BNWL-1550 Vol. I
Part 2
UC-48

PACIFIC NORTHWEST LABORATORY
ANNUAL REPORT FOR 1970
TO THE USAEC
DIVISION OF BIOLOGY AND MEDICINE
VOLUME 1 LIFE SCIENCES
PART 2 ECOLOGICAL SCIENCES

March 1971

AEC RESEARCH &
DEVELOPMENT REPORT

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BNWL-1550 Vol. I Part 2

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UNITED STATES ATOMIC ENERGY COMMISSION UNDER CONTRACT AT(45-1)-1830

3 3679 00047 1393

BNWL-1550 Vol. I
Part 2

UC-48, Biology
and Medicine

PACIFIC NORTHWEST LABORATORY
ANNUAL REPORT FOR 1970
TO THE
USAEC DIVISION OF BIOLOGY AND MEDICINE

VOLUME I LIFE SCIENCES
PART 2 ECOLOGICAL SCIENCES

by
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and
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Environmental and Life Sciences Division

March 1971

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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-1550 in two parts: Part 1, Biological Sciences and Part 2, Ecological Sciences. Volume II of this report is issued as BNWL-1551 also in two parts: Part 1, Atmospheric Sciences and Part 2, Radiological Sciences..

Printed in the United States of America
Available from
National Technical Information Service
National Bureau of Standards,
U.S. Department of Commerce
Springfield, Virginia 22151
Price: Printed Copy \$3.00; Microfiche \$0.95

FOREWORD

This document is part of the twentieth annual report on the life sciences at Hanford, written for the AEC Division of Biology and Medicine (DBM). It is the third annual report exclusively concerned with environmental biology. As such, it reflects the principal efforts of the staff of Ecosystems Department and others contributing to departmental programs during the past year.

Many of the goals set forth in the 1968 "Master Plan for Bioenvironmental Research at Pacific Northwest Laboratory" have been realized, and we have now commenced studies on modulation of natural ecosystems. Ecosystems Department continued its collaborative effort with other departments, on a strong multidisciplinary basis. Mathematical analysis has been applied extensively--to sampling strategies, to statistical control and to simulation models for the cycling of radioelements, pesticides, and other organic residues, in several kinds of natural systems. Programs are now well integrated, as regards field, theoretical, and laboratory efforts appropriate to environmental problems.

Important progress has taken place particularly in programs concerned with the Arid Lands Ecology (ALE) Reserve. One of the long-range objectives in the ALE programs was to study ecological changes resulting directly from modification of the environment by experimental or other means. Wildfire, irrigation, grazing, and herbicidal application are providing such opportunities. These studies represent a small but important part of the total effort. They draw on all of the departmental staff, including biometeorologists, soil specialists, hydrologists, plant and animal ecologists, data analysts, and systems modelers. Another long-range goal has been better integration of AEC programs with programs of the National Science Foundation (International Biological Program). Related-service studies on grasslands ecosystems have begun, and during the early part of 1971, Grasslands Biome of IBP will support its own studies on the ALE Reserve.

Considerable effort has been made to permit conservation-oriented groups to gain a better understanding of AEC's long interest and support in ecology. Successful meetings have been held, with representatives of the Audubon Society, the National Wildlife Federation, the Sierra Club, and other major groups. These meetings have involved tours and face-to-face discussions with the scientific staff of the Department. On a less technical level, completion of the moving picture film, "Endless Chain," dealing with the ALE Reserve ecosystem, has been well received by both technical and nonspecialist audiences.

On the Alaskan Arctic Program, both sampling in Alaska and dosimetry studies are continuing. Several elements of the simulation model for the lichen-caribou-eskimo food chain are being refined, and investigations are in progress to establish body burdens of ^{90}Sr , ^{55}Fe , ^{210}Pb - ^{210}Po and other radioelements less intensively studied than ^{137}Cs . The latter will be important in connection with possible dose-dependence of chromosomal aberrations.

In the area of thermal effects, a diversified program has been established. Now available are more sensitive criteria for thermal injury to fish than the usual mortality end-point, multidimensional hydrographic modelling of fish patterns, the heated discharge plumes, and delineation of disease and factors like nitrogen supersaturation, that confound proper assessment of the thermal effect. It is important to note that in the past, thermal studies at Hanford have been supported to a large extent by service assessment funds levied against DBM and other major onsite AEC programs. The studies have provided an important data base for setting thermal standards, and they have been made available to other Federal agencies for this purpose. Efforts are to be continued during the next year in reactor siting problems of interest to DBM.

Two new projects are providing data on the potential hazards associated with chronic discharge conditions at nuclear power plants. These are studies on the fixation and long-term accumulation of tritium in experimental aquatic and in marine environments. Both studies are specifically concerned with effects of slow-exchange or "bound" tritium, and will provide important data not otherwise available. The second of these projects is directed at determining the effects of irradiation by short-range particles acting on marine eggs. It will provide much needed data to resolve questions on the relative radiosensitivity of marine fish eggs. Preliminary efforts have involved use of freshwater organisms to work out methodological details in handling eggs, but also to examine the incorporation of tritium into organic components, where it turns over slowly as compared to body water tritium.

In other work, two 20-year studies have been assembled this year, as comprehensive reports dealing with Canada goose populations and salmon spawning on the Columbia River. Each of these studies has reached a definitive point and now provides a basis for formulating better management practices for species of sportfish or wildlife of concern near the reactor areas.

Finally, a comment should be made on administrative realignments with the department. The former Soils Relationship Section has been incorporated with the present Terrestrial Ecology Section, reflecting the high degree of interdependence of work in the two sections. Greater emphasis is now being placed at the programmatic level, for cost-awareness and planning, and these responsibilities have been strengthened by our present, simpler section structure.

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TERRESTRIAL ECOLOGY STUDIES

Major responsibility in the terrestrial ecology programs is to characterize functional roles, and response to disturbance, of important plants and animals. Various environments are currently under study, e.g. ALE Reserve, Alaska, Antarctica, and local areas. The effort is reported here by projects, but on the Hanford Reservation, for example, studies might well have been reported according to natural landscape units. Such units include riparian communities associated with the Columbia River and Rattlesnake Spring, desert steppe-shrub communities associated with the ALE Reserve, and grasslands communities (ALE Reserve and Columbia River). Both disturbed and undisturbed sites have been studied. In the past, the prominent natural disturbance to desert steppe terrain has been wildfire. Experimental modulations of these sites are now in planning stages, and they will include irrigation, grazing, and herbicide treatments. In riparian communities, investigations of the population dynamics of major wildlife species--Canada geese and Mule deer--continue. The goose study, in particular, has reached an important stage with respect to hydroelectric and nuclear plant development.

*WILDFIRE--AN IMPORTANT NATURAL MODULATION
OF THE DESERT-STEPPE

In the arid regions of the world, including desert steppes, and grasslands, one of the most dramatic factors altering the composition of the landscape is wildfire. After highly combustible material standing-dead accumulates for several seasons, lightning fires become an important consideration. Such fires alter the ultimate fate and conversion of stored energy and nutrients, the stabilization of soils, the microclimate, vegetative succession over a span of decades, and the fate of animals associated with the available food and cover. Large wildfires, which altered vast geographic portions of the arid regions of the Great Basin Desert, have become rare with the advent of agriculture and continuing reclamation. Little is known of the effects of such fires and their importance in ecological modulations. In 1970, however, a large burn on the Hanford Reservation afforded an arena for a team of ecologists to document the effects of wildfire.

During the growing seasons preceding 1970 a large amount of flammable dead plant material accumulated, particularly after the unusually luxuriant crop of annuals in 1969. After a long dry spell, rarely-seen mammato cumulus clouds and intense thunderstorm activity were recorded on July 15, and at least 7 to 11 lightning-caused fires resulted. Most were controlled during the night, but on July 16, some burning embers were fanned by wind gusts in excess of 30 mph. Before the blaze could be controlled, over 17,000 contiguous acres of the Hanford Reservation had been burned.

Immediately after the wildfire had subsided, ecology personnel began an assessment of the effects of the burn on the plant and animal communities. Transects were walked through several locations within the devastated area, and

* Effort supported under Terrestrial Plant Ecology and Terrestrial Animal Ecology programs.

nine photography reference points were permanently established to help document the damage and later revegetation. It was apparent that virtually all the shrubs, forbs, and grasses had been destroyed. Populations of mice, jackrabbits and grasshopper had been severely reduced.

This cooperative study was initiated to examine conditions contributing to the fire, the extent of the burn, and the ecological consequences. The team included a biometeorologist, soil scientists, plant ecologists, and mammalian ecologists. Preliminary results of their efforts are presented in this section.

Energy Flux During the 1970 Wildfire

T. P. O'Farrell, W. H. Rickard and
K. R. Price

Since wildfires appear to be an important means of liberating energy fixed in the standing-dead vegetation, a preliminary attempt was made to estimate the total caloric turnover during the extensive wildfire of 1970. Fortunately, there was important information on the biomass and caloric content of the vegetation of the burned area, which had been sampled in prior years for other purposes. To make use of the data we had first to estimate the extent of the burn in two previously existing vegetation types: undisturbed sagebrush-bitterbrush; cheatgrass fields, burned in 1963, which had no shrubs.

A flight was made over the area and sketches of the burn were made on topographic maps. At the same time photographs were taken for more exact placement of boundaries on aerial mosaics. Once the areas were estimated, using a planimeter, a matrix was established to estimate the caloric output of the fire. Table 1

summarizes the findings which indicate that about 121×10^{12} calories were liberated if we assume that total combustion occurred.

Effects of Wildfire on Native Rodent Populations

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

Scavengers entered the burn as soon as it cooled and only one pocket mouse, Perognathus parvus, and three jackrabbits, Lepus californicus, were found on the soil surface. Since most of the rodents in the area are fossorial it was impossible to assess mortality visually. Therefore, one of the objectives of the long-term study of the 1970 burn will be to estimate the species composition and relative abundance of small mammals for the next few years. We anticipate that sampling will take place at least six times per year so that changes in population indices can be related to climatic factors, changes in physiological and reproductive

TABLE 1. Estimated Area, Biomass, Caloric Content and Energy Flux of the 1970 Burn

	Shrub-Steppe	Old-Burn (annuals)
<u>Area</u>		
	11.62 square miles	15.59 square miles
	7436.8 acres	9977.6 acres
	3009.6 hectares	4037.8 hectares
<u>Biomass</u>		
Shrub	5300 kg/hectare	----
Forbs	3400 kg/hectare	1500 kg/hectare
Total	26183259 kg	6056685 kg
	28867 tons	6677 tons
<u>Energy</u>		
Shrub	4000 cal/g = 63.8×10^{12} cal	----
Forbs	3500 cal/g = 35.8×10^{12} cal	3500 cal/g = 21.2×10^{12} cal
<u>Total Energy of Burn</u>	= $\sim 121 \times 10^{12}$ cal	

rhythms, as well as to stages of succession and availability of food.

