12-month period, Table 8, further support the observation that female grasshopper mice are capable of producing a significant number of litters each day until they are at least 2.5 years old. Older females were as successful at weaning litters as younger dams until they reached an age between 2.5 and 3.8 years, at which time the percentage dropped.

The effects of chronological age on reproduction are difficult to define since they are often masked by changes in "physiological" age; i.e., a female's reproductive capability may not depend on her age as much as on the number, sequence and size of litters. In March of 1970, 20 females were weaned: ten were immediately paired with males and are shown in Table 8 as 1.5-year old females; the other ten were placed into isolated cages until March, 1971, when they were paired with young males. The data in Table 8 show that the number and sizes of litters born to the latter group are comparable with their siblings which had been breeding for one year. The most significant difference was the greater survival of young in the females which had been isolated for one year. The percentage of survival for the sibling females was never greater than 68.8% for the three 6-month period between March, 1970 and September, 1971. There is no ready explanation for the significant differences in weaning success.

The drop in weaning success associated with each group of young animals added to the experiment at six-month intervals, posed the possibility

TABLE 8. Reproductive Performance of Onychomys leucogaster of Various Ages (September, 1970-September, 1971)

Age, yr[a]	Number of Pairs	Number of Litters	Number Born	Number Weaned	Survival of Young, %
>4.5	1	0	0	0	
4.2	9	1	2	0	0
4.0	9	2	2	0	0
3.8	9	9	14	5	35.7
2.5	10	46	148	76	51.3
2.0	9	66	272	160	58.8
1.5	10	75	331	222	67.1
1.0	10	68	279	192	68.8
0.5	10	4	15	15	100
1.5[b]	10	35	153	139	90.8
Wild Cdught	8	32	120	119	99.2

a. Age on 16 September 1971. Experiment commenced March, 1969.
b. Not bred until one year after birth.

that interbreeding within the colony might be contributing to lowered success. In March, 1971, eight pair of wild-caught grasshopper mice were added to the experiment. Over the past six months they have been the most successful breeders in the programs losing only one young animal before weaning (Table 8). Further combinations of wild-caught and laboratory-reared grasshopper mice will be made to assess the possible influence of interbreeding on the reproductive performance of Onychomys leucogaster.

Publication

T. P. O'Farrell and J. D. Hedlund. "White-tailed Deer, Odocoileus virginianus, Range Extension in South-central Washington," J Mammal. (In Press) 1972.

Presentations

T. P. O'Farrell. "Endless Chain--Arid Lands EcoZogy", Oregon Museum of Science and Industry, Portland, Oregon, January 24, 1971.

T. P. O'Farrell. "Project ALE--An Environmental Laboratory", American Society for Metals, American Society of Mechanical Engineers, Richland, Washington, April, 1971.

T. P. O'Farrell. "Effects of acute radiation in captive and free-ranging pocket mice, Perognathus parvus, Third National Symposium on Radioecology, Oak Ridge, Tennessee, May 10-12, 1971.

T. P. O'Farrell. "Endless Chain--Arid Lands Ecology", American Society of Mammalogy, Vancouver, B.C., June 21-24, 1971.

T. P. O'Farrell. "Small mammal studies on the ALE grasslands", Annual Meeting of the NSF International Biological Program, Grasslands Biome, Fort Collins, Colorado, November 3-5, 1971.

T. P. O'Farrell. "Critique of Consumer Studies, IBP Grasslands Biorne, 1971," Annual Meeting of the NSF International Biological Program, Grasslands Biome, Fort Collins, Colorado, November 3-5, 1972.

D. ENVIRONMENTAL QUALITY

Continued Canada goose nesting surveys have been conducted to provide the quantification needed to assess the results of wildlife management experiments. The unique record of nesting success of the Canada goose may ultimately be useful as an index to changes in the quality of the environment of the Columbia River during the past two decades.

Intensive small mammal trapping was also conducted as a part of the overall terrestrial ecology program. Results of these studies have confirmed the presence of the sagebrush vole (Lagurus curtatus) in Benton County, Washington. These studies provide an insight into the preferred habitat and population density of the species.

Canada Goose Populations on the Hanford Reservation, 1971*

R. O. Gilbert,** H. A. Sweany and T. P. O'Farrell

For the past 19 field seasons a continuous record has been kept of the nesting success of the Canada geese, Branta canadensis moffitti, which breed in the Hanford stretch of the Columbia River. Originally, the objective of the study was to assess possible long-term environmental effects of continued nuclear reactor operations on Columbia River fauna, particularly Canada geese. The data gathered indicated that neither the numbers of reactors operating during any one time, nor the proximity of the goose breeding grounds to the reactors, had any measurable effect on fertility or fecundity of the birds.

Other factors, including predation, disturbance of nesting sites by humans or their cattle, and destruction or desertion of nests due to natural flooding and water management techniques proved to be more important in altering population dynamics than reactor operations. All but natural predation can be related to man's impact on environmental quality, either through use of the river for hydroelectric development or as a recreation site for an expanding local population. The unique record of nesting success of the Canada goose may ultimately be more useful as an index to changes in the quality of the environment of the Columbia River during the past two decades.

In 1971 the number of nests (Table 9), declined, continuing the downward trend over the past 18 years. Neither the average clutch size nor the fate of the eggs (Table 10) has changed significantly over the same period. This indicates that the number of paired geese and the availability of suitable, undisturbed habitats is largely

* *Funded by Service Assessment*
** *Mathematics and Physics Research Department*

TABLE 9. Number of Canada Goose Nests and Eggs Recorded on the Hanford Stretch of the Columbia River, 1971

	Number
Number of Nests	114
Successful Nests	99
Eggs in Successful Nests	566
Eggs Per Successful Nest	5.7
Young From Successful Nests	536
Young Per Successful Nest	5.4

TABLE 10. Fate of Eggs Contained in Successful Canada Goose Nests During 1971

Fate of Eggs	Number	%	18-Year Average, %
Unfertile	11	2	3
Broken, Missing	2	<1	2
Fertile, Embryo Died	17	3	
1st Week of Development	10	2	4
2nd Week of Development	3	1	1
3rd Week of Development	1	<1	1
4th Week of Development	3	1	1
Dead Goslings	0	0	<1
Hatched	536	95	89
Total	566		

responsible for the apparently declining numbers.

The extensive data obtained during the past 10 years on nesting site preferences and population dynamics should provide a sound background for possible experimental studies aimed at reducing the impact of man's chronic and increasing demand on the last undisturbed portion of the Columbia River. Continued nesting surveys will provide the quantification needed to assess the results of these wildlife management experiments, as well as an index to further changes in the quality of the environment affecting a population of migratory waterfowl in western North America.

Occurrence of the Sagebrush Vole, *Lagurus curtatus*, on the Hanford Reservation

T. P. O'Farrell

The sagebrush vole (*Lagurus curtatus pauperrimus*) is a small rodent which occurs in the most xeric habitats occupied by the sub-family Microtinae in Washington State. The species presents an interesting problem regarding ecological distribution in Washington because the type-specimen was collected in the Walla Walla County in 1860 and no additional specimens have been reported there or in bordering counties since that time. James and Booth of Walla Walla College reported more recent information on the distribution of *Lagurus* using their trapping records as well as the extensive data of C. W. Clanton. They speculated that *Lagurus* might occur in Benton County but trapping was not conducted there since the prime habitat was located within the U. S. Atomic Energy Commission's Hanford Reservation.

Since 1966 intensive small mammal trapping has been conducted on the Hanford Reservation as part of the overall terrestrial ecology program. Results of these studies have confirmed the presence of *Lagurus curtatus* in Benton County, Washington. Fig. 16 illustrates locations on the Reservation that have been sampled and the distribution of captures. The number of captures in Fig. 16 should be interpreted only as an index to relative abundance since the trapping effort was not uniform for all sites.

On the Hanford Reservation, more *Lagurus* were trapped between 1000-2000 ft, and above 3000 ft than at any other elevations. The greatest numbers were taken at 3500 ft, which is the summit of Rattlesnake Mountain. Only four transient voles were taken at elevations below 1000 ft: three were captured at 800 ft in pitfall traps set for ground-dwelling beetles (W.H. Rickard, unpublished data, 1964); one *Lagurus* was trapped at 640 ft. The latter vole represented the only capture of the species after three years and 28,000 trap-nights of effort at that elevation. Other investigators have reported that in Washington the sagebrush vole occurs mainly between 1000 and 2800 ft. This trapping information supports their observation.

The occurrence of *Lagurus curtatus* in Benton County, Washington still does not clarify the enigma of why sagebrush voles have not been captured in the area surrounding the type-locality in Walla Walla County. These data do extend the range of the species into a county bordering the type-location. Perhaps *Lagurus* will be

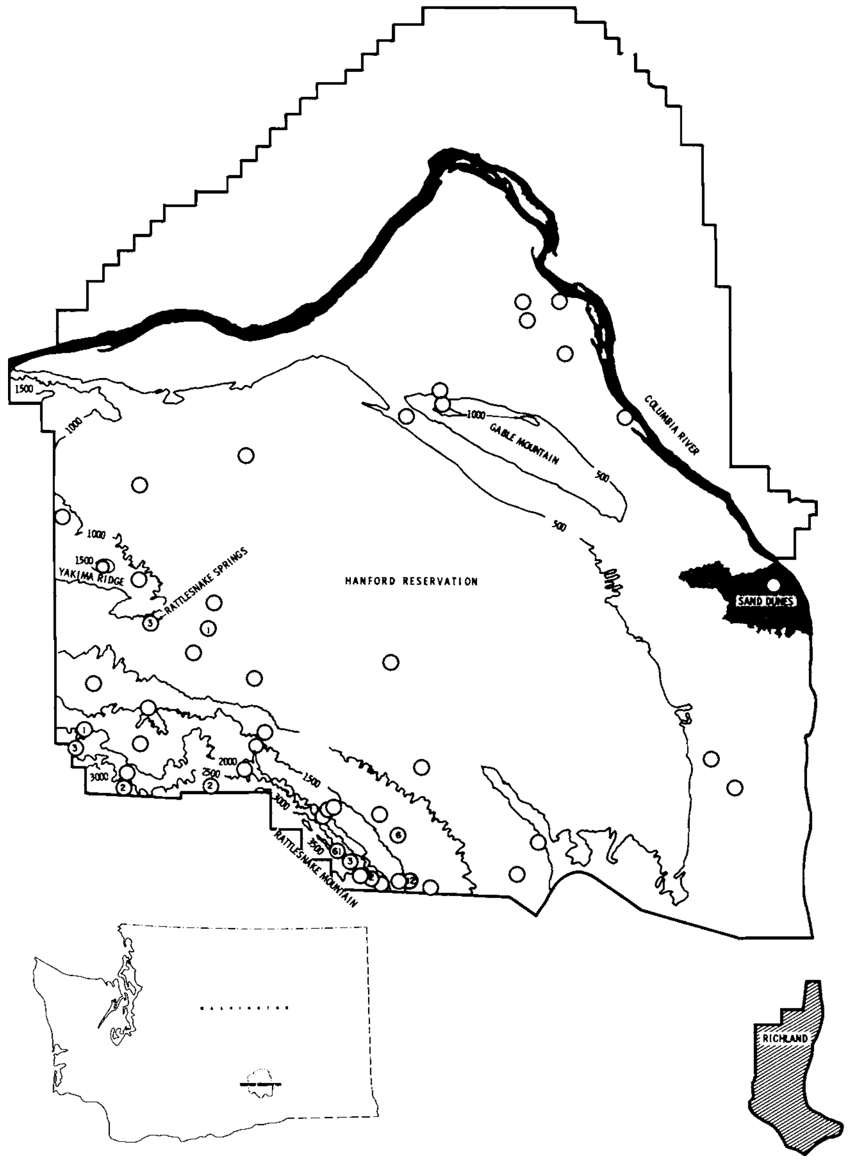

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FIGURE 16. Small-mammal Trapping Sites (Open Circles) on the U. S. Atomic Energy Commission's Hanford Reservation, Benton County, Washington. Numbers in circles indicate the number of *Lagurus curtatus* trapped at that site.

trapped in the higher elevations of the Rattlesnake and Horse Heaven Hills which extend from Benton County into Walla Walla County. However, the Columbia River, which has been an effective barrier to the free movements of other small mammals, breaks the continuity of these ridges at Wallula Gap. Modern agricultural practices have greatly reduced the *Lagurus* habitat in Walla Walla County since 1860 and few relick populations may exist.