Four live-trapping areas, three in the burn and one outside, were established. Each plot was 0.25 hectare and had 25 live traps in a grid with 10 meter centers. The areas were operated for 100 trap-nights each, one week after the burn. The data are presented in Table 2. More pocket mice were captured in the control area than in any of the burned plots, but the variance prevented any rigorous test of these differences. There did appear to be a decrease of at least 20% in trapping success between the control and burned sites.

In November the traps were opened for an additional 100 trap-nights each to describe population levels prior to the onset of hibernation (Table 2). However, most of the ani-

mals had already begun their period of torpor, and the few active animals did not show any preference for the burned or unburned sites.

The most critical season for the small mammals will be the spring of 1971. Laboratory tests indicated that many of the annual plant seeds were destroyed in the intense heat of the fire. If germination is restricted the grain-eating pocket mice will be stressed by food deprivation as they emerge from torpor. Since the quality and quantity of vegetation acts as an environmental cue triggering reproduction, breeding may be seriously curtailed, resulting in a decline in the numbers of small mammals. Trapping efforts will be intensified during this critical period to document any changes in the population dynamics of the rodents.

TABLE 2. Trapping Success of Pocket Mice, *Perognathus parvus*, Following Wildfire, 1970

	Burned Plots			Control
	17	18	19	20
8/4 to 8/7/70				
Total Captures ^(a)	48	31	41	61
Range/night	9 to 15	7 to 9	8 to 12	12 to 18
Mean Captures/night	12	7.8	10.3	15.3
11/10 to 11/13/70				
Total Captures ^(a)	6	0	4	4
Range/night	1 to 2	0	1	1
Mean Captures/night	1.5	0	1	1

a. Total of 100 traps at risk

Estimates of Wind Erosion over Newly Burned Sand Surfaces

W. T. Hinds and J. M. Thorp

The large wildfire on the Hanford Reservation (July 16, 1970) left large areas of sandy soil (Rupert sand) without vegetation. To estimate the importance of wind in moving this unprotected soil, 33 sand traps were buried at the prow of an old dune trail: 17 traps were buried transverse to the axis of the trail, and 16 buried parallel to the trail's axis. Both lines of traps started in horizontal surfaces and traversed the ridge line of the raised dune trail, thus providing the possibility of measuring sand movement on windward and lee slopes as well as on horizontal surfaces between and on the crest of dune trails. The traps were cylindrical ice cream cartons

17 cm deep (one quart size) buried to the lip in the sand. There was little evidence of wind erosion around the lip of the traps, so the catch in the traps should be an approximation of the total flux of sand over the trap.

The total flux consists of two types of movement: saltating (flying) grains and creep of larger grains struck by the saltating grains. Table 3 lists the estimate of total flux from the different exposures of the traps. Note that many of the estimates of flux are minimum estimates, indicating that so much sand was moving that the traps filled completely between visits, causing some unknown amount of sand to be blown by without being caught. The very large amount of blowing sand indicated by the trap catch is qualitatively substantiated by observation

TABLE 3. Estimates of Total Flux of Wind Driven Sand, July-October, 1970

<u>Trap Exposure</u>	<u>Average Catch, cm</u>	
Windward Slope	45	minimum
Lee Slope	35	minimum
Swale	43	minimum
Crest	25	

of phenomena in the locale. Burned cheatgrass stems with nearly 3 cm of root structure exposed by wind erosion were observed 40 days postburning. Subsequently, even more soil was lost, indicating that plant shoots provide more effective protection against wind erosion than plant roots, since the root structure continues to be exposed by soil removal. The large difference between trap catch and visual evidence of soil removal indicates that sand is being removed continuously over the burn, that is, that the flux of wind-driven sand is not in equilibrium with the surface topography, and the wind-driven sand is finally deposited somewhere downwind.

Germination of Seeds from Soil in Burned and Unburned Sagebrush-Bitterbrush Vegetation

W. H. Rickard and J. F. Cline

In late July the surface inch and the subsurface 1-inch layers of soil

were collected from 20 randomly selected locations in one unburned and one burned site, each representative of sagebrush-bitterbrush habitat on the Hanford Reservation. The soil surface area collected was 0.05 m².

In the laboratory the soil was mixed and aliquots were placed in small ice cream cartons which served as garden pots. Each pot was 4.25 cm in diameter. The pots were kept in a plant growth chamber for two weeks and watered daily to maintain a moist environment for seed germination.

After two weeks the number of seedling that appeared in each pot was recorded (Table 4). Only four species of annual plants appeared. These were Brõmus tectorum, Amsinckia lycopsiodes, Descurainaea pinnata and Draba verna.

The data indicate that the number of seedlings appearing in the unburned soil far exceeded that in the burned soil. If these data can be extrapolated to the field, it is expected that the density of winter annuals on the burned area will be greatly reduced in the spring of 1971. The ability of these annuals to recolonize the burned area will determine in a large part the degree of soil erosion and the adequacy of the food supply for herbivorous animals during 1971. The success of the 1971 crop of annuals will also determine at least in part the available seed supply for 1972.

TABLE 4. Number of Seedlings Appearing in Soil Samples from Burned and Unburned Areas After 2 Weeks in a Growth Chamber

Location	Unburned Soil		Burned Soil	
	0 to 1 inch	1 to 2 inch	0 to 1 inch	1 to 2 inch
<u>Cheatgrass</u>				
1	4	0	0	0
2	6	0	0	0
3	1	0	0	0
4	0	2	0	0
5	8	0	0	0
6	1	3	1	2
7	13	2	1	0
8	15	2	0	0
9	7	0	0	0
10	3	12	0	0
Mean	5.8	2.1	0.2	0.2
<u>Forbs</u>				
1	0	0	0	0
2	12	0	0	0
3	0	0	0	0
4	28	0	0	0
5	0	0	0	0
6	0	0	0	0
7	5 ^(a)	0	0	0
8	10	1 ^(a)	0	0
9	8 ^(b)	4 ^(c)	0	1 ^(a)
10	3 ^(a)	0	0	1 ^(a)
Mean	6.6	0.5	0	0.2

a. *Descurainaea pinnata*

b. *D. pinnata* 6, *Amsinckia lycopsiodes* 2, otherwise forbs are *Draba verna*

c. *D. pinnata* 3, *A. lycopsiodes* 1

Autumn Emergent Beetles in Recently Burned Bitterbrush-Sagebrush Vegetation

W. H. Rickard and J. F. Cline

Fire effectively removed the standing-dead and accumulated litter on

the soil surface. Sagebrush shrubs were essentially reduced to ash but the main stems and branches of bitterbrush remained in place, although severely charred. Past studies of beetle populations in bitterbrush-sagebrush vegetation indicated the following:

- Of the two most important autumn emergent beetles on the Hanford Reservation, *Stenomorphus* and *Pelecyporus*, only *Pelecyporus* was present in sagebrush-bitterbrush vegetation.
- The emergence of adult *Pelecyporus*, as indicated by pitfall trapping, began in early September and persisted through November, with peak trap catch occurring during the first week in October.

The data of this investigation are summarized in Figure 1 and show that *Pelecyporus*, as expected, survived the burning because pre-adult life stages are spent buried in the soil. These data also indicate that the peak trap catch occurred during the third week of September in the burned area as compared to the third week of October in the unburned area. The data suggest that the early peak catch in the burned area is a result of early emergence and of a trap-susceptible population moving without obstruction over an essentially vegetation-free ground surface.

Autumn emergent darkling beetles are relatively immune to the immediate impact of summer fires. On the other hand, autumn fires could have deleterious impacts on *Pelecyporus* when the adult breeding population is highly exposed upon the soil surface for a period of several weeks.

FIGURE 1. The Total Trap Catch of *Pelecyphorus densicollis* in Burned and Unburned Stands of Sagebrush-Bitterbrush Vegetation During the Autumn of 1970

● TERRESTRIAL ANIMAL ECOLOGY

Work in this area involves: (1) small mammal studies, in which population changes and reproductive behavior are documented for the ALE Reserve, (2) irradiation studies in the natural habitat, which are concerned with the important question of whether environmental stress compounds the deleterious effects of irradiation, (3) mathematical analysis of population dynamics, and (4) disease survey of the native animals of the ALE Reserve.

A milestone was reached upon completion of a comprehensive report of a 20-year study of waterfowl populations on the Hanford Reservation. This provides background for future studies aimed at reducing the impact of hydroelectric and other development on the Columbia River on populations of breeding waterfowl.

Reproductive Behavior of the Northern Grasshopper Mouse, *Onychomys leucogaster fuscogriseus*

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

The grasshopper mouse, *Onychomys leucogaster*, is one of the small mammals most sensitive to acute ionizing radiation. Throughout its range it is one of the least numerous rodents, and relatively little is known of its ecological life history and reproductive potential. While establishing a colony for studies of the fate and effects of radiation in this species, an opportunity was afforded

to acquire important information related to these parameters.

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. However, recent publications speculate that female grasshopper mice undergo reproductive senility after 1 year of age. An experiment was started in March, 1969, to test this hypothesis.

In the previous annual report data were presented which indicated that female grasshopper mice were reproductively active into the third year of life. Data on reproductive performance from 1 to 1 1/2 years after the start of the experiment are presented in Table 5. The number of litters produced as well as the number of young born appeared to be inversely proportional to age. However, the greatest depression in breeding success did not occur until after the animals were 2 years old, and some animals were breeding in their third year. It is doubtful that many *Onychomys* reach this age under natural conditions; therefore, the drop in reproductive performance does not appear to be an important consideration in assessing low populations in the field.