ERRATUM

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Page 109, 2nd paragraph, lines 1-7 should read:

In measuring petroleum effects, two formidible technical problems arise: first, major fluctuations in the multi-phase system of oil, air, and water are caused by energy expenditure and manner of mixing in the influent supply; and second, the selective partitioning of specific toxic fractions may markedly alter mortality and other biological end-points.

Publications

W. C. Hanson and L. L. Eberhardt. A Columbia River Goose Population, 1950-1970. BNWL-1606, Battelle-Northwest, Richland, Washington, 1971.

W. C. Hanson. "The 1966-67 Snowy Owl Incursion in Southeastern Washington and the Pacific Northwest," Condor vol. 73, pp. 114-116, 1971.

T. P. O'Farrell. "Occurrence of the Sagebrush Vole, Lagurus curtatus, in Benton County, Washington," J. Mammal. (In Press) 1972.

E. ALASKA

The objective of this study was to define routes, rates, and amounts of fallout radionuclides in natural ecosystems of northern Alaska. Surveys show the persistence of small but ubiquitously distributed quantites of man-made radionuclides in vegetation, affected little by the activities of people. These surveys also provide a means of examining the functional role of radionuclides within an ecological system. This research has made clear the need for detailed, continuing studies of natural systems.

Fallout Radionuclides in Northern Alaskan Ecosystems

T. P. O'Farrell, J. D. Hedlund and H. A. Sweany

The objective of this study is to define the routes, rates, and amounts of fallout radionuclides in natural ecosystems of northern Alaska. Special emphasis is placed on determining the ^{137}Cs body burdens of Eskimos living in Anaktuvuk Pass.

Measurements of body burdens were made during January and July, 1971, to quantify the low and high portions of the annual cycle in the people. Results are shown in Table 11. The peak value obtained in July was at least 50% lower than the peak measured in 1970. Apparently, the anomalous pattern of high body burdens observed in 1969 and 1970 was broken (Fig. 17). The sudden increases in those years and the latest decline in body burdens is still unexplained. Samples of caribou used for food during this period as well as lichens from the vicinity are being analyzed to provide more information for study of the food chain relationships. The next sampling is scheduled for January, 1972, at which time the people's body burdens should be at their seasonal minimum value.

Results of the continuing long-term study of radiation in the arctic food chain have been published in several articles including the most recent ones listed in the annual summary of publications. The research has made clear the need for detailed, continuing studies of natural systems. Valid mathematical modeling, like that developed from these data, depends upon a continuous record over a period of years as an analytic framework. Such studies also provide a means of examining the functional roles within an ecological system. The complexities of describing a food chain, particularly when it involves human variables, are clearly demonstrated in the latest paper by Hanson (1971). Fublished results such as these have, over the years, served as an excellent indicator of the caution which should be exercised in making predictions regarding cycling within a natural system.

TABLE 11. Body Burdens of Anaktuvuk Pass, Alaska Residents During 1971

Age-Category	No.	^{137}Cs Body Burden, nCi Mean $\pm$ Standard Error	Range
Jan.-Feb.			
Adults	31	230 $\pm$ 18	110-510
Minors	1	170	
Children	37	32 $\pm$ 13	20-80
July			
Adults	35	383 $\pm$ 24	30-670
Minors	5	168 $\pm$ 28	100-260
Children	34	67 $\pm$ 5	40-150

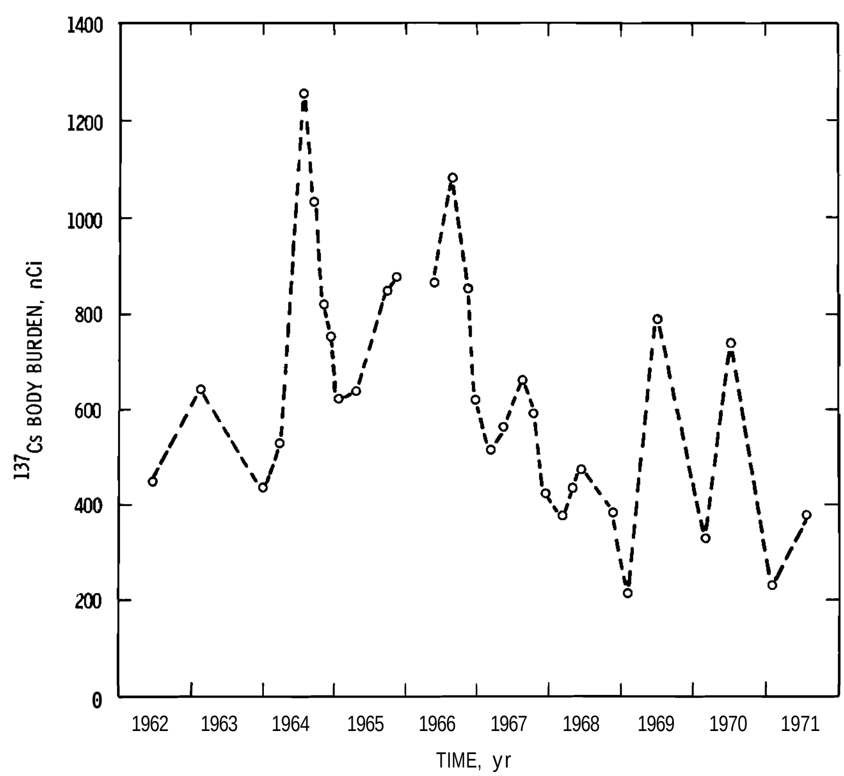

FIGURE 17. Measurements of ^{137}Cs Body Burdens in Residents of Anaktuvuk Pass, Alaska Between 1962 and 1971. (Values prior to 1970 are taken from records and publications of W. C. Hanson).

Fallout Radiocesium in Alaskan Tundra Vegetation 1961 and 1971*

W. H. Rickard, J. D. Hedlund and H. A. Sweany

The mouth of Ogotoruk Creek on the coast of northwestern Alaska was chosen by the United States Atomic Energy Commission as a possible site for the excavation of a ship harbor through the use of buried nuclear explosives. Because relatively little environmental information was available for this region, funds and facilities were provided to conduct a comprehensive base-line environmental study. Field work was actively conducted during 1959, 1960 and 1961; however, in 1962, it was decided to defer the excavation and field activities declined. By 1971, biological field work had almost ceased.

One of the objectives of the environmental studies was to measure the man-induced radionuclides introduced into the valley as fallout.

This investigation compares the fallout radiocesium content of vegetation samples collected in 1971 with those collected a decade earlier in the same places and analyzed in the same way. The data show little change in the amount of radiocesium associated with the vegetation of the Ogotoruk Creek Valley in the 10-year interval.

Important plant habitats are the stony ridges dominated by lichens and woody perennials; ponds with emergent species especially Arctophila fulva and Hippuris vulgaris; wet meadows dominated by Carex aquatilis and Eriophorum angustifolium and tussock meadows dominated by W. phorum vaginatum. In as far as was practical, the same places were sampled in 1961 as in 1971. For biomass estimates, two to five 0.25 m^2 plots were randomly selected in each vegetation-type by hand clipping with shears. Collections were placed into separate plastic bags and sent to the laboratory for processing. Oven dry plant material was passed through a Wiley Mill then packed into 500 ml capacity plastic bottles and counted for 30 minutes in a well-type sodium iodide (Thallium activated) crystal connected to a 256 channel analyzer. Results are expressed as picocuries of cesium-137 per gram of dry material.

Many kinds of radionuclides are produced during nuclear explosions and many of these have short physical half-lives and are regarded as environmentally ephemeral. Radiocesium, however, has a half-life of 30 years and will persist in the environment for decades. A comparison of radiocesium values in plant samples obtained in 1961 and in 1971 is made in Table 12. These data show that aquatic macrophytes have the smaller concentrations of radiocesium and that pure or nearly pure collections of lichens have the highest concentrations. Other kinds of plants are intermediate in radiocesium values with new growth having less radiocesium than the persistent

* *This work was performed under United States Atomic Energy Commission Contract AT(45-1)-1830.*

TABLE 12. Radiocesium (Picocuries per Gram Dry Weight) in Samples of Vegetation from Four Habitates in the Ogotoruk Creek Valley, Alaska, 1971

	1971	1961
Pond		
Arctophila fulva	0.38 ± 0.15	0.47 ± 0.70
Hippuris vulgaris	0.82 ± 0.48	0.91 ± 0.65
Ridge		
Cetraria richardsonii	40.0 ± 7.3	37.0 ± 1.4
Dryas octopetala	8.1	4.5 ± 0.53
Cassiope tetragona	13.0	--
Ledum decumbens & lichen	13.0 ± 4.1	--
Wet Meadow		
Carex aquatilis (dead & live)	5.0 ± 0.71	6.5 ± 0.46
Carex aquatilis (live)	0.96 ± 0.16	--
Salix alaxensis (new leaves)	0.26 ± 0.26	--
Tussock Meadow		
Eriophorum vaginatum (live & dead)	8.1 ± 0.84	7.0 ± 0.90
Eriophorum vaginatum (crown)	9.4 ± 0.63	--
Eriophorum vaginatum (live only)	2.3	--
Sphagnum Sp.	2.0 ± 0.61	--

$\bar{x}$ ± Standard Error.

or more aged plant parts. The data also show relatively little change in radiocesium values. Apparently atmospheric deposition has kept pace with the expected losses from plant senescence, leaching and physical decay.

The ridge communities accumulated most of the fallout radiocesium (Table 13). Moderate amounts of radiocesium were retained by plants of the tussock meadow community and low amounts were retained by the plants of the wet meadow community. The high value of 27 nanocuries per square meter in the ridge habitat is only about one-fourth that measured in the floor of undisturbed Conifer forests in the Cascade Mountains of Washington. The values are, however, much like those obtained for similar kinds of tundra communities

TABLE 13. Aboveground Biomass and Cesium-137 Expressed as Nanocuries per Square Meter in Three Plant Communities in the Ogotoruk Creek Valley, Alaska, 1971

Community	Aboveground biomass g/m^2	^{137}Cs pCi/m^2
Ridge (Ledum & lichen)	1930 ± 233	27
Tussock Meadow		
Crowns	1010 ± 150	9.5
Standing live & dead	412 ± 24	3.3
Total	1422	12.8
Wet Meadow		
Live	480 ± 62	0.46
Standing dead & litter	20 ± 23	1.08
Total	500	1.54

$\bar{x}$ ± Standard Error.

at Anaktuvuk Pass in inland Arctic Alaska.

This survey shows the persistence of small but ubiquitously distributed quantities of a man-made radionuclide in a vegetation mosaic that has over many years experienced little modification through the activities of people. Radiocesium is likely to persist in tundra vegetation for many more years even without additional inputs of fresh radiocesium from nuclear weapons testing.

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ANALYSIS OF NATURAL SYSTEMS

MATHEMATICAL MODELING*

The increased awareness of ecological understanding as an essential feature of environmental protection emphasizes the need for better ways of translating theory into action. Progress was made on the development of mathematical and computer simulation models suitable for description and interpretation of ecological data. An analytical framework for field and laboratory research activities was also devised. Development of this program indicates a need for continued improvement of our modeling and analytical capabilities.

Modeling of Mineral Cycling by Periphyton

C. E. Cushing and L. L. Eberhardt

Work was continued on modeling the results of the zinc-65 cycling data by periphyton communities in the simulated stream microcosms. Modeling was undertaken to provide information on 1) rate values, 2) the fit of known models, and 3) what is going on in the community.

The modeling techniques viewed the system as a closed system with two compartments: first, the water or ambient component, and second, the periphyton or uptake component. Two rates were involved - μ_1, the rate of uptake of zinc-65 by the periphyton from the water and μ_2, the rate of loss of zinc-65 from the periphyton back to the water. Using certain assumptions, equations were developed for solution of the asymptotic uptake of zinc-65 by the periphyton, the asymptotic loss of zinc-65 by the water, the sum of the two rates μ_1 and μ_2, and two equations describing the amounts of zinc-65 in the water and periphyton. The data were fit by nonlinear, least squares methods using two different

* *Portions covered by program, i.e., T.A.E.*

routines, one of which provided estimates of standard errors.

An analysis was made of data from four experimental runs. The results are summarized below.

- An estimate to account for the total zinc-65 spike by summing estimates of the asymptotic values in the periphyton and water resulted in two good estimates and one fair one. The standard errors were substantial, thus indicating the need of taking more samples of ambient levels. Estimates of the loss rate, μ_2, also showed some consistency; however, they were higher than calculated rates of retention.
- Estimates of the sums of the two rates, μ_1 and μ_2, resulted in good agreement in three of the four experiments. Again, high standard errors interfered. Estimates of the asymptotic uptake by the periphyton ran into a procedural problem since these data were in CPM and not absolute values. However, a plot of the values obtained against each other showed that they were linearly related.
- Fitting of actual and predicted uptake curves resulted in a good fit (Figure 18) except for the unusual pattern of deviations. In fitting retention curves, it soon became evident that the single-component equation was not adequate Again, an unusual pattern of deviations occurred (Figure 19). Computed slopes also varied from the previously estimated values of μ_2. An alternate model, involving three parameters to fit, resulted in a fit with less deviations which was also more random.

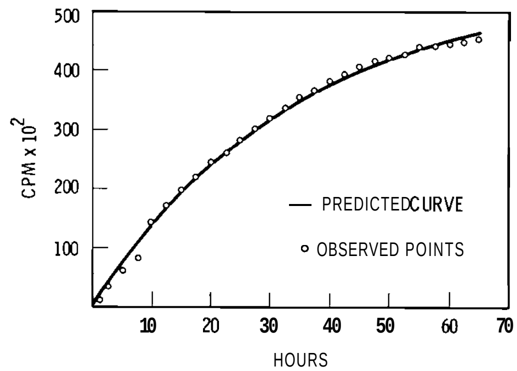

FIGURE 18. Actual and Predicted Uptake of Zinc-65

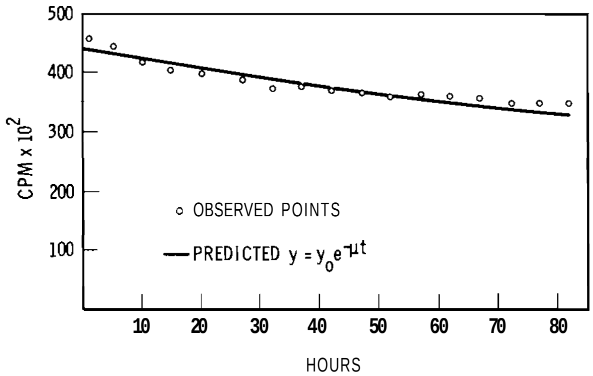

FIGURE 19. Actual and Predicted Retention of Zinc-65

Modeling an Antarctic Seal Population

L. L. Eberhardt

In November of 1970 and again in the fall of 1971, the author participated in a study of the Weddell Seal (Leptonychotes weddelli) in McMurdo Sound, Antarctica. The work was done in cooperation with investigators from the University of Minnesota, whose research is sponsored by the National Science Foundation (all transportation and facilities for the author were provided under the NSF support grant). The 1970 study was reported in our 1971 Annual Report, and many similar activities were scheduled for the 1971-72 expedition (but details were not available at the time this report was prepared). The present report deals with a computer simulation model of a Weddell seal population.

The present computer model was devised as a tool for exploring the available data on seal populations, and planning investigations for the 1971-72 field season. Each of 14 "pupping colonies" is modeled separately, with main emphasis on female seals. Adult females are assumed to seasonally occupy the same colony until death (each adult female is subjected to an annual random draw to determine survival). The entire surviving pup population goes into a common pool and remains there until age three, being subjected to random mortality (at pre-assigned rates) each year. The three-year olds are individually and randomly assigned to breeding colonies with probabilities proportional to the "space" available, as determined by comparing the current number of adult females in the colony with a designated carrying capacity.

The computer program prints out two tables of data, the first listing total population, sex ratio, pregnancy rate, and surplus individuals (over carrying-capacity). The second table shows pup populations for each colony by year.

Manipulation of various rate constants in the model has permitted us to approximate those values which will maintain the population at about constant size (beyond stochastic fluctuations) over 15-20 year time periods. These rates are in general agreement with those obtained in the field, but experience with the model has suggested several areas of needed study, as well as various prospects for changing the model to make it better approximate actual conditions.

One important prospect for ultimate use of the model is in predicting allowable harvest in this and similar seal populations, a reality which has to be considered in the not very distant future. An interesting sidelight is the close similarity between the circumstances involved in modeling this Antarctic seal population and the Canada Goose population inhabiting Columbia River islands at Hanford.

Sampling Food Chains

L. L. Eberhardt, J. M. Thomas and R. O. Gilbert

Our experience over the last few years in modeling various food chain phenomena indicates that much of the present knowledge of kinetics of radionuclides in food chains is directly applicable to a much wider range of substances, such as DDT and mercury. A major concern here is with what may be called "the sampling problem". That is, if it is assumed that the principles of first-order kinetics provide a reasonable mathematical model of the actual processes governing pollutants in food-chains, then what constitutes an efficient field sampling program?

The rationale of our recent efforts has these components: 1) to establish some "case histories" by examining a number of sets of actual field data, 2) to construct computer simulation models for individual case histories, 3) to investigate nonlinear least-squares methods as tools for fitting models to data, 4) to attempt to elucidate some general principles that may be appropriate for predicting rate constants for substances and species that have not been directly studied, and 5) to formulate questions about efficient sampling procedures. Given a "good" set of questions about sampling problems, and some potential strategies for sampling, a logical next step seems to be to build a computer simulation model that reflects what we know about some actual field situations, and to use the simulator to test the efficiency of various sampling programs. At present, it seems necessary to limit an approach via simulation to some rather simple situations, inasmuch as there are a number of unresolved questions about the systems of concern here.

An examination of the conditions and results of a number of field studies leads us to believe that inputs from a source (release of DDT, radiotracers, etc.) will most generally not be constant, and that an exponential decline may often be the best approximation to actual conditions. It is then necessary to deal with rather complicated expressions, and our experience thus far suggests that it will be essential to fit the resulting curves sequentially, starting with the source term and working progressively up the food chain.

We have not yet had enough experience with the system to judge exactly how much random variation can be dealt with in fitting output data. The present simulator contains generators to produce random variables from a log-normal or gamma distribution at each stage. Each such generator depends on an adjustable common parameter (the coefficient of variation), so that variability in the entire system can be set at zero in order to test the various nonlinear least-squares fitting schemes. Most of our initial experience was with a "linearization" (or Taylor series) fitting method, but we have now changed over to a version of a program developed by Marquardt, which combines the Taylor series and "steepest descent" methods.

Recent experience with a scheme for selecting optimum sampling points in time is causing us to modify an earlier conclusion that a substantial number of sampling times are required for good estimates of rate parameters. It now appears that "optimum" sampling schemes may be much more efficient than we had supposed.

Similarity Ratios in Retention of Trace Substances

L. L. Eberhardt, J. M. Thomas
and R. O. Gilbert

One of the major problems facing all biologists is the extrapolation of results to species other than those directly observed in laboratory and/or field studies. Environmental pollution and the subsequent food-chain passage of substances presents a particularly difficult aspect of this problem. The myriad of possible organisms and interactions makes analysis using usual step-by-step methods nearly impossible. Obviously, underlying relationships of "similarity" among species could greatly reduce the time and effort necessary to predict the ultimate fate of pollutants, at least for large segments of food chains.

The uptake and retention of many substances has been observed to be proportional to a fractional power of body weight. When such "power-laws" have been extended to interspecies comparisons, the resulting power coefficient is usually substantially lower than that anticipated on the basis of the well-known relationship between body size and metabolic rate. It has been proposed that interspecies comparisons ought to be based on "similarity ratios" that depend on the proportionality coefficient (a) in the equation:

$$y = \alpha w^{\beta}$$

where y pertains to retention time (or some equivalent measurement), w represents body weight, and β is taken as 0.75 (with appropriate sign). We have investigated the use of such an analysis for a variety of published and unpublished data, and conclude that there is a great deal of potential for wider application.

The possible ultimate uses for an analysis such as this are either as a method for predicting expected biological equilibrium level for a larger organism, or as a beginning step for predicting the fate of substances in food chains. In the former case, biological equilibrium level for humans could be predicted from data on, for example, rats by computing a for rats, estimating a for humans from charts prepared from data on other substances, and then calculating equilibrium level using body weight for humans. Such a procedure could thus circumvent the laborious testing of many species and compounds. It is, in effect, another idea for "extrapolating to man."

An extension to more general food chain analysis would be predicated on demonstrations that many more substances (pesticides, mercury, etc.) and species could be incorporated into our postulated "Similarity Ratios." If rates of loss and uptake through a food chain are of major interest, then metabolic measures other than the one used in our recent studies (biological equilibrium level) could be investigated.

We have done some preliminary work which indicates that the biological equilibrium level for the last component of a retention function, and for readily absorbable nuclides, yields similarity ratios nearly the same as those we have previously obtained.

We believe that the methods of similarity and allometry are applicable over a wide range of nonruminant mammalian species and radionuclides. Our analysis has led us to speculate that there are prospects of much wider applicability than to the behavior of isotopes in biological systems alone.

Evaluation of Pseudo-Random Number Generators

Richard O. Gilbert, Lee Eberhardt and John Thomas

The lognormal and gamma distributions may be suitable distributions to represent observations of the concentration of substances such as radionuclides and DDT in samples of biota. An important question in the study of movement of such substances through food chains is the particular sampling strategy to use; i.e., when and how intensively should one sample a natural system? One way to approach this problem is to design appropriate monte carlo (computer) simulation experiments.

Since the validity of the results from this approach depends on the performance of the pseudo-random number generator used, a monte carlo simulation experiment was conducted to evaluate the performance of four pseudo-random number generators in generating numbers following lognormal and gamma distributions.

Each of the generators is designed to generate independent uniformly distributed numbers between 0 and 1. These numbers are then transformed to lognormal or gamma variates. Each generator was evaluated for randomness by computing chi-square goodness-of-fit tests and the lag-product test for correlations. In addition, goodness-of-fit tests of the generated lognormal and gamma distributions to their known counterparts were computed as well as several other tests of significance.

The results indicate one of the generators to be somewhat less desirable than the others, in that generated numbers tend to be correlated resulting in distributions being generated which differ significantly from expected. Information on the speed and periodicity of each generator was also obtained.