TABLE 5. Reproductive Performance of *Onychomys leucogaster* of Various Ages (March to September, 1970)

Age, yr	Number of Pairs	Number of Litters	Number Born	Number Weaned	Survival of Young, %
>3	2	0	0	0	0
2.7	8	6	12	0	0
2.5	10	33	88	38	43.2
2.3	10	26	74	48	64.9
1	10	22	221	122	55.2
6 months	10	50	244	149	61.1
1 month	10	29	105	14	75.0

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

T. P. O'Farrell, J. D. Hedlund,
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R. J. Olson*

Populations of pocket mice, *Perognathus parvus*, have been followed for the past four years, and estimates of numbers have been derived from trapping data using Jolly's stochastic model (Figure 2). Over 30,000 trap-nights have been logged, and approximately 1,583 individual pocket mice have been identified and captured over 13,000 times.

Population fluctuations during 1967-1969 have been summarized in previous annual reports. Briefly, 1967 was an "average" year with regard to plant production and rodent reproductive success. In 1968, which had the lowest plant biomass produced, there was virtually no small mammal breeding. This catastrophic year was followed by the biological maximum in winter annual germination and production in 1969. This increased forage triggered the greatest reproductive activity of small mammals recorded to date, and conditions were so favorable that we found breeding juveniles as well as adults.

Although the precipitation during the winter of 1969-1970 was almost as

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FIGURE 2. Population Sizes of Perognathus parvus Estimated from Trapping Data Using Jolly's Stochastic Model. (Band widths indicate the 0.95 confidence intervals.)

great as that during the previous winter, low temperatures and drying winds during March and April reduced the plant production to close to the average for the past 5 to 7 years.

Pocket mouse breeding paralleled this drop, and only adults bred, producing 2 to 3 litters per female. Unlike 1969, the peak month for captures was July and not September, reflecting the lack of juvenile breeding. Perhaps more significant is the fact that almost as many pocket mice were captured in April, the beginning of the breeding season, as were captured in July (303 versus 308). This indicates that mortality in the overwintering adults was minimal since 351 individuals were captured just before hibernation in 1969. This reduced winter mortality is a singular attribute of pocket mouse populations in this area, and may, in fact, be a characteristic of other heteromyid

populations. Unfortunately, few populations have been studied as intensively as this one.

Distribution and Abundance of Small Mammals on Rattlesnake Mountain (ALE Reserve)

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 (Peromyscus maniculatus) as a function of altitude and season. These are the two most important species of mammals 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 gathered on 1.5 acre quadrats at four elevations, 500, 1500, 2500 and 3500 feet above

sea level, is presented in Figure 3. In general, 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 and summer.

What is perhaps most significant about these data is the lack of symmetry in the histograms of trapping data gathered in 1969 as compared with 1970. The variability in trapping success, peak number of each species captured, and chronology of peaks and troughs, makes interpretations of results as a function of time or altitude pure speculation. We have only managed to strengthen the old maxim of field ecology that "One year equals one data point."

Radiation Effects in Free-Ranging Pocket Mice

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

Earlier progress reports contained data which did not show a difference between mortality ($LD_{50/30}$) in the laboratory as compared with mortality under free-ranging conditions. Apparently, the immediate effects were the same under both sets of conditions.

To test for long-term effects, reproductive performance and longevity were examined annually in control and irradiated mice. In three breeding seasons no exposed females showed signs of estrus and were probably sterile. Males of all treatment doses had scrotal testes in subsequent reproductive periods, and they probably bred successfully.

The average and median longevity of animals surviving more than 30 days postirradiation is presented in Table 6. Except for the 500 rad data, it appears that longevity of the control and 600 rad animals was similar, and that life spans decreased with increasing exposures greater than the threshold dose (600 to 700 rad). The variance in life span was wide for all dosages except 900 rad, which is close to being supralethal in Perognathus. The data on life shortening are comparable with results published in many classical radiation effects studies.

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FIGURE 3. Relative Population Sizes of Deer Mice (*Peromyscus maniculatus*) and Pocket Mice (*Perognathus parvus*) as Determined by Live-Trapping on 1.5 Acre Quadrants (50 traps/night)

TABLE 6. Average and Median Life Spans of Free-Ranging Pocket Mice, *Perognathus parvus*, Exposed to Acute Ionizing Radiation

Dose, rad	Longevity, months		
	Mean	Range	Median
0	14.4	2-36	12
500	9.3	2-28	8
600	15.8	2-36	10.5
700	11.3	3-22	8.5
800	9.8	2-34	7.0
900	2.3	2-3	1.5

Disease Survey of Native Mammals of Project ALE

T. P. O'Farrell, J. D. Hedlund and
G. E. Cosgrove*

Wild animals are important reservoirs for infectious diseases affecting man and his livestock. Epidemiology for the cold deserts is poorly known as compared with that for more southern areas, and data concerning diseases and their vectors are necessary in making judgements regarding the possible importance of the local wild species as vectors in an epidemic.

The last progress report summarized information gathered at 32 trapping stations on seven transects of the ALE Reserve. This included estimations of the relative abundance and distribution of the small mammals, and preliminary data on the important ectoparasites, particularly fleas and ticks. In the last six months histopathological diagnoses were completed

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and a cursory check was made for endoparasites. Data are summarized in Table 7.

Most of the lesions seen were minor except the kidney abscess and the liver necroses. The latter may indicate a reaction to bacteria, virus or toxic compounds. Considering the small sample sizes no definite correlation with altitude was shown, the possible exception being the decrease

TABLE 7. Summary of Histopathological Diagnoses of Native Mammals

	<i>Peromyscus maniculatus</i>	<i>Perognathus parvus</i>
Number	33	80
Diagnosis		
Negative	12	20
Visceral		
Nematode	14	16
Muscle		
Sarcocystis	9	14
Skin		
Ectoparasites	1	14
Increased		
Hemopoiesis	11	21
Focal Leucocytic		
Aggregate	2	15
Kidney Abscesses	1	
Kidney-Harderian		
Gland-		
Degeneration	1	
Kidney-Old		
Pyelonephritis		1
Kidney Cortical		
Scar	1	1
Liver Necrosis	1	3
Lung Granuloma		1
Abdominal		
Adhesions	1	
Intestinal		
Tapeworm	1	3
Skin Granuloma		1
Skin Keratosis		1
Muscle Degeneration		1

in muscle sarcocystis with increasing altitude. Comparisons between Peromyscus and Perognathus indicate an essentially similar spectrum of minor pathology in both species.

Identification of the endoparasites found has not been completed but the nematodes have been tentatively assigned to the following genera: large gastric nematodes, Protospirura; smaller visceral nematodes, Rictularia; Perognathus pinworms, Syphacca; and Peromyscus pinworms, Wellconia. The small sample sizes precluded any attempts at correlating parasite infestations with altitude. No unusual species or infestations were encountered.

Canada Goose Population Studies on the Hanford Reservation (AEC), Southeastern Washington, During the Period 1950-1970*

W. C. Hanson and L. L. Eberhardt

During the past 20-year period, hydroelectric development of the Columbia and Snake Rivers has gradually inundated the natural nesting habitat of Canada geese, Branta canadensis moffitti Aldrich. Inundation has proceeded to such an extent that the Hanford population now occupies the only major remaining habitat on the Columbia. Maintenance of populations in the Columbia and Snake River systems depends critically on nesting habitat, which in turn depends almost exclusively on islands.

* Funded by Service Assessment

Apart from hydroelectric development and its effects, it was primarily important to document continued normal fertility of the local goose population in the presence of continuing nuclear reactor activity. Substantial evidence was already at hand that argued against environmental damage from reactor effluents, but continued long-term observations were made to confirm initial findings. Infertile eggs were of prime interest because they represented a measure of reproductive performance of adults reared and resident near the reactor complex. Average fertility of such adults has been about 97% (Table 8), which is equal to or better than that reported from areas in which there was no exposure to the very low amounts of environmental contamination found at Hanford. Fertility ranged from 95 to 99% during the

TABLE 8. Fate of 14,594 Eggs Contained in 2,592 Successful Canada Goose Nests During the Period 1953-1970

Fate of Eggs	Number	%
Unfertile	373	3
Broken, missing	289	2
Fertile, embryo died		
1st week development	513	4
2nd week development	100	1
3rd week development	131	1
4th week development	198	1
Dead goslings	50	<1
Hatched	12,940	89
Totals	14,594	101

study, with no pattern with respect to time or location. The data indicate that neither the number of reactors operating during any one time nor the proximity of the goose breeding grounds to the reactors had a measurable effect.

Secondary factors perturbing the goose populations were studied as well. These are predation (by coyotes, people, and magpies, in that order) and destruction or desertion of nest due to natural flooding and water management techniques (Figure 4). The predation factor is reflected in declining numbers of nests for the area under study (Figure 5). Banding as well as nesting studies have been carried out for both radioecological purposes and as a contribution to wildlife management practice. The extensive data obtained during the past 20 years, on

nesting site preferences and population dynamics, provide a sound background for possible experimental studies aimed at reducing the impact of hydroelectric and other river manipulations.

Neg 703581-1

FIGURE 5. Annual Variation of Average Clutch Size and Number of Goose Nests During the Period 1953-1970

Neg 703581-2

FIGURE 4. Fate of 3,824 Canada Goose Nests on the Hanford Reservation During the Period 1953-1970

Tagging Hanford Deer

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

Mule deer are an important member of the Hanford fauna. They are the only large herbivores, have access to production facilities and waste areas, range over large areas (some no doubt leave the reservation), and are considered a trophy by many local sportsmen. Little, however, is known about the mule deer herd indigenous to the project, and only in recent years has an effort been made to collect rudimentary information on their numbers, distribution, age structure, and movements.

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

The metal ear tags were small and difficultly visible so investigators had to wait for animal deaths to obtain information on the marked cohort. This severely limited the usefulness of the operation. In 1970 large plastic ear tags with consecutive numbers were also placed in the ears of 51 fawns captured with the aid of helicopter (Figure 6). These tags are easily visible with field glasses, and data may now be obtained on the movements of live deer.

During the fall and winter, attempts were made to observe the

ratio between tagged and untagged mule deer fawns as a means of assessing the proportion of this year's increment which were handled. The data also yielded information on movements of the fawns from the fawning areas, and served as a limited index to the total number of fawns surviving to the winter season. A significant amount of information will not be available for 5 to 7 years, at which time a high proportion of the herds will have been marked.

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Neg 7022-7

FIGURE 6. Mule Deer Fawn Captured During June 1970. (The conspicuous, numbered ear tag greatly aided the gathering of important movement information on live animals.)

● TERRESTRIAL PLANT ECOLOGY

The role of green plants is being investigated on the ALE Reserve in relation to the energy transformation cycle. Primary production, consumption by herbivores, seed production, and germination performance are important variables under investigation. (Supporting data on edaphic and climatic variable are reported in the subsequent section).

Field irradiation studies are continuing for long-term behavior of radiocesium and radiostrontium in soils. After 16 years, significant radiostrontium is still removed in cropped plants, and the distribution is maximal at 4 inches in untilled plots. Of interest also is the indication of less prompt seed germination response under stress temperature conditions (25°C), using the contaminated soils.

Primary Production and Consumption in
a Desert Shrub-Steppe Community
Terrestrial Ecology Section Staff

Relationships of primary productivity to key environmental parameters and the subsequent dependence

of primary consumers on productivity can be studied effectively through field modulation experiments. Detailed and careful investigations conducted in past years on the Arid Lands Ecology (ALE) Reserve have clearly indicated the need for

experimental verification using the technique of large-scale field modulation.

Three 6.25 hectare plots were established in a sagebrush-hopsage-cheatgrass (Artemisia tridentata-Grayia spinosa-Bromus tectorum) community-type. Primary productivity (cheatgrass productivity) will be modified in one plot by water augmentation during the spring growing season and in another plot by herbicide application in the fall. The third plot will not be treated and thus will represent natural productivity. Primary consumption and its relationship to population dynamics of the pocket mouse (Perognathus parvus) will be determined on 10 by 10 trapping grids (10 m spacing) located in the center of each plot.

Natural precipitation, soil temperatures, soil moisture and changes in availability of soil nitrogen will be monitored, and floristic composition and vegetation characteristics will be determined and compared among plots. Biomass and energy changes in vegetation (primarily cheatgrass fruits) induced by experimental treatments will be documented and these changes will be related to population size, phenology and rate of reproduction, and length of torpor in pocket mice. Results of these modulations will be described, as results become available, in the subsequent annual report.

Germination Performance of Cheatgrass
Seeds from Plants Raised in Field
Soils Treated with Radiocesium and
Radiostrontium

W. H. Rickard, Royce Jones* and
J. F. Cline

Under field conditions a most critical time in the life cycle of seed plants inhabiting arid regions is the few days required for seed germination and the establishment of rooted seedlings. During this time seedlings may be exposed to severe drought conditions. Annuals such as cheatgrass brome ordinarily have a high percentage of seed germination which helps in maintaining a high population density year after year.

This paper presents data on the germination performance of cheatgrass seeds from parent plants grown on field soil treated with ^{90}Sr and ^{137}Cs . All soils presently contain 2.1 mCi/m^2 of ^{137}Cs but the ^{90}Sr is equally distributed between high plots, 0.99, and low plots, 0.18 mCi per square meter. Cheatgrass seeds from plants growing on an adjacent field with no added radionuclides are used as a control. Cheatgrass seeds were germinated in lots of 25 seeds each on moistened filter papers in Petri dishes. The dishes were

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stacked inside cylindrical containers and placed in two temperature controlled incubators maintained at a low temperature of 15 °C and a high temperature (stress) of 25 °C. In all, 300 seeds were used for controls and 600 seeds each for high and low ^{90}Sr treatments.

The results are shown in Figure 7. Under a moisture regime of 15 °C, all treatments showed 97% germination or

better after only 6 days. Under the high temperature regime less than 10% of the seeds had germinated after 9 days from the radionuclide-treated plots but 35% of the seeds had germinated from the control plot. These data indicate that under high (125 °C) temperature stress conditions, seeds from plots treated with radionuclides exhibited a less prompt germination response than did the controls.

FIGURE 7. Percentage Germination of Cheatgrass Seeds from Parent Plants Grown in Soil with Different ^{90}Sr Concentrations

Litter Decomposition in Abandoned Cultivated Fields

W. H. Rickard and J. F. Cline

One of the most obvious characteristics of ungrazed vegetation of abandoned cultivated fields is the large accumulation of litter. The rate of litter decomposition is believed to be a relatively slow process in arid regions because of the lack of moisture throughout much of the year. Nitrogen is scarce in arid land soils and if it is incorporated into organic materials for long periods of time the primary productivity of old fields can be reduced by reducing the ability of the soil to supply nitrogen to plants.

This paper presents data obtained by the nylon mesh bag technique showing the weight loss of litter after field exposure for 5, 8 and 12 months and also shows the nitrogen content of the remaining litter (Table 9, Figure 8). These data indicate that the nitrogen content of litter was highest at the low elevation field and that there was little change in nitrogen concentration of litter even after 1 year of field exposure.

Weight loss was most pronounced on the low elevation field. At the end of 1 year about 40% of the initial weight was lost from the bags. Only about 20% of the weight was lost from the bags at the two higher elevations.

In all cases most weight was lost during the fall and winter period

TABLE 9. Percent Nitrogen in Plant Litter of Abandoned Fields After Exposure for 5, 8 and 12 months. (Mean $\pm$ Standard Error)

Elevation	3/2/70	6/2/70	10/7/70
600	1.03 $\pm$ 0.05	1.19 $\pm$ 0.06	1.19 $\pm$ 0.10
1000	0.54 $\pm$ 0.04	0.65 $\pm$ 0.04	0.58 $\pm$ 0.03
1700	0.49 $\pm$ 0.05	0.61 $\pm$ 0.02	0.64 $\pm$ 0.02

FIGURE 8. Weight Loss of Litter from Nylon Bags at 600-, 1000-, and 1700-foot Elevations in the Rattlesnake Hills

(October through February) when surface moisture is most plentiful, but seasonal temperatures are lowest.

The Effect of Temperature on Ammonium and Nitrate Formation in Soil

J. F. Cline and W. H. Rickard

The availability of soil nitrogen and soil moisture are two important factors determining primary productivity in arid regions. Nearly all of the soil nitrogen is in the organic fraction and only the nitrogen released as ammonium or nitrate by breakdown of organic matter is potentially available as a plant nutrient. The release of nitrogen from organic matter is regulated by the chemical

composition of the organic matter (O.M.), the soil temperature, moisture and the microbiota.

This study evaluates the influence of soil temperature on the formation of ammonium and nitrate in the soil of an abandoned cultivated field on the ALE Reserve. The soil had an average pH of 7.6, 2.2% O.M., and soil texture of 62% sand, 32% silt and 6% clay.

Soil from the field was placed in containers and incubated under conditions of adequate soil moisture and various temperatures (Figure 9).

FIGURE 9. Change in Nitrate and Ammonium Ions in Soils Incubated at 5, 10 and 15 °C

The data show that at a low temperature regime (5 °C) relatively small amounts of ammonium and nitrate were measured in the soil. At 10 and 15 °C temperature regimes, relatively large amounts of available nitrogen were measured in the soil. In all cases most of the available nitrogen was produced during the first 60 days of incubation.

In the field, soil moisture is most prevalent in the upper soil layers during late autumn, winter and early spring. December and January are the coldest months of the year. Early fall rains would be beneficial to the formation of available nitrogen because soil temperatures are relatively warm; also, spring rains would be beneficial to available nitrogen formation because soil temperatures are on a warming trend.

Maximal production of winter annuals on the ALE Reserve occurred in 1969, a year of abundant early fall and spring precipitation. It seems likely that the productivity was due at least in part to above average nitrogen releases from the soil.

Influence of Soil Beneath Greasewood and Hopsage Canopies and Its Influence on the Growth of Cheatgrass
W. H. Rickard and J. F. Cline

Studies of mineral uptake by greasewood and hopsage shrubs have previously shown that the soil beneath greasewood becomes enriched with sodium while the soil beneath hopsage becomes enriched with potassium. However, measurements of total

nitrogen and available phosphorus have not previously been made on the soils affected by these shrubs.

Field observations indicate that cheatgrass often grows tallest and in the most dense stands in the vicinity of the canopy spread of these shrubs. This paper reports the effect of shrub-influenced soil on the growth of cheatgrass grown under controlled conditions of moisture, temperature and light.

The results of soil chemical analyses are shown in Table 10. These data indicate that the nitrogen and phosphorus content beneath shrub canopies is greater than that in the open soil between canopies.

Cheatgrass seedlings grew taller in the hopsage affected soil (Figure 10). The total biomass produced in hopsage soil was 3 times greater than that produced in nonshrub influenced soil and 3.4 times greater than that produced in greasewood affected soil. The plants grown in hopsage soil had nearly equal amounts of root and shoot biomass. The plants grown in greasewood soil had more shoot

TABLE 10. Chemical Analyses of Soil Beneath and Between Shrubs

	Beneath Greasewood	Beneath Hopsage	No Shrub Canopy
Nitrogen, %	0.124	0.116	0.058
Phosphorus, ppm	23	66	15
Potassium, ppm	1500	2100	1000
Calcium, meq/100 g	12	8	9.3
Magnesium, meq/100 g	2.3	4.2	3.0
Sodium, meq/100 g	4.7	0.1	0.3
pH	8.9	8.3	7.7

FIGURE 10. Photograph of 30-Day Old Cheatgrass Seedlings Grown in Hopsage- and Greasewood-Affected Soils and Soil Collected from Between the Shrubs (Open) Areas

than root biomass and the plants grown in the open soil had more root than shoot biomass.

Clearly the soil beneath shrubs had a strong influence upon the growth of cheatgrass. These data suggest that shrubs, especially hopsage, can have a beneficial effect on the growth of associated herbaceous plants by supplying soil with scarce essential nutrients like nitrogen and phosphorus.

Estimation of Plant Biomass in Old Fields, 1970

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

Estimates of living and dead plant biomass at three elevations on the ALE Reserve were obtained during the spring growing season of 1970. Esti-

mates were made on abandoned fields at Benson Ranch (600 ft), Lower Snively (1000 ft) and Upper Snively (1700 ft) at approximately two-week intervals on five harvest days beginning in March, 1970.