Statistical Evaluation of the Old Field Sampling Plan

R. O. Gilbert, W. H. Rickard and J. F. Cline

Plant biomass data collected at the Lower and Upper Snively "old field" sites on ALE during 1970 and 1971 were analyzed to determine whether the field sampling plan should be modified for future use.

The present design employes two replications at each site. Each replication is divided into five equal areas (blocks) and two plots of size 0.1m^2 are randomly chosen within each block for hand clipping on each harvest day during the spring growing season.

Questions of interest are: 1) Has blocking resulted in more precise estimates of mean biomass over that obtainable with simple random sampling? 2) Can the number of replications, blocks, or plots within blocks be altered to obtain more precise estimates for the same cost? 3) Can precision be improved by using a larger plot size?

An examination of the standard errors of total living aboveground biomass and fallen litter at the two sites indicate no consistent improvement using blocks over simple random sampling, although there were individual cases of significant improvements in precision using the former.

Question (2) was investigated by computing nested analyses of variance for the data of each site and harvest day in 1971. The data indicated that on most harvest days, an increase in the number of replications or the number of sample plots within blocks would not have significantly reduced the standard errors, but would have increased the cost considerably.

Ten additional plots were harvested on the fifth harvest day in 1971 in order to investigate question (3). Although the data are meager, they suggest that the present plot size need not be increased.

In general, the present design appears adequate for the purposes for which the data are being collected. More precise estimates can be obtained but only with considerably increased costs.

Review of NSF/IBP Sampling Program

R. O. Gilbert and R. J. Olson reviewed the IBP Grasslands sampling program currently underway at the Cottonwood, South Dakota experiment station of South Dakota State University. Recommendations were made regarding the correct method of estimating the variance of the resulting estimates of plant biomass. Suggestions were also made regarding the alteration of the current plan so that more accurate estimates may be obtained.

Publications

J. M. Thomas, L. L. Eberhardt "Similarity Ratios and Patterns in Retention of Trace Substances," Third National Symposium on Radioecology, Proceedings in press.

L. L. Eberhardt. "Modeling Radionuclides and Pesticides in Food Chains," Third National Symposium on Radioecology, Proceedings in press.

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W. C. Hanson and L. L. Eberhardt. "A Columbia River Canada Goose Population," Wildlife Monographs, vol. 28, p. 61, 2971.

L. L. Eberhardt. "Resources and Man." (Book Review), The Journal of Wildlife Management, vol. 35 (Part 1), pp. 184-186, 1971.

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R. O. Gilbert. "A Monte Carlo Study of Analysis of Variance and Competing Rank Tests for Scheffe's Mixed Model," Journal of the American Statistical Association, vol 67, pp. 71-75, 1972.

Presentations

L. L. Eberhardt. "Survival Estimation from Tagging and Marking Methods," Workshop in Computer Approach to Management of Fishery Resources, College of Fisheries, University of Washington, March 25-19, 1971.

H. L. Hollister (DBER, AEC) and L. L. Eberhardt. "Effects of Pollutants on Health and Environments; Strategies for Empirical Research," Seminar, Department of Statistics, Univ. of California, Berkeley.

TERRESTRIAL PLANT ECOLOGY

The impact of the abiotic and biotic environments on plant distribution, growth, reproduction and yield is of major importance in this study. Because of the close relationships of plant growth, productivity, reproduction and soil water, those studies previously conducted under the title of Hydrologic Cycling on the ALE Reserve have been incorporated into the terrestrial plant ecology studies. Terrestrial plant ecology, a focal point of the ecology studies, is also concerned with the movement and accumulation of mineral nutrients and radionuclides by plants and their relationship to the soil substrate. Also, a new direction has been taken in "physiological ecology" where moisture use and mineral behavior within the plant is being studied.

TERRESTRIAL PLANT ECOLOGY

TERRESTRIAL PLANT ECOLOGY

- TERRESTRIAL PLANT ECOLOGY
- HYDROLOGICAL CYCLING ON ALE RESERVE
- GEOLOGY AND PALEOECOLOGY OF ALE RESERVE

A. VEGETATIONAL DYNAMICS AND CHARACTERIZATION

B. NUTRIENT AND HYDROLOGICAL FACTORS

C. INFLUENCE OF ENVIRONMENTAL FACTORS ON BIOTIC INTERACTIONS WITH SOIL

D. CLIMATOLOGY

A. VEGETATIONAL DYNAMICS AND CHARACTERIZATION

Detailed information on the functional roles of plants are a requisite for interpreting and predicting transfers of energy and nutrients. Sampling surveys of the vegetation on the ALE Reserve were conducted throughout the year. These studies of annuals growing on abandoned cultivated fields are expected to continue and results added to data of previous years. Several years of data accumulation are necessary to obtain average values for means and extreme production figures. A study of the impact of cattle grazing initiated in 1971 will be continued in 1972.

Botanical Description of the ALE-IBP Grassland Biome Study Site

K. R. Price and W. H. Rickard

The vegetation of the grassland biome study site is representative of the Artemisia/Agropyron association described by Daubenmire (1970).[1] Under the administration of the U.S. Atomic Energy Commission the study site has been essentially ungrazed by livestock for 28 years. The land use history prior to that time is not known in detail, but the site was probably only lightly grazed because of the long distance to drinking water.

A wildfire burned over the general area during the summer of 1957 but only a corner of the study site was affected by this fire. The canopy cover provided by living sagebrush shrubs was determined by line intercept on 24 randomly located blocks (15 × 30 meters) scattered throughout the study area, prior to experimental livestock grazing for 1971. All living shrubs located inside each block were counted to obtain density values. The maximum height of every shrub encountered along intercept lines was also measured.

On the average, 3.4% of the ground surface was covered by shrub canopies The average density amounted to 13 shrubs per 100 m^2 and the average maximum height was 41 cm.

The most frequently harvested plants are listed below:

Shrubs
- Artemisia tridentata

Perennial grasses
- Agropyron spicatum
- Stipa thurberiana
- Poa secunda
- Poa cusickii

Annual grasses
- Festuca octoflora
- Bromus tectorum

Half shrubs
- Phlox longifolia
- Antennaria dimorpha
- Erigeron filifolius

Perennial forbs
- Crepis atrabarba
- Lupinus laxiflorus
- Townsendia florifer
- Brodiaea douglasii
- Calochortus macrocarpus
- Astragalus purshii
- Achillea millefolium
- Allium acuminatum

Annual forbs
- Descurainea pinnata
- Draba verna

The early flowering plants are Poa cusickii, Poa secunda, Draba verna and Antennaria dimorpha. The mid-season blooming plants are Crepis atrabarba, Lupinus laxiflorus, Phlox longifolia, Bromus tectorum, Festuca octoflora and Brodiaea douglasii. Late season plants are Agropyron spicatum, Stipa thurberiana, Townsendia florifer and Calochortus macrocarpus. Artemisia tridentata is an autumn blooming shrub.

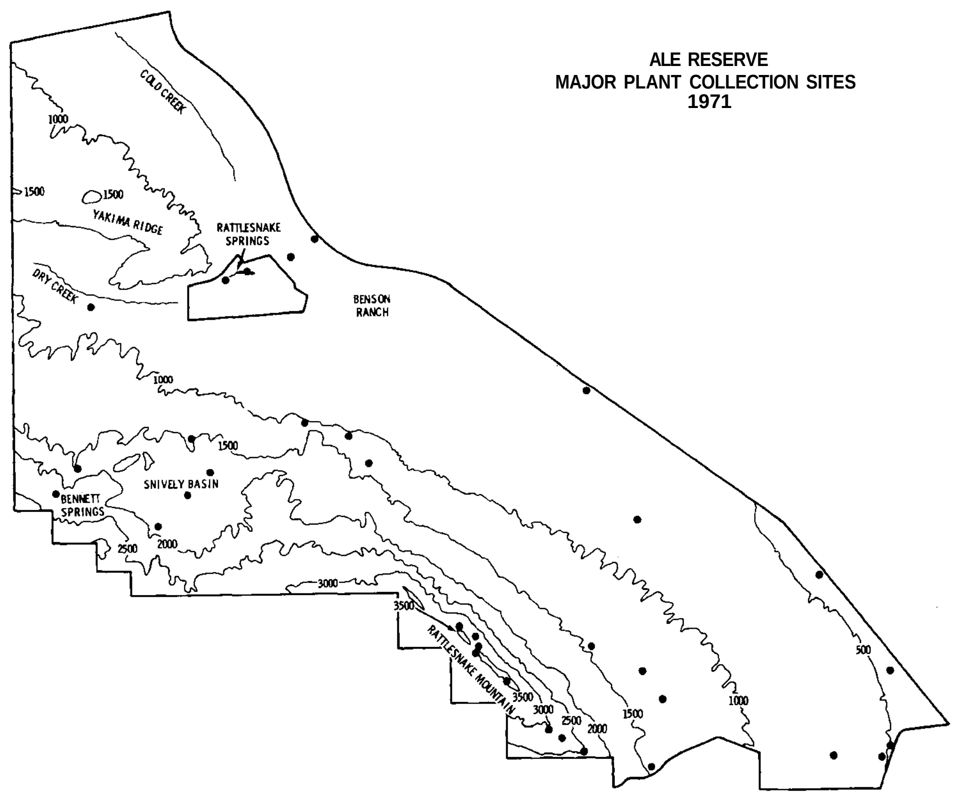
<u>Flora of the ALE Reserve</u>

Joan T. O'Farrell*

One of the major objectives of the terrestrial ecology program on Project ALE is the characterization of the flora and fauna. In the past, staff ecologists had to order their priorities such that completion of some basic tasks, including a collection of native plants, preparation of reference herbarium specimens, and cataloging of local species, was not possible. This was unfortunate since a good reference collection, as well as an adequate working herbarium, is basic to documenting present floral characteristics. An herbarium also provides the baselines for examining alterations in species composition in the future. An adequate herbarium also allows plant ecologists to compare species on the site with other habitats in the Great Basin to learn the affinities and possible origin of the flora of the ALE Reserve.

During 1971, 25 collection trips were made to various locations on the Reserve (Figure 20). Trips commenced

* *JCGS Appointment*



<u>FIGURE 20</u>. Locations on Project ALE Where Major (>3 species) Collections of Indigenous Plant Species Were Made During the 1971 Growing Season

in April when many flowers began to bloom, and additional visits continued into October when the last autumn flowers were collected. An attempt was made to visit the major habitats, particularly those on the altitudinal gradient, several times during the growing season to insure that most species would be collected the first year.

A total of 170 different species were collected. They included 17 shrubs, 24 grasses, and 129 forbs. Several unusual species were discovered and as soon as taxonomic identifications are confirmed, the significant range extensions will be published. Presently, the specimens are being mounted on herbarium sheets after preliminary identification.

At the same time that specimens were collected, photographs were made to document the habitat, growth form, and colors of the species (Figure 21). When the collection is completed we hope to have a reference collection of photographs which will be cross-referenced with the actual herbaruim specimens. This should greatly increase the usefulness of the ALE plant collection.

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FIGURE 21. Bitter-Root, *Lewisia redeviva*, Blooming During June on the Windswept, Lithosol on the Crest of Rattlesnake Mountain

Aboveground Productivity of Winter Annuals on Abandoned Cultivated Fields in 1970 and 1971

W. H. Rickard, J. F. Cline and
R. O. Gilbert

One of the main objectives of ecological studies is to obtain reliable estimates of primary production in different kinds of plant communities in different kinds of world environments. This paper provides primary production values for winter annuals, growing on abandoned agricultural fields in the shrub steppe region of southeastern Washington.

The aboveground production of winter annuals on abandoned cultivated fields varies from year to year depending in large part upon the seasonal availability of soil moisture. On the ALE Reserve, precipitation generally increases with increasing altitude and it can be expected that increased moisture will be reflected in increased plant yields.