At each location two 20×50 m replicates were chosen and each divided into five equal strata of size 10×20 m. On each harvest day two plots of dimension 2×5 dm were harvested in each stratum yielding a total of 20 harvested plots per location per harvest day. The creation of strata insured a more uniform sampling over each replicate. All plots were chosen at random before sampling began to prevent any inadvertent disturbance before their assigned harvest day.

Each plot was harvested by collecting all aboveground living and

dead plant material within the plot. This included living plants (sorted by species), standing-dead material and fallen litter, all of which were oven dried and weighed. For each harvest day, averages and standard errors were computed and expressed in grams per square meter for standing-dead litter, fallen litter, living aboveground biomass by species, and total living aboveground biomass. The last was broken down into percent composition by species and estimates were obtained of the sample size required to estimate biomass with a specified precision given the plot-to-plot variability observed.

The average total living aboveground biomass on each harvest day at three locations is plotted in Figure 11. The standard errors of these means are given in Table 11.

The biomass in grams per square meter is seen to increase throughout the spring growing season at all three elevations. At Upper Snively, biomass production started later in the spring but continued to increase after growth was essentially complete at Benson Ranch and Lower Snively.

TABLE 11. Standard Errors of Average Living Aboveground Biomass in Grams per Square Meter

Harvest Day	Benson Ranch	Lower Snively	Upper Snively
1	6.2	3.6	4.1
2	8.1	6.1	3.0
3	9.1	5.5	8.4
4	8.9	12.4	11.6
5	15.5	7.8	20.0
6	11.4	--	--

FIGURE 11. Average Living Aboveground Biomass in Grams per Square Meter, 1970

Fallout Radiocesium in Mulch at
Three Elevations in the Rattlesnake
Hills

W. H. Rickard and H. A. Sweany

The primary source of ^{137}Cs in the Rattlesnake Hills is aerial depositions from worldwide fallout. When deposited over vegetated landscapes radiocesium adheres to plant surfaces both living and dead. If the plant materials are not removed by grazing or fire the dead plant material tends to accumulate on the soil surface as mulch. Abandoned cultivated fields on the ALE Reserve are good places to evaluate the long-term accumulation of radiocesium in mulch because the vegetation consists almost entirely of annual plants growing in more or less even swards that are renewed from seeds every year. There are no grazing livestock to remove plant materials and fire has not been a factor for at least 13 years. The major loss of mulch is through the process of decomposition which is relatively slow in this arid region.

The concentration of radiocesium in the mulch from three elevations in 1970 is shown below.

Elevation	^{137}Cs , pCi/g	Mulch, g/1/10m ² (n = 100)	^{137}Cs , nCi/m ²
600	8.1	24.887 ± 1.52	2.0
1000	9.3	19.015 ± 1.21	1.8
1700	10.9	24.616 ± 1.30	2.7

The results indicate that the concentration of ^{137}Cs per gram of dry mulch tends to increase with increas-

ing elevation. However, on the average, ^{137}Cs in mulch amounted to only 2.2 nCi/m². This is about one-fiftieth of that in coniferous forest stands on the western slopes of the Cascade Mountains of Washington and about one-fifteenth of that for Arctic tundra in interior Alaska. These data further substantiate the premise that the shrub-steppe ecosystem of Washington has over the years accumulated less fallout than other kinds of ecosystems in Western North America.

Field Observations on Radiostrontium
and Radiocesium Under Conditions of
Cropping and Abandonment

J. F. Cline and W. H. Rickard

Cultivated soil, to the surface of which ^{90}Sr had been added 16 years ago, was cropped for 10 years then abandoned to allow colonization by the plants characteristic of early plant succession stages in the shrub-steppe region of southeastern Washington. After 5 years of abandonment, some alfalfa clumps still survive even without irrigation. Winter annuals, especially cheatgrass brome and tansy mustard, are the important colonizing plant species. After 16 years all plants were still able to obtain ^{90}Sr from the soil. In plots that had been tilled repeatedly to a depth of 4 to 6 inches, ^{90}Sr was more or less equally distributed to this depth and deeper. In untilled soil strontium was lowest in the surface inch, higher at the 4 to 6 inch depth and lower at a depth of 10 inches (Figure 12).

FIGURE 12. Distribution of ^{90}Sr and ^{137}Cs in Untilled Soil in 1970 Added 16 and 8 Years Ago, Respectively, to the Soil Surface

Radiocesium added to these same plots 8 years ago remains available for plant uptake but in much smaller amounts than radiostrontium. In tilled plots radiocesium tends to be concentrated at the tillage depth

but in untilled plots ^{137}Cs is confined to the upper inch of soil (Figure 12).

When the dead standing stalks were harvested it was found that ^{90}Sr concentration was lower in the dead stalks than in living shoots but that ^{137}Cs concentrations were higher in dead stalks than in living stalks. Cesium-137 was most abundant in dead stems that had aged at least one winter. The increased ^{137}Cs concentration in dead stalks is tentatively explained as splash-up of soil particles with strongly attached ^{137}Cs adhering to the basal portions of the stalks. Since most of the precipitation in the region occurs in fall and winter months it seems likely that this season is most suited for this kind of contamination.

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- ECOLOGICAL MICROMETEOROLOGY AND CLIMATOLOGY OF THE ALE RESERVE
- CHARACTERISTICS OF HANFORD PROJECT SOILS

Apart from standard climatological factors, important "micro-environmental" factors are being studied. Precipitation, light, and soil chemical factors have controlling influence in the immediate vicinity of growing plants, thus modifying structure and function in the plant community. Quantitative approaches have been established to measure insolation, precipitation, evapotranspiration and edaphic factors.

Photosynthetic Efficiency Estimates
for Cheatgrass Growing on Contrasting
Slope Exposures of Small Earth Mounds
W. T. Hinds

Weekly harvest of cheatgrass shoots growing on north and south exposures of small earth mounds were made during the spring of 1969. Environmental conditions during the respective growing seasons were reported last year (Hinds, Rickard and Gilbert, 1969). Using the energy equivalent of the shoot biomass and the incident solar radiation, estimates of the efficiency of the photosynthetic process in the contrasting

stands of cheatgrass were possible. (Efficiency is here defined as the ratio of energy fixed in aboveground plant tissues to incident radiation during the spring growth season). Figure 13a shows the plot of efficiency versus time during the spring season; note that the growth season was much longer on the north exposure, a point discussed last year. Figure 13b (the same efficiency data plotted against a normalized growth season) shows that there is no statistically significant difference between the springtime photosynthetic efficiency of cheatgrass in these contrasting exposures. Figure 13c

FIGURE 13. Photosynthetic Efficiency of Cheatgrass Growing on Small Earth Mounds During the Spring of 1969

(a plot of efficiency against weekly increase in biomass) examines the importance of each weekly increase in biomass in increasing efficiency. Note that the south exposure indicates a linear increase throughout the season, whereas the north exposure shows a linear increase parallel to the south exposure for the smaller increments of biomass (i.e., early in the season). However, later in the season, the north exposure curve falls away from parallelism, indicating that some change in tissue productivity had occurred. The change in slope occurred after flowering on the north exposure. It is not known at this time what physiological change caused the change in slope for the north exposure.

Precipitation Patterns on the ALE Reserve

W. T. Hinds and J. M. Thorp

A network of 26 rain gages was placed on the ALE Reserve in 1968. During the past bioyear (the moisture accumulation and growth season, from October through May), the gages were visited regularly, leading to the pattern of total rainfall and snowfall (in centimeters) on the Reserve shown in Figure 14. The precipitation is strongly influenced by the crosswind obstruction of Rattlesnake Hills, leading to a pronounced maximum in total precipitation below the crest. It is not known at this time whether this maximum is an artifact introduced by wind errors, or is in fact real.

Likewise, it is not known whether a similar maximum exists on the windward slopes of the Rattlesnake Hills, where successful wheat and grazing operations are numerous.

Evaporation from Bare and Vegetated Lysimeters at Different Elevations

W. T. Hinds

Small weighing lysimeters, 137 cm² in area and 60 cm deep, were placed in two old fields, at elevations of 600 and 1700 ft. At each elevation 33 lysimeters were installed: 21 planted to cheatgrass, and 12 bare. The lysimeters were emplaced February 27, 1970, and weighed at weekly or semiweekly intervals, allowing estimation of evaporation and transpiration between weighings. The results, shown as cumulative totals in Figure 15, indicate a substantial and important difference in cumulative moisture use between the two elevations. At the 1700 ft elevation, more moisture was lost from bare soil than at the 600 ft elevation; but, for most of the spring growing season, a higher rate of transpiration was observed at 600 ft than at 1700 ft. Only after the death of the plants at 600 ft did the transpiration at 1700 ft elevations surpass the lower. The higher evaporation from the bare soil at 1700 ft indicates that at least part of the precipitation excess at the higher elevation (relative to the lower) was biologically unavailable, even during the growing season. A further point noted was that a larger proportion of soil moisture was

FIGURE 14. Pattern of Total Rainfall and Snowfall on the
ALE Reserve, October 1969 Through May 1970, in cm of Water

FIGURE 15. Moisture Use of Bare Soil and Cheatgrass Lysimeter Study, Spring 1970

transpired at the lower elevation (about 37%) than at the higher elevation (about 23%). Thus, these data indicate that the lower elevation provided a more efficient environment for moisture usage by cheatgrass than the higher elevation, partially offsetting the advantages of the higher precipitation totals measured at the higher elevations.

Alteration of the Nonexchangeable Nitrogen Content and Acid Strength of Plant Lignin on Reaction with Ammonia

R. E. Wildung

The mechanisms of organic matter degradation in soil and the concomi-

tant incorporation of nitrogen into the soil humus are unknown yet these reactions often govern the rates of carbon and nitrogen cycling in soil. Plant lignin is believed to function as a major source of organic carbon to the soil humus, however if lignin is a major precursor of soil humic acids the lignin must undergo considerable transformation as exemplified by substantial differences in nitrogen content and cation exchange capacities. It is generally accepted that lignins contain carbon, hydrogen and oxygen only, whereas humic acids contain up to 7% nitrogen as an integral part of the molecule. Furthermore, humic acids contain a

larger number of stronger acidic groups than lignins resulting in a decidedly higher humic acid cation exchange capacity at pH values less than 10.

In these investigations a lignin-ammonia complex, formed on prolonged exposure of lignin (Indulin A) to an atmosphere of ammonia, exhibited a nonexchangeable nitrogen content approximating that of soil humic substances (Table 12) and a pH-dependent cation exchange capacity (Table 13) intermediate between established values for isolated plant lignins and soil humic colloids. The marked

increase in the cation exchange capacity (CEC) of the lignin-ammonia complex above pH 5.5 relative to the untreated lignins suggests the formation of a stronger acidic functional group with a pKa approximating 5.5.

A reaction accounting for the observed changes might involve aromatic ring fission, incorporation of nitrogen into a heterocyclic nitrogen complex and concomitant conversion of a phenolic to a carboxylic acid functional group on ring closure. Thus, a single mechanism may be in part responsible for observed increases in nitrogen content and cation exchange capacity on lignin degradation in soil.

TABLE 12. The Elemental Composition of Lignin Preparations

Sample	Content ^(a) of			
	Ash % total sample	C % ash-free	H sample	N sample
Indulin A	2.2	67.6	5.9	0.5
Indulin A-NH ₃	0.4	66.9	5.1	7.2

a. Based on oven dry (60 °C) weight

A Simplified, Accurate Method for the Measurement of the Cation Exchange Capacity of Soils, Sediments, and Suspended Particulate Matter

R. E. Wildung and R. L. Schmidt

The cation exchange capacity is an important index of the extent of solid phase influence on ion behavior

TABLE 13. CEC of Lignin Preparations as Influenced by pH of the Saturating Solution

Sample	CEC at pH values of						
	2.5	3.5	4.5	5.5	6.0	7.0	8.0
	-----meq/100 g ^(a) -----						
Indulin A	9.3	12.7	19.3	22.6	26.7	29.1	29.1
Indulin A-NH ₃	1.7	4.3	13.1	21.9	29.4	39.3	57.7

a. Based on oven dry (60 °C), ash-free sample

in soils and sediments. The measurement normally involves saturation, in test tubes, of the exchange complex with an index cation, removal of excess saturating solution by repeated washings with water or polar organic solvents, and displacement of the index cation with another cation. The quantity of index cation displaceable by mass action effects with another cation is taken as a measure of the cation exchange capacity. Measurements of this type are subject to errors resulting from hydrolysis of the index cation or dispersion of the solid phase during the washing steps. Several attempts have been made to improve upon the classical method, including elimination of the wash step by gravimetric measurement of the excess saturating solution. However, alternatives to the classical method are often time-consuming requiring many procedural steps and often inherent errors render the modifications unsuitable for measurements on small samples. For these reasons, a column technique for measurement of cation exchange capacity was developed. The new method proved highly convenient and results were comparable with those from the best existing methods.

The new method involved 1) saturation of the exchange complex with ^{85}Sr -labelled strontium by treatment of a column containing the solid phase to constant ^{85}Sr activity in the effluent, 2) washing the exchange complex with small quantities of water to remove excess ^{85}Sr solutions, and 3) measurement of the retained

^{85}Sr activity by direct counting of the column with an appropriate detector.

Cation exchange capacity measurements for soils, sediments and suspended particulate matter, obtained with the expenditure of 90% less operation time, were quite comparable with those from the best existing methods.

The Efficiency of Low Temperature Plasma Ashing for the Removal of Carbon from Soil

R. E. Wildung

Measurements of the contribution of soil organic carbon to ion exchange reactions are essential to a predictive model of the role of soil in mineral cycling within the arid ecosystem and to evaluation of the suitability of surface soil as a medium for the disposal of radioactive wastes. Determination of the role of soil organic carbon in these reactions must involve the efficient removal of organic matter from soil without alteration of the mineral substrate. Previous investigations suggested that low temperature plasma ashing (LTA) may be suitable for this purpose, however carbon removal by LTA was not complete after a 3 hour reaction period and removal appeared to be a function of soil carbon content and soil texture (sand, silt and clay content). In simple hydrocarbon systems, the reaction of carbon with plasma may be expected to follow first order kinetics, i.e., the reaction rate will be a function of carbon concentration.

It was postulated that increased carbon removal from soil would occur with increased reaction time. However, the rate of removal would be a function of the chemical nature of the soil organic matter complex. Furthermore, if the efficiency of LTA carbon removal was reduced by the presence in soil of organomineral bonds, as indicated by the observed textural influence on efficiency, subjection of soil to ultrasonic vibrations, (recently postulated to rupture soil organomineral bonds) might be expected

to increase the extent of carbon removal. To test these hypotheses, the rates of carbon removal as a function of LTA reaction time were determined for soils of different textural class, organic matter contents, and degree of ultrasonic pretreatment.

The organic carbon content of soil was reduced by LTA treatment and the quantity of carbon removed increased with increased treatment time (Figure 16). Prolonged treatment (greater than 3 hours) minimized

FIGURE 16. Soil Carbon Content as a Function of LTA Reaction Time

differences in the rate of carbon removal as influenced by soil type and/or organic matter content; 61 to 70% of the soil organic carbon was removed after 96 hours of LTA treatment.

Pretreatment of the soils with ultrasound markedly increased LTA removal of soil carbon relative to the untreated samples during the initial 3-hour treatment period (Figure 17). After 3 hours of treatment, removal of organic carbon continued but at

a reduced rate corresponding to first order kinetics. Ultrasonic treatment apparently releases a fraction of the soil organic carbon. The observed differences in carbon. The observed differences in LTA reaction rate with soil carbon components suggest that the LTA method may have promise for estimation of the readily oxidizable (microbially available) carbon fraction of soil.

FIGURE 17. Carbon Content of Ultrasonically Treated Soil as a Function of LTA Reaction Time

Organic Matter Degradation in Soil as Influenced by Soil Type

R. E. Wildung and J. W. Blaylock

Over 90% of the energy flow and carbon oxidation within the ecosystem takes place in the soil system. A satisfactory predictive model encompassing carbon must therefore be predicated upon a knowledge of the factors influencing the fate of carbon in soil. As part of continuing investigations to develop this knowledge a study of the influence of soil type on carbon degradation was initiated.

Untreated Burbank ls, Warden s1 and Licksillet 1 containing 0.29, 0.64 and 3.65% carbon, respectively, were incubated at 18% moisture for

25 days and soil respiratory activity, i.e., the rate of carbon dioxide evolution, was taken as an index of the rate of organic matter degradation. After 25 days of incubation, degradation ranged from 7 to 21 mg of carbon per 100 g of soil amounting to 0.6 to 2.4% of the total soil carbon present (Figure 18). Evolution of carbon as carbon dioxide increased with increased soil carbon content but the percentage of soil carbon degraded was inversely related to initial soil carbon content.

Amendment of the soils with Agropyron shoot tissue at the 1% concentration level resulted in increased carbon dioxide evolution (Figure 19). Correction for degradation occurring

FIGURE 18. Release of Carbon from Untreated Soils

FIGURE 19. Release of Carbon from Soils Amended with Agropyron Short Tissue (Corrected for Release of Residual Carbon)

in the unamended soils allowed estimates of the degradation rate of the added tissue. After 25 days of incubation, degradation amounted to 34 to 106 mg of carbon or 8 to 24% of the carbon initially applied. The rate of carbon degradation was a direct function of soil type and soil organic carbon content. It is apparent that the Agropyron degradation rate was markedly influenced by soil type likely reflecting differences in microbial numbers or types with microfloral activity enhanced in the finer-textured, higher organic matter soils.

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GEOLOGY AND PALEOECOLOGY OF THE ALE RESERVE

Geological studies continue to show that the ALE Reserve is unique. Its geological record is more complete and some of the stratigraphic units show a better relationship to each other than at other sites in the Pasco Basin. Those features are the result of (1) the basin centering early at a point southwest of its current center (southwest of ALE Reserve), prior to uplift of Rattlesnake Hills and (2) the uplift of that anticlinal ridge, so that colluvium interfingers with the classical Ringold Formation sediments and subsequent deposits.

Geological studies on the ALE Reserve contribute materially to knowledge of the integrated geology and development of the Pasco Basin. Additionally the interrelationship of the geology of the ALE Reserve and of the Hanford Project improves understanding of the ALE conditions.

Pleistocene Stratigraphy of the ALE Reserve

R. E. Brown*

In the geological record, a major hiatus in the center of the current Pasco Basin lies between the top of the classical Ringold Formation and the earliest flood deposits of the glacial Lake Missoula. Depending upon the final determination of the age of the uppermost classical Ringold Formation and the age of the oldest

flood deposits, the hiatus may represent several hundred thousand to possibly more than a million years time. That period of time would have permitted the Columbia River to lower its base level in Wallula Gap by more than 500 ft and to erode much of the Ringold Formation beneath the Hanford Project and the ALE Reserve.

During the period of downcutting, the uplift of the Rattlesnake Hills and associated anticlinal ridges created steepening slopes that increasingly became subject to mass wasting processes. With the onset of the

* Water and Land Resources
Department

Pleistocene Epoch (Ice Age), increased effective precipitation resulted in increased mass wasting, particularly canyon cutting and the consequent growth of alluvial fans along the front of the Rattlesnake Hills. Those fans interfinger with the classical Ringold Formation sediments but additionally overlie them in a continuous sedimentary sequence that terminates upward in fanglomerates which, by their association with the Glacier Peak ash bed, are about 12,000 years old.

The fanglomerates that overlie the classical Ringold Formation sediments probably should be considered an extension of the Ringold Formation. Firstly, they represent a continuity of deposition from older, classical Ringold Formation deposits; secondly,

they are the result of the uplift of the anticlinal ridges that caused the deposition of the Ringold Formation sediments. They thus reflect the previously recognized evolutionary development of the Pasco Basin.

Publication

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Presentation

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HYDROLOGIC CYCLING ON THE ALE RESERVE

Detailed studies of the surface water hydrology have defined the areal extent and general hydraulic gradient of the perched water table. Measurements of annual fluctuation in water level, sap flow (see section on plant ecology), and near-surface soil moisture (by piezometer and neutron probe) have progressed toward quantification of the water budget. Transpired soil water, groundwater depletion, and spring discharge constitute the total output from this system.