The results of harvests of winter annuals at low and high altitude fields during 1970 and 1971 are shown in Figure 22. These data show that 1971 yields were greater than 1970 yields at both locations. The lowest yield 120 g/m^2 was obtained at the low elevation in 1970 and the highest yields of 260 g/m^2 was obtained at the high elevation in 1971. Clearly, several years of data accumulation are necessary to obtain average values for means and extreme production figures for winter annuals.

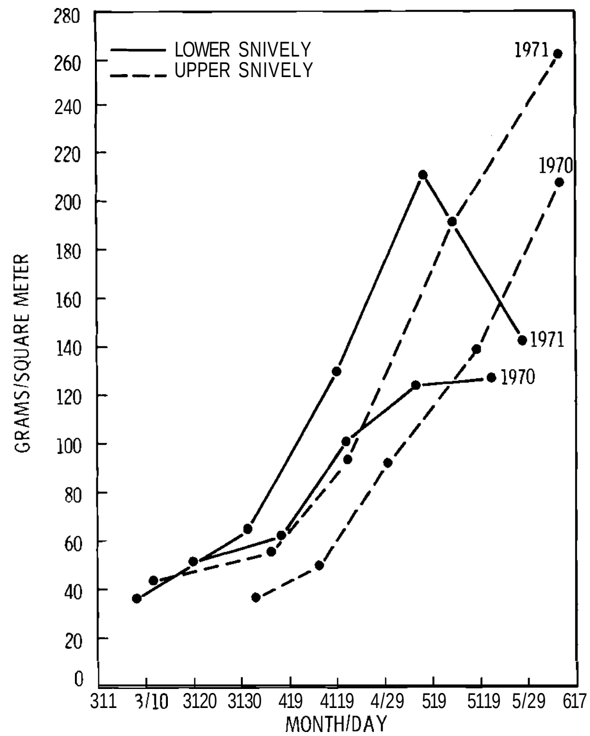


FIGURE 22. Average Living Aboveground Plant Biomass in Grams Per Square Meter for 1970 and 1971 in Old Fields

Comparison of Aboveground Productivity of Old Field and Pristine Vegetation on the ALE Reserve - 1971

W. H. Rickard, J. F. Cline and
R. O. Gilbert

Shrub-steppe vegetation in relatively undisturbed condition is represented by the ALE-IBP Grassland Biome study plot. At the other extreme, the vegetation of lower Snively field represents vegetation that has colonized the severely disturbed soil of an abandoned cultivated field. The dominant plants are different as to species composition and appearance.

Both sites are located on gently sloping topography on the northeasterly facing slopes of the Rattlesnake Hills. The old field is situated at an altitude of 1000 ft and the pristine site is located at about 1200 ft. The soil of both sites is a deep silt loam with no stones in the upper meter of soil profile. Both sites have not been burned or grazed for a quarter of a century.

Clearly, the old field vegetation comprised of winter annuals produced more herbaceous dry matter than the pristine community (Figure 23). At peak harvest, the old field produced an average of 210 g/m^2 as compared to an average of 55 g/m^2 in the pristine community. The total aboveground production of pristine community is more than the 55 g/m^2 presented here because the contribution of shrubs is not included in Figure 23. However, it is probable that shrub production on this site is less than herb production.

A tentative conclusion is that winter annuals are more productive than perennials in the shrub steppe region of southern Washington.

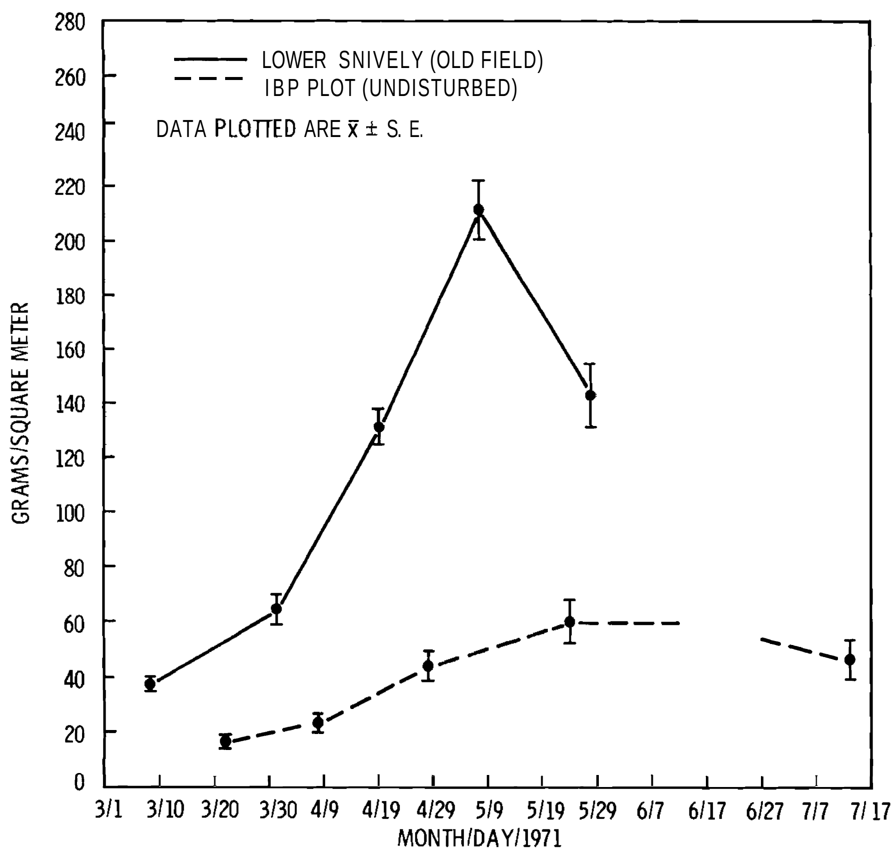


FIGURE 23. Comparison of Production from Old Field and Undisturbed Field

Root Biomass Under a Cheatgrass Stand on the ALE Reserve

W. H. Rickard and J. F. Cline

Estimation of total root biomass at two altitudes on the ALE Reserve were obtained during the growing season of 1971. Estimates were made on cheatgrass dominated fields at Lower Snively Ranch (1000 ft) and Upper Snively Ranch (1700 ft) at the beginning of the spring growing season in March and again at the end of the growing season in June.

The root borings were taken from within two 20 × 50 meter replicate plots at each altitude. Within each replicate, five borings of soil containing roots were taken at one decimeter intervals to a total depth of 5 decimeters. After the roots were washed, they were dried in a forced air oven at 60°C for 48 hr and then weighed. Weights in Table 14 are gross oven dry weight and were not corrected for noncombustible content; however, other studies have indicated that approximately 35% of the root dry weight is noncombustible material. The root material is presently undergoing an ashing process but the results are not available for this report.

New growth was calculated from the differences between the average total root weights of the sample prior to and after the 1971 growing season. Approximately 22% of the biomass from Lower Snively and 33% from Upper Snively were calculated to be new root growth. Ninety percent of the root biomass was found in the upper 3 decimeters of soil profile. More than 65% of the root biomass was measured in the first decimeter depth of soil.

These data show that the decomposition of underground biomass is slow

TABLE 14. Average Root Mass in Cheatgrass Stands (grams per m^2) in the Upper 5 Decimeters of Soil Profile

Depth, dm	Lower Snively (1000 ft) 3-18-71	Lower Snively (1000 ft) 6-3-71	Increase	Upper Snively (1700 ft) 4-5-71	Upper Snively (1700 ft) 6-3-71	Increase
0-1	1162 ± 217	1425 ± 190	+263	621 ± 58	878 ± 142	+257
1-2	234 ± 40	351 ± 46	+117	144 ± 17	265 ± 40	+121
2-3	132 ± 6	171 ± 17	+39	82 ± 17	136 ± 23	+54
3-4	71 ± 10	117 ± 10	+46	54 ± 12	69 ± 10	+15
4-5	65 ± 8	92 ± 10	+27	40 ± 8	42 ± 8	+2
Total	1664	2156	492	941	1390	449

and is not complete between growing seasons. On the average, 72% of the root biomass during the 1971 growing season was shown to be carried over from previous years.

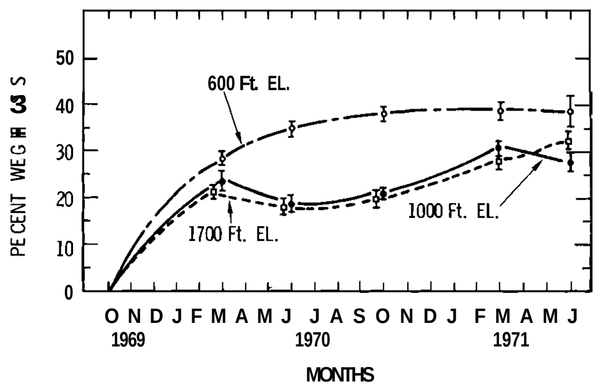
<u>Weight Losses of Litter from Nylon Mesh Bags on the ALE Reserve</u>
W. H. Rickard and J. F. Cline

In the autumn of 1969 the standing dead litter of old fields was collected and placed in nylon mesh bags and returned to field locations at three different altitudes on the ALE Reserve. Five bags were collected periodically during 1970 and 1971 until the supply was exhausted. The weight loss of the enclosed materials was determined after oven-drying at 60°C.

The results of this study are shown in Figure 24. The loss of weight is marked by an initially rapid decrease. About 28% of the weight was lost at the 600-ft altitude during the period October to March and about 20% of the weight was lost at the 1000 and 1700-ft altitudes during the same time period.

After 21 months, about 61% of the initial weight remained in the bags at the low elevation and about 70% remained in the bags at the two higher elevations. The material remaining in the bags consisted mainly of the culms of cheatgrass and the flowering stalks of tumble and tansy mustard.

The relatively slow weight loss of dead herbaceous material is attributed to the short periods of time that the dead plant material is moist enough to sustain microbial activity.



<u>FIGURE 24</u>. Weight Loss of Litter from Nylon Mesh Bags Placed on Old Fields at Three Different Altitudes on the ALE Reserve

<u>Publications</u>

R. D. Harr and K. R. Price. "Evapotranspiration from a Phreatophyte Community," <u>Ecology</u> (In review). 1971.

R. E. Wildung, B. F. Hajek and K. R. Price. "Chemical Properties of the Arid Soil Organic Fraction," <u>Northwest Science</u>, vol. 45, pp. 73-79, 1971.

<u>Presentations</u>

K. R. Price. "The Arid Land Ecology Reserve - An Outdoor Laboratory," BNWL-SA-4087, presented to the Oregon Museum of Science and Industry, Portland, Oregon. September 30, 1971.

<u>Reference</u>

R. Daubenmire. "Steppe Vegetation of Washington." Washington Agricultural Experimental Station, Technical Bulletin, vol. 62, 1970.

B. NUTRIENT AND HYDROLOGICAL FACTORS

Soil studies continued to determine 1) soil moisture, 2) mineral elements, 3) soil nitrogen, and 4) water usage on the ALE Reserve. These factors contribute to plant growth as well as to the nutritional requirements of the animals that live in these plant communities.

Water Use Patterns of Shrub-Steppe Communities

K. R. Price

Soil moisture measurements in three different types of communities were collected for the second consecutive year to quantify water use patterns. Table 15 summarizes the results and indicates distinctive features of soil moisture relationships.

The differences in precipitation efficiency between sites are in sharp contrast and must reflect differences in temperatures between the two areas Phenology is nearly always advanced at the lower elevation site and could account for the low "water stored" and "water used" values there. The cheatgrass community contains winter annuals which may use a considerable amount of water prior to the period of maximum soil storage measured in April.

At the beginning of the 1971 water year, the sagebrush community profile

TABLE 15. Precipitation and Soil Moisture for Three Plant Communities at Two Different Locations on the ALE Reserve (All units are cm)

	Artemisia/ Agropyron	Agropyron	Bromus
Lower Snively (305 meters)			
Precipitation (Oct-April)	14.6	14.6	14.6
Soil Water Stored (Oct-April)	4.8	4.4	4.1
Maximum Penetration (April)	90	110	130
Soil Water Used (May-Oct)	5.2	4.8	4.0
Upper Snively (500 meters)			
Precipitation (Oct-April)	15.7	15.7	15.7
Soil Water Stored (Oct-April)	5.9	9.2	9.7
Maximum Penetration (April)	90	130	130
Soil Water Used (May-Oct)	5.6	9.4	10.7

was completely depleted of soil water whereas the other community-types were not. Thus, total 1971 recharge may be more accurately reflected by the sagebrush community, whereas water usage in the other communities represents 1970 as well as 1971 water.

Differences in maximum depth of moisture penetration may be due to this residual water, as well as the fact that the sagebrush community has a shrub cover of about 15% which would increase the surface area available for sublimation and evaporation. The amount of water available for soil recharge would be significantly reduced.

Effect of Soil Nitrogen Amendments on Cheatgrass Yields

J. F. Cline and W. H. Rickard

Yields of cheatgrass at the high altitude field at Upper Snively Ranch in the Rattlesnake Hills were thought to be limited by the lack of available soil nitrogen rather than a deficiency of soil moisture. A random block experiment was established in February 1971 using four nitrogen treatments and a control, with each being replicated five times. The nitrogen treatments were 0, 1.1, 3.3, 6.6 and 11.1 g of available nitrogen per square meter applied as ammonium nitrate pellets.

Duplicate samples from 0.1 m^2 areas within each of the twenty-five plots were harvested and green vegetation was separated from standing dead plants and litter.

Nitrogen amendments increased yields of cheatgrass (Figure 25). When compared to the controls, the high treatment increased the annual yield from 210 to 720 g of oven-dry material per meter. Yields from the intermediate treatment plots were variable and a linear yield increase was not obtained.

The total amount of nitrogen assimilated by cheatgrass amounted to 1.35 g/m^2 under no treatment conditions and 5.98 g/m^2 under the highest treatment conditions. From these values, it can be calculated that about 40% of the added nitrogen was incorporated into the cheatgrass harvest in 1971.

The conclusion is that a deficiency of soil nitrogen is limiting to primary productivity on this field.

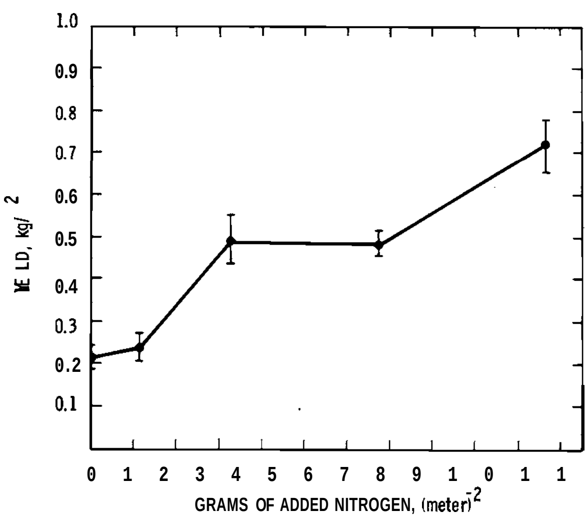


FIGURE 25. The Influence of Nitrogen Amendment in the Yield of Cheatgrass

Watershed Characteristics of the Snively Basin

K. R. Price

Characterizing the surface hydrology of a watershed includes defining the source, residence pattern and outflow of water from the basin. Precipitation, streamflow and soil moisture were measured during the 1971 water year in the Snively Basin of the ALE Reserve. Heated recording precipitation gages were installed near the eastern and western boundaries of the basin, and one unheated totalizing gage has been in service near the center of the basin for several years. Recording streamflow gages were installed on the only perennial surface outflow stream. Soil moisture was periodically determined with neutron probe soil moisture meter.

The average total precipitation recorded in the basin was 15.7 cm for the period October through April. Streamflow was remarkably constant throughout the study period. Prior to the occurrence of diurnal fluctuations in flow, indicative of transpiration by riparian vegetation, total surface outflow from the basin was 5.1 liters/sec. With the onset of evapotranspiration losses, the flow rate decreased about 5% over a period of several months. Streamflow stabilized at 4.6 liters/sec after mid-June following a period of maximum diurnal fluctuation. A total of 80% of the measured surface outflow originates from two springs located midway in Snively Canyon where basalt layers are exposed.

Soil moisture determinations indicate a maximum moisture front penetration of 1.3 meters occurring by late April. Where depth to bedrock is known, maximum water penetration was 45% of the soil depth. At the end of April there were 8.3 cm of water stored in the soil profile, attributable to winter and spring precipitation. With 15.7 cm recorded as total incoming precipitation, the average precipitation efficiency is about 53%. Evapotranspiration accounted for complete loss of stored soil moisture as has been noted in previous years.

These data together with carbon-14-age dating analyses indicate that the perennial stream flow from the Snively Basin is not of watershed origin, but rather from springs producing ancient water trapped between layers of basalt which underlie this arid region.

Mineral Composition of Old Field Vegetation on the ALE Reserve, 1971

W. H. Rickard, J. F. Cline and R. O. Gilbert

Although estimates of primary productivity in various kinds of plant communities is a major goal of ecological studies, the behavior of mineral elements essential for plant growth is of ecological concern in regard to nutritional requirements of animals that live in these plant communities. Also, knowledge of mineral behavior lends insight as to the behavior of radionuclides that may be added to plant communities as tracers or as releases from accidents into the environment.

Nitrogen, phosphorus, potassium and calcium determinations were made at peak harvest dates on 1971 plant growth on two fields at different elevations on the ALE Reserve (Table 16).

These data indicate that dry matter production was less on the low elevation field as compared to the high elevation field, but the amount of nitrogen assimilated by the vegetation was greater on the low elevation field; i.e., 2.1 g/m^2 as compared to 1.7 g/m^2. The total amount of potassium assimilated was also greater on the low elevation field, but the amounts of phosphorus and calcium assimilated were not greatly different when compared as to field origin.

These data support the hypothesis that nitrogen is an important factor in limiting primary productivity on the high elevation field. It would be of interest and value to determine if there are such differences in mineral behavior in the undisturbed vegetation at different altitudes on the ALE Reserve.

TABLE 16. Mineral Composition of Aboveground New Growth of Plants (g/m^2) growing on Abandoned Cultivated Fields on the ALE Reserve at the End of the Growing Season, 1971

	g dry wt/m^2	N	P	K	Ca	
			1000 ft Elevation			
	198.3	1.880	0.300	1.540	0.650	Bromus tectorum
	1.1	0.001	0.001	0.006	0.010	Poa secunda
	9.8	0.250	0.020	0.317	0.270	Sisymbrium altissimum
	2.0	0.026	0.004	0.055	0.042	Amsinckia lycopsioides
Total	211.2	2.157	0.325	1.918	0.972	
			1700 ft Elevation			
	233.50	1.471	0.257	0,911	0.770	Bromus tectorum
	6.90	0.041	0.003	0.017	0.054	Holosteum umbellatum
	13.70	0.112	0.030	0.199	0.096	Tragopogon dubius
	1.90	0.027	0.006	0.046	0.026	Microseris lanciniata
	0.50					Descurainea pinnata
	6.40	0.054	0.010	0.047	0.044	Sisymbrium altissimum
Total	262.90	1.705	0.306	1.220	0.990	

C. INFLUENCE OF ENVIRONMENTAL FACTORS ON SOIL PROCESSES

Studies were conducted to determine the influence of soil temperature and moisture, grazing, irrigation and herbicide application on the respiration rate of soils on the ALE Reserve. Seasonal changes were monitored and influential parameters identified and quantitated for development of models to predict carbon flow through the soil system. Studies were also initiated to determine the rate and extent of mineral weathering in a closed watershed on the Reserve. Future studies will be oriented toward development and validation of predictive models for carbon flows and mineral weathering in soils.

Influence of Environmental Factors on Arid Soil Respiration Rate

I. Temperature and Moisture

R. E. Wildung and R. L. Schmidt

The soil is the principal medium for return of photosynthetic energy to the atmosphere. Soil microorganisms may be represented as receiving reduced forms of carbon in plant and animal residues and ultimately oxidizing the carbonaceous materials to the lowest energy state of carbon, i.e., carbon dioxide. The rate of carbon dioxide evolution from soil results primarily from the activity of soil microorganisms, but also includes root respiration and respiration by soil animals. To predict carbon and energy flow through an ecosystem, it is necessary to understand the environmental factors influencing soil respiration rate. Field measurements of soil respiration rate are perhaps the best means of integrating these effects.

To determine the influence of soil temperature and moisture on soil respiration rate, 12 locations were randomly selected from four strata in an undisturbed (18 ha) field plot located on a Ritzville silt loam soil in the Arid Land Ecology Reserve. Vessels which could be sealed to form a canopy over the soil surface were inserted to a soil depth of 19 cm and carbon dioxide evolution was measured for 24 hr periods from April to September, 1971. Concurrently, surface soil moisture (0-8 cm) and temperature (10 cm) were also monitored.

Seasonal changes in soil temperature (range, 6.4 - 31.0°C) were not significantly correlated with changes in soil respiration rate. Soil moisture content (range, 1.2 - 19.7%) was however strongly correlated (r, 0.825, $p < 0.001$) with respiration rate as indicated in Figure 26. Increases in respiration were apparently due to increases in microbial and plant root respiration. The results emphasize the strong dependence of higher plants and the soil microflora on moisture in arid regions and suggest that carbon flow through unperturbed arid ecosystems during the spring and summer is limited largely by adequate soil moisture.

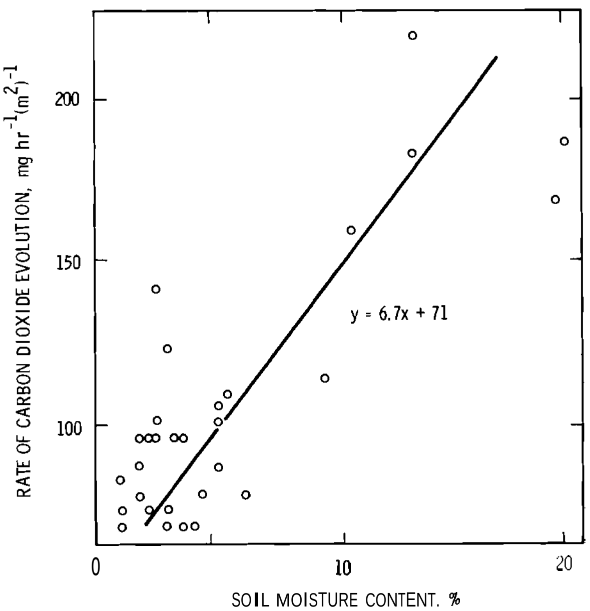


FIGURE 26. Relationship Between Soil Carbon Dioxide Evolution Rate and Seasonal Changes in Soil Moisture Content. (Each point represents the mean of 6 values.)

Seasonal changes in soil respiration rate on grazed and ungrazed soils are illustrated in Figure 27. The seasonal variation in respiration rate was due primarily to changes in soil moisture (Part I). Soil respiration rates on grazed and ungrazed plots (Figure 27) were not significantly different ($p < 0.01$). Grazing may be expected to influence soil respiration rate by altering conditions which influence microbial activity and plant root respiration, e.g., alteration of soil fertility levels, increased availability of readily available sources of carbon, disturbance of surface soil structure, and plant harvest. These effects may be expected to become more pronounced as grazing is continued in subsequent years.