Water Use Patterns of Shrub-Steppe

Communities

K. R. Price

The amount of water used by a natural community during its growing season is the difference between soil moisture present at the beginning and at the end of the season plus precipitation during the same period. Community water use patterns in arid regions can be estimated from the difference between the maximum soil water present in the spring and minimum present in the fall. Because ample energy is available for evaporation, the importance of late spring and summer precipitation to the overall water budget is minimal.

Measurements were taken monthly with a neutron probe soil moisture meter in two abandoned fields which are similar in floristic composition but differ in elevation and total precipitation. The amount of water used by each field community is plotted as a function of soil depth in Figure 20. Total soil moisture lost by evapotranspiration for the period April 1970 to November 1970 at Lower Snively field was 13.0 cm and at Upper Snively field, 17.1 cm. These values are 74 and 77% of the respective precipitation measured during the recharge period October 1969 to April 1970.

Soil moisture also was monitored at the beginning of the 1970-71

FIGURE 20. Water Use Curves for Two Old Fields. (Upper Snively: elev. 500 m, October to April precipitation, 22.1 cm; lower Snively: elev. 305 m, October to April precipitation 17.6 cm)

growing season in communities near the abandoned fields. Preliminary data are shown in Figure 21 and depict soil moisture present before significant fall precipitation. It is evident that during the 1969-70 season the sagebrush-bunchgrass community was the most efficient user of soil water followed by bunchgrass alone, and then the cheatgrass-mixed forb community. The fact that sagebrush is the only major plant which retains functional leaves all during the year is significant to these water use patterns.

Stream Characteristics at Rattlesnake Spring

R. D. Harr

Numerous holes were augered at varying short distances from the

FIGURE 21. Soil Moisture Present in Three Community Types at the Onset of the Fall Growing Season. (a. Lower Snively Area; b. Upper Snively Area)

perennial stream in lower Dry Creek throughout 700 m of its length to compare relative elevations of water in the stream and in the holes. This information was used in conjunction with known elevations of groundwater and reference points to show the relationship between

groundwater and streamflow. The resulting longitudinal section (Figure 22) of the stream channel agrees very well with results of analysis of streamflow records. Streamflow originates in the 350 m reach where the Dry Creek channel is lower than the perched water table. Below this reach the stream channel is higher than the surrounding water table indicating outflow from the stream to the groundwater. The stream continues another 800 m before completely percolating downward. Here

phreatophyte vegetation is restricted to riparian plants.

Streamflow below the spring and seeps have been relatively constant at 13 l/sec reflecting their constant discharge. However, peak streamflow during rapid snowmelt on frozen soil was estimated at 5,300 l/sec on January 14, 1970. A peak of 10,000 l/sec was estimated for similar conditions on January 13, 1969. Because of its microrelief, the area in the vicinity of Rattlesnake Spring contributed very little to this surface runoff.

FIGURE 22. Longitudinal Section of Lower Dry Creek in the Vicinity of Rattlesnake Spring. (Note the vertical exaggeration.)

Groundwater Depletion by Phreatophyte Communities

R. D. Harr and K. R. Price

Groundwater elevation was measured weekly in small-diameter observation wells (piezometers) located within greasewood (*Sarcobatus vermiculatus*) and big sagebrush (*Artemisia tridentata*) communities overlying a perched water table at Rattlesnake Spring. Rates of groundwater recharge, estimated from annual curves of groundwater fluctuation,

were added to weekly groundwater drawdown to obtain use of groundwater by each community type (Figure 23). Comparison of water level curves revealed that each could be placed in one of three general groupings: (1) greasewood, 20% canopy cover, water table 10 to 13 m deep; (2) greasewood, 30 to 40% canopy cover, water table 6 to 7 m deep; and (3) sagebrush, water table 4 to 6 m deep. There was very little variation of community evapotranspiration within each

FIGURE 23. Evapotranspiration of Groundwater by Phreatophyte Vegetation. (Numbers corresponding to each curve are mean annual depth of the water table. Average maximum daily temperature serves as an index of evapotranspiration demand.)

group. Groundwater depletion was inversely proportional to the depth of the water table amounting to 3.4, 8.0, and 15.9 cm for groups 1, 2 and 3, respectively.

Evapotranspiration of groundwater from sagebrush sites began in late February. Here the capillary fringe extended to the soil surface so that during spring and early summer, evaporation and movement of capillary water from the water table to the soil surface supplemented depletion by transpiration. The start of groundwater use in greasewood coincided with the emergence of greasewood leaves in mid-March. Transpiration was the sole means of groundwater depletion where the water table was at least 6 m deep. Evapotranspiration of groundwater at all sites essentially ceased in late September.

Annual Evapotranspiration of Two Greasewood Stands

R. D. Harr and K. R. Price

The following water balance equation was used to evaluate evapotranspiration of two greasewood stands in relation to their obvious physiographic and physiologic differences:

$$ET = P + G$$

where ET = annual evapotranspiration, P = annual precipitation, and G = transpiration of groundwater. The year was divided into two parts based on soil moisture and perched groundwater recharge or depletion.

During the recharge period 87% of total annual precipitation fell, 87% of which was stored as soil moisture, and the remainder was evaporated. Groundwater reached its highest level in early April. The contribution of local precipitation to perched groundwater recharge was not detected and assumed nonexistent. From April through September groundwater was depleted by greasewood transpiration, and previously stored soil moisture from precipitation was removed primarily through transpiration by cheatgrass (*Bromus tectorum*), Figure 24. Spring and summer rain was lost through evapotranspiration.

Vegetation at each stand was characterized in terms of canopy cover, shrub size, and leaf surface area. The latter was obtained from calculated surface area-weight ratios. Results are summarized in Table 14.

TABLE 14. Comparison of Two Greasewood Stands

<u>Plot Characteristics</u>	<u>Plot A</u>	<u>Plot B</u>
Depth of water table, m	7.1	12.7
Average shrub height, m	1.7	0.8
Percent canopy cover	42	21
Relative leaf surface area	6.5	1
<u>Water Balance, cm</u>		
Annual precipitation	17.1	17.1
Soil moisture storage	12.7	13.2
Evapotranspiration during recharge period	2.2	1.7
Spring-summer precipitation	2.2	2.2
Transpiration of groundwater	7.7	3.7
Annual evapotranspiration	24.8	20.8

FIGURE 24. Profiles of Soil Moisture Use for Two Greasewood/Cheatgrass Communities. (Values are based on differences in soil moisture content on March 24 and October 1, 1970.)

Apparent Sap Velocities in Two Desert Shrubs

R. D. Harr and K. R. Price

The velocity of a heat pulse injected into a plant's sap stream is directly proportional to the velocity of the sap stream. Sap velocities indicate timing and relative magnitude of transpiration.

The heat pulse velocity technique was used to determine the daily timing of summer transpiration of greasewood (*Sarcobatus vermiculatus*) and sagebrush (*Artemisia tridentata*) in the vicinity of Rattlesnake Spring. Results are shown in Fig-

ure 25. In all cases transpiration, as indexed by relative heat pulse velocity, showed a rapid increase immediately after sunrise, fluctuated widely during the morning hours, and decreased rapidly just prior to sunset. The immediate increase and decrease associated with sunrise and sunset and the extremely low heat pulse velocities (<0.25 cm/hr) noted before sunrise indicate that transpiration between sunset and sunrise under field conditions was negligible. Heat pulse velocities in November were below the limit of detection.

FIGURE 25. Apparent Transpiration of Greasewood and Sagebrush Shrubs

MECHANISMS OF TRANSPORT AND UPTAKE OF RADIONUCLIDES
IN THE ALASKAN ENVIRONMENT

These studies concern movement of radioelements through an Arctic food chain from lichen to caribou to man, and they have proven to be important in several ways. The information provided input necessary for application of systems modeling to the Arctic ecosystem as described in the 1969 Annual Report. Second, it has provided quantification of principal body burdens in native Eskimos sampled for chromosome aberrations as described in this section. Sampling is continuing at Anaktuvuk Pass, in order to further the data base for the modeling studies.

Fallout Radionuclides in Northern
Alaskan Ecosystems

W. C. Hanson

The objectives of this study are to further define routes, rates, and amounts of fallout radionuclides in natural ecosystems of northern Alaska. Cesium-137 whole-body burdens of 75 residents of Anaktuvuk Pass were measured during the period of July 30 to August 1, 1970. Results are shown in Table 15. The adult category does not include about six men who were away from the village on firefighting training, and the observed average ^{137}Cs body burdens value may be slightly lower

than the true mean if the measurement had been made earlier and included those six men.

The average ^{137}Cs body burden in the adults was greater than expected, being only 5% less than one year ago. A decrease of 30 to 40% had been anticipated from past studies of the population. This continues the anomalous pattern begun last year by the unexplained sudden increase in ^{137}Cs content in caribou flesh, and consequently, in the people using it for food, the increase not being observed in lichens. Samples of 20 caribou stored in permafrost cellars and additional lichen samples were

TABLE 15. Body Burdens of Anaktuvuk Pass Residents During 1970

Age Category	No.	¹³⁷ Cs Body Burden, nCi	
		Mean ± Standard Error	Range
Adults (>21 years)	28	740 ± 55	80-1500
Minors (15-20 years)	3	380 ± 51	260-520
Children (<15 years)	44	150 ± 12	70-390

obtained and will be analyzed to provide more information for study of the food chain relationships that account for these concentrations.

The values in the people represent the seasonal maximum, gradually achieved from eating appreciable amounts of spring-killed caribou. The body burdens will probably remain near or slightly below this level until the fall caribou migration provides animals with much less ¹³⁷Cs in their flesh. A sudden decrease in the people's body burdens should follow utilization of that meat and should reach a seasonal minimum during January-February, when the next measurement is planned.

Radiation Dose Estimation of Eskimos in Anaktuvuk Pass

J. K. Soldat and T. P. O'Farrell

The establishment of an annual whole-body dose to certain Eskimos of Anaktuvuk Pass due to fallout is under study at this time. Rather comprehensive information is required

for quantitative measurement although it now seems possible to construct order of magnitude estimates from more limited data. Because of the relatively long period when fallout was a factor, and because of the number of working groups involved during this period, we are now attempting to collate pertinent data. The minimum list of radioelement data needed has been established as follows:

- Whole body counting: ¹³⁷Cs and other gamma emitters
- Bioassays: ⁵⁵Fe, ⁸⁹Sr, ⁹⁰Sr, ²¹⁰Pb-Po
- Assays of food, water and air samples: ⁴⁰K, ⁵⁴Mn, ⁵⁵Fe, ⁸⁹Sr, ⁹⁰Sr, ¹³⁷Cs, ²¹⁰Pb-Po
- Soil assays: above plus uranium, thoron, and daughters.