Influence of Environmental Factors on Arid Soil Respiration Rate

II. Livestock Grazing

R. E. Wildung and R. L. Schmidt

As part of the International Biological Program, grassland Biome effort to determine the influence of grazing on ecological processes, soil respiration rate was measured in grazed and ungrazed sections of a field plot (36 ha) located on a Ritzville silt loam soil in the Arid Lands Ecology Reserve. Cattle (15 head) were allowed to graze from April 14 to June 10 on a section (18 ha) of the plot, whereas grazing was not permitted on the remainder. Soil respiration rate was measured as described in Part I of this report.

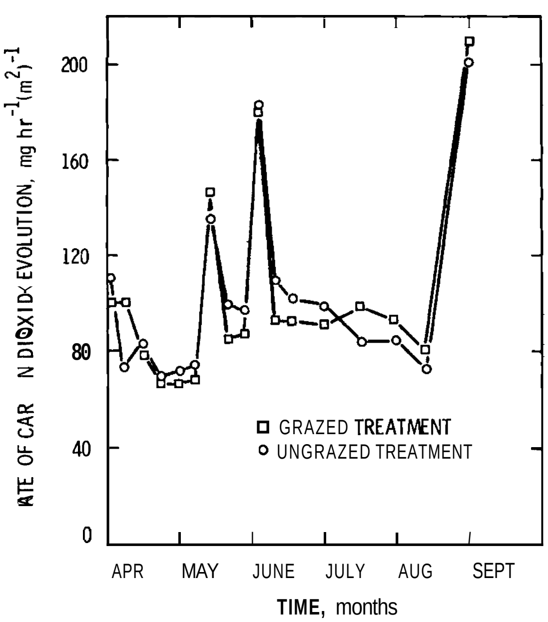


FIGURE 27. Seasonal Changes in Soil Carbon Diozide Evolution Rate Under Grazed and Ungrazed Conditions

Influence of Environmental Factors on Arid Soil Respiration Rate
III. Irrigation

R. E. Wildung and R. L. Schmidt

Previous studies (Part I) indicated the marked influence of soil moisture content on soil respiration rate in the arid shrub-steppe. Increased soil respiration with increased soil moisture during the spring and summer when temperatures were above 15°C apparently resulted from increased soil microbial activity and increased root respiration. In the previous studies, investigations were conducted on a Ritzville silt loam dominated by blue bunch wheatgrass (*Agropyron spicatum*). Soil moisture changes resulted from seasonal changes in climatic conditions and moisture use by plants. In the present study, a field plot was established on a Hezel sand dominated by cheatgrass brome (*Bromus tectorum*). Soil moisture was maintained by sprinkler irrigation at approximately 30% field moisture capacity during the spring, ending in June 1971, in an attempt to increase the productivity of native plants. Soil respiratory activity was monitored from early June to late August.

Soil respiratory activity decreased over the monitoring period corresponding to seasonal decreases in soil moisture (Figure 28). Application of additional moisture by irrigation in the spring resulted in maintenance of higher levels of soil moisture (range, 0.8 - 13.1%) throughout the summer in the irrigated plot compared to the nonirrigated control (range, 0.6 - 9.7%). Increased residual soil moisture resulted in an increased soil respiration rate on the irrigated plot relative to the control; i.e., the treatments were significantly different at the $p < 0.01$ level (Figure 28). During late August, moisture contents of the irrigated and control plots were equivalent (1.2%). However the irrigated soil maintained a higher respiration rate suggesting that increased plant root growth and root respiration with irrigation contributed in part to observed increases in soil respiration rate.

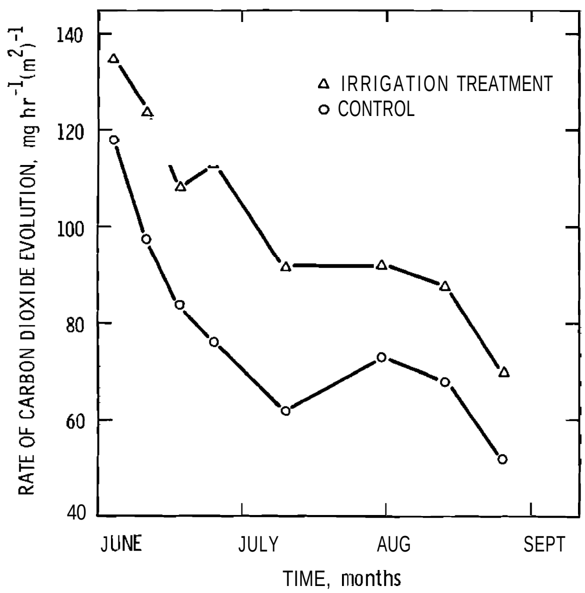


FIGURE 28. Influence of Irrigation on Soil Carbon Dioxide Evolution Rate

Influence of Environmental Factors on Arid Soil Respiration Rate
IV. Herbicide Application
R. E. Wildung and R. L. Schmidt

Field measurements of soil respiration rate do not distinguish between soil microflora and plant root respiration. Selective removal of a plant species should provide insight into the contribution of that species to total soil respiration provided the plant selected made detectable contributions to soil respiration, and herbicide treatment did not influence microbial respiration rate.

The herbicide CIPC was applied to the nonirrigated portion of the field plot previously described (Part III). The herbicide, effective against Bromus tectorum which comprised the dominant grass understory, was applied in December to kill young Bromus seedlings. Soil respiratory activity was monitored from early June to late August.

Although the herbicide was effective in eliminating Bromus growth, no significant differences ($p < 0.01$) in soil respiration rate between the herbicide treatment and a control plot were detected (Figure 29) when the seasonal data were combined. However, by the first part of June, Bromus plants were in senescence. Thus, monitoring must be maintained during the next growing season before the complete effects of herbicide treatment can be assessed.

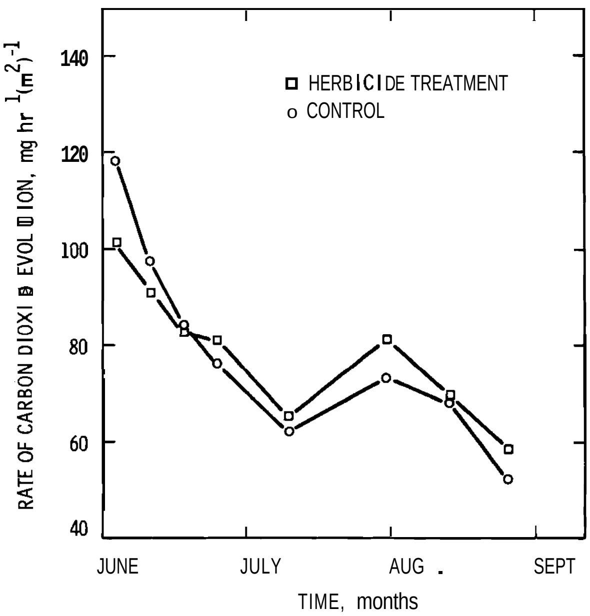


FIGURE 29. Influence of Herbicide Treatment on Soil Carbon Dioxide Evolution Rate

Mineral Weathering Processes
R. E. Wildung, R. C. Routson*, R. J. Serne* and R. L. Schmidt

To define the release of nutrients through mineral weathering of ALE Reserve soils, it is necessary to identify soil mineral assemblages and to determine the rate and sequence of weathering reactions. Rainfall provides the medium for mineral reactions and also contains soluble nutrient elements. Measurement of the quantities of nutrients entering

* *Water and Land Resources Department*

a watershed in rainwater and the quantities of nutrients in watershed drainage waters should allow development of a thermodynamic model of soil weathering reactions and estimation of watershed nutrient budgets.

As a first phase in the development of this knowledge, the perennial streams and springs in watersheds of the ALE Reserve were analyzed for calcium, magnesium, sodium and potassium. The sites included three springs draining watersheds on the northeast slope of Rattlesnake Mountain (Stations 1-3) and the perennial stream at Rattlesnake Springs near the base of the Rattlesnake Mountains in the northeastern section of the reserve (Station 4).

The results are outlined in Table 17. The ALE Reserve waters may generally be classified as calcium bicarbonate types. Composition of spring waters did not differ significantly with location; however, the cations in stream water were present in higher concentrations than the spring waters perhaps as a result of evaporative processes or increased travel through local sediments.

TABLE 17. Elemental Composition of Perennial Waters of the ALE Reserve

Sample Station	Concentration, mg/liter Calcium	Magnesium	Sodium	Potassium
1	17.42	9.39	7.39	1.20
2	19.91	8.09	7.06	1.61
3	19.67	9.63	9.30	1.46
4	26.01	10.14	13.47	2.31

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W. H. Rickard, J. F. Cline and R. O. Gilbert. "Growth of Winter Annuals as Influenced by Microtopography and Elevation," A.I.B.S. Meeting, Fort Collins, Colorado, August, 1971.

W. H. Rickard and L. L. Eberhardt. "Fallout Radiocesium in Trout and Sedges of a Cascade Mountain Bog," Radioecology Symposium, Oak Ridge, Tennessee, May, 1971.

J. F. Cline and W. H. Rickard. "Predicting the Yields of Winter Annuals in a Shrub Steppe Ecosystem," A.I.B.S. Meeting, Fort Collins, Colorado, August, 1971.

J. F. Cline and W. H. Rickard. "Radiostrontium and Cesium in Cultivated and Abandoned Field Plots,' Radioecology Symposium, Oak Ridge, Tennessee, May, 1971.

R. E. Wildung and R. L. Schmidt. "Soil Microbiological Studies in the ALE Reserve," Annual Meetings, Grassland Biome, International Biological Program, Fort Collins, Colorado, December 1971.

D. ECOLOGICAL MICROMETEOROLOGY AND CLIMATOLOGY OF THE ALE RESERVE

Climatological studies are concerned with determination of the long-term means and fluctuations of important environmental variables, both by measurement and by deduction from past records. Studies included setting up an artificial earth mound, as well as continued soil water monitoring by lysimeters. Transpiration, evaporation, precipitation, and temperature are monitored and the data documented. Use of lysimetry to provide moisture and productivity information is expected to continue.

Work described here represents an interdisciplinary effort intended to relate vegetational studies on the ALE Reserve to climatological studies in the Atmospheric Sciences Department.

An Artificial Earth Mound for Systematic Study of Slope Exposure Effects

W. T. Hinds and W. H. Rickard

Systematic study of ecosystem functioning requires a thorough understanding of the interrelations of the primary producers in the system with microhabitats, and the modifications (if any) of energy relations that may be induced by changing microhabitat characteristics. Ecologically important aspects of energy relations that may differ between microhabitats include:

(1) Temperature and relative humidity in the lower atmosphere--these are coupled together through the energy budget, and usually differ between topographically different sites;

(2) Surface and soil temperatures--these are also coupled together, by the mechanisms of heat transfer in a solid with radiant heat loading on the surface, and differ as the angle between directional incident radiation and the surface changes;

(3) Quantity and quality of incident short wave (solar) radiation--the principal independent variable in the system, this is strongly affected by terrain and cover conditions;

(4) Energy fixation by green plants--there is some evidence that identical plants growing in different microhabitats may produce different energy contents of shoot tissue and differing amounts of dry matter per unit area.

In view of the several aspects of community relations that may be expected to differ between microhabitats, it seemed appropriate to construct an outdoor laboratory for study of different habitats: an artificial earth mound of significant proportions. The advantages of a specially constructed mound include the following: 1) control of substrate composition, to assure possibility of study of root environments; 2) control of placement of the mound, close to adequate laboratory facilities; 3) control of slope aspect to north and south exposure, to maximize insolation contrast between habitats; and 4) control of size, to provide adequate sampling area.

The earth mound was constructed with a flat and horizontal top about 3 meters wide, sufficient to allow access and a horizontal "control" surface (see Figure 30).

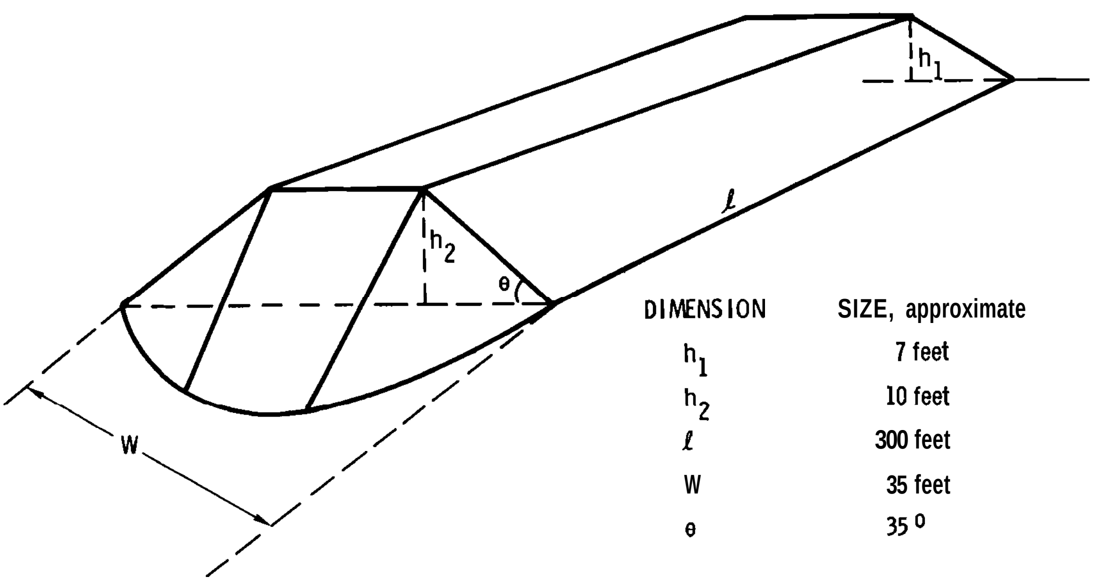
It was constructed near the ERC laboratories in a readily accessible site approximately a quarter mile due east of the building.

Productivity and Energy Fixation in Lysimeters
W. T. Hinds

Cores of a Bromus tectorum (cheatgrass) stand growing in an old field at an elevation of 600 ft were inserted into small lysimeters (described in last year's annual report). Half of the lysimeters were deployed in the 600-ft elevation site (Benson Ranch) and half were set out at 1700-ft elevation (Snively Ranch). The cores were inserted into the lysimeters in late March, 1971, and were retrieved after the end of the growing season in June 1971.

A similar study was conducted last year, at the same sites, but instead of cores from the Benson site, seeds were planted in bare soil surfaces, in mid-February.

The cheatgrass growing in the lysimeters was harvested by clipping at the soil surface. Roots were washed out of the soil of the first decimeter of the lysimeters, then floated to separate them from non-bouyant material. The roots and shoots were



DIMENSION	SIZE, approximate
h_1	7 feet
h_2	10 feet
ℓ	300 feet
W	35 feet
θ	35^{0}

FIGURE 30. Constructed Earth Mound Sufficient to Allow Access and a Horizontal "Control" Surface

dried at 60°C, weighed, ground in a rotating-blade mill to 20 mesh fineness, and tested for caloric content. The results are summarized in Table 18.

In 1970, when the plants were started from seed in the spring, roots-to-shoot ratios and total productivity were relatively close at the two sites, even though the differences were significant at the 0.001 level. In 1971, when established seedlings were inserted into the lysimeters via soil cores, the root-to-shoot ratio was about unity. The root-to-shoot ratio in 1971 was probably due to a change in vigor of the plants, because cheatgrass requires a significant exposure to sufficiently cold temperatures for successful flowering. The 1970 plants apparently did not achieve sufficient cold treatment, for their reproductive activity was sparse and weak, whereas the 1971 plants reproduced heavily and in phase with the plants in the field. Therefore, the energy fixation figures shown in the second part of Table 18 must be viewed as suggestive rather than accurate, because they result from 1970's unrepresentative stands of cheatgrass. Even so, the indication is that significant differences in tissue energy content (e.g., shoots) do not necessarily induce significant difference~in photosynthetic efficiency between stands. This result tends to support similar results from opposing exposures of small earth mounds, reported last year. However, the scatter of the earth mound data was such as to preclude comparisons of efficiencies in contrasting exposures and elevations.

The root, shoot, and total productivities of the Benson and Snively areas in 1971 were drastically different. This difference accurately reflected the differences seen in the field. However, there is at this moment no clear reason why the productivity at Benson, the lower, warmer site, should be so low, considering the relatively favorable moisture conditions in 1971 (see Elevation Effects on Transpiration and Evaporation). Apparently, the productivity of a site is a function of more than just moisture relations and soil physical conditions.

TABLE 18. Productivity and Energy Fixation in Lysimeters

	ROOTS				SHOOTS				TOTAL				Photosynthetic Efficiency	
	Production		Energy Content		Production		Energy Content		Production		Energy Content			
Site	gm m^{-2}	s.e.	cal gm^{-1}	s.e.	gm m^{-2}	s.e.	cal gm^{-1}	s.e.	gm m^{-2}	s.e.	cal cm^{-2}	s.e.	%	s e
Benson, 1970	96	7	2980	110	149	7	4040	32	245	7	89	5	0.29	0.014
Snively, 1970	122	7	2900	84	160	5	3850	71	288	6	97	4	0.31	0.014
Benson, 1971	78	19	--	--	74	9	--	--	152	15	--	--	--	--
Snively, 1971	125	20	--	--	140	16	--	--	265	18	--	--	--	--

Temperature, Precipitation and Climatology

W. T. Hinds and J. M. Thorp

Climatological studies usually are unrewarding for several years, which is the length of time required to begin to establish a meaningful average for the various climatological variables. In an attempt to shorten the interval required to form useful generalizations about the climatology of the ALE Reserve, the three years of record available to date were subjected to an analysis of variance. Each transect was treated independently, because of the variable elevations of the sites within each transect (see BNWL-SA-2733). The variance for each transect was partitioned into elevation, time, and error components for each of the variables--precipitation, maximum temperature, and minimum temperature. Because there was only a single observation of each variant at each elevation each year, the error variance includes any interaction between elevation and time. The interaction is probably small. The precipitation data are cumulative total precipitation between October and May, providing an estimate of biologically available moisture. The temperature data are averages of April and May maximum and minimum temperatures, providing estimates of the temperature factor during the spring growing season. The results of the analysis of variance are summarized in Table 19.

TABLE 19. Analysis of Variance of Microclimatological Data

Transect	Source	df	Precipitation MS	Precipitation F	Max. Temp. MS	Max. Temp. F	Min. Temp. MS	Min. Temp. F
Snively	Elevation	3	5.76	80.0[c]	65.7	65.7[c]	43.6	21.8[b]
	Time	2	3.35	46.5[c]	55.0	55.0[c]	50.5	25.2[b]
	Error	6	0.07		1.0		2.0	
	Total	11	9.18		121.7		96.2	
Benson	Elevation	5	7.29	21.1[c]	98.0	109[c]	84.8	29.2[c]
	Time	2	6.25	18.1[c]	85.5	95[c]	108.5	37.4[c]
	Error	10	0.35		0.9		2.9	
	Total	17	13.89	184.4			196.2	
Blacktop	Elevation	5	0.78	4.22[a]	43.6	36.3[c]	27.2	4.8[a]
	Time	2	8.34	45.1	86.5	72.1[c]	58.5	10.4[a]
	Error	10	0.18		1.2		5.6	
	Total	17	9.30		131.3		91.3	

df = degrees of freedom

MS = mean square

a. = $p < 0.05$

b. = $p < 0.01$

c. = $p < 0.001$

The effects of elevation and time were both significant, as should be expected. However, there are pertinent points that need to be pondered. First, the elevational effect on precipitation for the Blacktop transect is only marginally significant, in strong contrast with the other transects, and the variance due to elevation on the Blacktop transect precipitation is significantly smaller ($p < 0.025$) than that due to time, again in strong contrast with the other transects. The implication of these findings is that elevation is not as important on the Blacktop transect as it is for the other transects. This may be an important point, due to the large number of studies that lie along the Blacktop transect. Although this result is still only conjectural, it deserves close appraisal as the climatological record builds up.

Second, the effects of elevation and time are about of equal importance in the temperature data, except that elevational effects on minimum temperature are marginally significant for the Blacktop transect. The implications of this finding are similar to those for precipitation, above.

Third, the average error variance for minimum temperatures is significantly larger ($p < 0.001$) than for maximum temperatures, indicating a less repeatable pattern of minimum temperatures with time and elevation, an interesting but not unexpected result.

Transpiration and Evaporation from Lysimeters

W. T. Hinds

Small lysimeters, as described last year, were placed at Benson Ranch (elevation 600 ft) and Snively Ranch (1700 ft). Cores from the stand of *Bromus* at Benson Ranch were inserted into lysimeters at both sites, to remove the inherent differences in soil nutrients. One half (i.e., 16) of the lysimeters at each site were left in the native state, while the other half were "weeded" to prevent any green plant from growing. This provided an estimate of evaporation from the surface in the absence of transpiring plants, but with the mulch remaining intact. (Last year, the control lysimeters were left with a bare soil surface.)

The results are summarized in Table 20, including data from last year (spring, 1970) to contrast results from bare soil surfaces with soils protected by litter.

The results are about as expected. Transpiration at Snively greatly exceeded that at Benson in 1971 as did dry matter production. Evaporation from unvegetated surfaces was very much less at Snively than at Benson in 1971; in fact, unvegetated surfaces at Snively indicated a net gain in moisture during the growing season, resulting from the generous rainfall during spring 1971. This is in stark

TABLE 20. Evaporation and Transpiration from Lysimeters

Site	Evaporation (from unvegetated lysimeters), cm	Transpiration, cm	Precipitation, cm
Benson, 1970	6.8 ± 0.2	5.2 ± 0.3	2.4
Snively, 1970	7.6 ± 0.2	6.0 + 0.3	3.7
Benson, 1971	2.8 ± 0.8	7.2 ± 0.8	3.8
Snively, 1971	-0.6 ± 0.1	12.0 ± 0.6	5.6
Benson, flat litter, g m^{-2}		1250 ± 85	
Snively, flat litter, g m^{-2}		1410 ± 75	

contrast with spring 1970, with bare soil surfaces, when Snively lysimeters indicated evaporation losses about 10% greater than from Benson lysimeters (the difference in evaporation losses in 1970 was significant at the 0.001 level). The difference between the two years indicates the importance of the flat litter in community moisture relations; it has as much effect on evaporation as does the intensity of solar radiation. The presence of flat litter should not be ignored, for it is the cumulative result of many years of community production, and its magnitude depends upon both community and environmental variables.

Two points should be noted: First, the flat litter at the two sites was from the Benson stand. There is no doubt that the flat litter in the field at Snively is different. Second, the difference in flat litter in the lysimeters was significant (see Table 20). This difference may be partly due to a greater litter fall in the Snively region, but there is no proof of this; it is probably due to a one-in-twenty sampling inequality. At least part of the difference in the evaporation losses during 1971 must be attributed to the greater mulch effect of the Snively litter. Nonetheless, the interchange in moisture relations between 1970 and 1971 shows that the presence of mulch is important in community moisture relations.

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