In many cases, data are available, but presently there are gaps. Radioanalysis of current soil samples will aid in determining natural background radioelements, and it will give an approximate check point for calculation of accumulated fallout deposition for purposes of ascertaining external exposure. For internal deposition, radioanalysis of foods and water over the past 7 years coupled with knowledge of current data, alone, may be adequate for purposes of order of magnitude estimate. Radioanalysis of current foodstuff and water will establish the concentrations of natural background radioelements probably present at all times, and will establish a check-point for calculations of probable concentrations of fallout radioelements in food and water.

ANALYSIS OF NATURAL SYSTEMS

Systems analysis has been meaningfully applied to several ecological problems, as described in last year's Annual Report--notably the environmental dissemination of DDT, and of fallout radiocesium in Alaska. Major theoretical problems now seem to limit the realistic application of modeling theory to other situations, and several of these problems concern fundamental assumptions underlying commonly used statistical designs.

Distinguishing Between Alternate Models for Food-Chain Kinetics

L. L. Eberhardt

Nearly all studies of a variety of trace substances in biological systems show decidedly non-normal (skewed) frequency distributions of body burdens or other measures of accumulated substance. Valid statistical treatment of such data is important on several accounts, for example, in setting protective regulations and in estimating parameters of pathways of exposure. The commonly-used frequency distribution is the log-normal, but there are both compelling arguments and some support-

ing evidence to show that the gamma distribution may provide a better model.

Our study of the problem has taken several directions. One considers methods for discriminating between distributions (very large samples are required). A second effort deals with significance tests and comparisons, while a third provides an analysis of some actual data on a pesticide (DDT).

Two test statistics, the variance of log-transformed data and a logarithmic function of untransformed data, have known (or approximately determined) sampling distributions for the two frequency distributions

and can thus be intercompared. Further tests were obtained by computer simulation. It is concluded that either test performs reasonably well on both distributions so that several useful comparisons can be made without undue concern as to which of the two theoretical distributions is really appropriate. Assumption of the log-normal distribution is, of course, rather more convenient in practice.

Modeling Food Chain Kinetics

L. L. Eberhardt

Detailed knowledge of the behavior of trace substances in food chains has become increasingly available in recent years. Most of the available data deals with radionuclides, but information on pesticides and other pollutants or contaminants of biological significance (e.g., DDT, mercury) is becoming more abundant. Problems with such substances have also become more numerous and urgent, so there is a pressing need to assemble and disseminate the available knowledge on food chain systems as rapidly as possible.

We have devoted a substantial amount of effort to two modeling activities concerning food chains. One attempts to produce realistic models for specific sets of data, while the other generalizes such models in a computer simulation and uses the results to test various kinds of estimation and significance-testing schemes. This kind of activity is particularly important in view of the nonlinear behavior exhibited in these kinetic systems.

One efficient means for rapidly becoming acquainted with complex material is through interaction with computer simulation models designed to mimic a real-world situation. Our efforts along these lines were incorporated into a summer workshop in the Center for Quantitative Science at the University of Washington. Several simulation models were assembled along with a nonlinear least-squares fitting routine and tested on a time-sharing computer. A manual for the instructor and user was drafted. The manual describes and attempts to motivate development of the basic equations for food-chain kinetics while the actual computer models are sequenced from very simple to moderately complex. One model is structured as a "game" to permit the student to acquire also some feeling for the problems of managing the use of a pesticide.

A related activity in this project was participation in a Symposium on The Development and Implementation of Courses and Curricula in Natural-Resources Biometry, held at Fort Collins, Colorado in April of 1970. Our efforts there were directed toward assembling reference material and describing possible content for a "food-chain kinetics" component of courses in resource biometry. Details are available in The Symposium Proceedings.

An Antarctic Seal Study

L. L. Eberhardt

In November of 1970, 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 N.S.F. grant). In addition to general participation in the overall program (which involved five scientists and a wide variety of research activity), the present investigator conducted a series of census operations on several seal rookeries. In one area, 12 daily counts were made in the period November 4 to November 19. The resulting data will be used to test several different census methods to define a method for larger scale use and as a part of a general study of animal census techniques. Another large rookery was visited twice and counts made of all seals present (over 350 adults). We also participated in aerial (helicopter) surveys of the general area of McMurdo Sound, radiotelemetry studies, and behavioral research (employing a closed-circuit, underwater television system and hydrophone).

In addition to the opportunity to study various census techniques, and their application to study of the population dynamics of the Weddell Seal, there was an opportunity to appraise some of the procedures and difficulties of field operations in a hostile environment. Experience in the program should be useful in our on-going operations in the Arctic. Discussions with personnel from a variety of other Antarctic research programs at McMurdo Station should

also be helpful in this regard. A detailed report on the research program will be prepared in cooperation with the principal investigator, Dr. D. B. Siniff, Ecology Department, University of Minnesota.

Estimating the Bias in Jolly's Capture-Recapture Model

R. O. Gilbert*

The capture-recapture data obtained by O'Farrell et al. on wild mouse populations on the ALE Reserve since 1967 have been analyzed using Jolly's stochastic model.⁽¹⁾ This model allows for the estimation of population size, ingress and egress, probability of capture, etc. The validity of these estimates, however, rests upon the assumption (among others) that all mice have the same probability of capture on a given trap night. Analysis of the above mentioned mouse capture-recapture data indicates that such an assumption probably does not hold and that there is some distribution of probability over the population at a given time.

Estimates of this distribution, for mice previously marked at different times, have been obtained. In addition, estimates of the bias of Jolly's estimate of population size have been found under a wide variety of distributions by means of approximate formula obtained using Taylor series expansions and Monte Carlo simulations, when the distribution

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remains constant on all trap days. To date, all results are applicable to a closed population (no births, deaths, ingress or egress), whereas the mouse population on ALE is certainly open. However, the following conclusions seem applicable:

- 1) A population can be seriously underestimated using Jolly's procedure if a large proportion of the population has a very low probability of capture. [The fact that any distribution of probability of capture will result in some negative bias if the distribution remains constant over time (as assumed here), is discussed by Marten.]⁽²⁾ Our analyses indicate that most mice being captured on ALE do not have a very low probability of capture.
- 2) The estimates of population size with least bias are obtained near the middle of the trapping experiment, not on the first or last few trap days. This is strictly applicable only to a closed population when the probability distribution remains constant over time.
- 3) The negative bias can be substantially reduced by increasing the number of trap days, particularly if the level of effort on each trap day is low.

As indicated above, all results were obtained under the assumption that capture at one time does not affect future catchability. However, it has been shown⁽²⁾ for the case of two trap days in a closed population,

that if this assumption fails, negative or positive bias will result depending on whether the correlation between probability of capture at different times is positive or negative, respectively. Assuming this statement also holds for the open population on ALE for more than two trap days, our estimates of population size probably have negative bias [other than that indicated in 1) above] since the trapping procedures used here on ALE most likely result in positive correlations between probability of capture on different trap days.

Thus, pending anticipated research into Jolly's procedure under the assumption of an open population when the distribution of probability does not remain constant on all trap days, the conclusion appears to be warranted that the mouse population on ALE is somewhat larger than currently being estimated using Jolly's procedure. Also, our lack of knowledge concerning the number of mice never captured leaves open the possibility of even greater underestimation than indicated by the above research.

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Analysis of the Spatial Distribution
and Weights of Darkling Beetles

R. O. Gilbert and W. H. Rickard

Counts were obtained on the number of darkling beetles Stenomorpha and Pelecyporus found in 1-meter-square plots at Lower Snively and Upper Snively at six sampling times during October and November of 1968. The plots were spaced 10 meters apart along a straight line 50 meters long. Three lines were used at Lower Snively and two at Upper Snively.

The data have been analyzed to determine the 95% confidence intervals around the estimated mean density of beetles on each harvest day. Since the method of computing these confidence intervals is dependent on the underlying distribution of the beetle count data, statistical tests were conducted to determine if the count data were best represented by the Poisson or the Negative Binomial distributions. For each harvest day at each location, estimates of the parameters of these two distributions were computed from the count data and goodness of fit tests performed. As an example, Figure 26 shows the count data obtained at Upper Snively on October 7, 1968 and the Negative Binomial curve which was fitted to the data.

The results suggest that, when considering the beetle counts over all lines at each location the Negative Binomial is appropriate, whereas if we restrict our attention to counts obtained along a single line, the

FIGURE 26. Fitted Negative Binomial Distribution to Observed Stenomorpha Beetle Counts

Poisson distribution is a better fit. This implies that for relatively small areas of a field, represented here by the counts obtained along a single line, the beetles seem to be randomly distributed, but over a larger area the density changes from place to place, i.e., the beetles tend to be clumped. These results are not unexpected from what is known of the darkling beetles' life cycle.

It was also determined that the average density of Stenomorpha was statistically greater at Lower Snively than at Upper Snively.

Statistical tests were also performed on the weights of darkling beetles obtained at three elevations (700, 1,000 and 1,700 ft) on native fields (undisturbed) and old fields (disturbed by past cultivation). In both habitats, these tests indicate decreasing average weight with increasing elevation.

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AQUATIC ECOLOGY

Major emphasis of the aquatic programs is to determine the effects of man-made stress on aquatic environments. Significant progress has been made in delineating and predicting the direct effects of thermal increments and radiation. However, potentially serious problems remain in the area of sublethal effects of these stress factors, and they require a high degree of sophisticated thinking and experimentation to elucidate. The base line studies on primary productivity, growth and rates of transfer of essential elements are important parameters against which sublethal effects can be measured.

- ECOLOGIC CHARACTERISTICS OF THE COLUMBIA RIVER
- FRESHWATER ECOLOGY OF RATTLESNAKE SPRINGS
- RATES AND MECHANISMS OF BIOGEOCHEMICAL PROCESSES OF THE COLUMBIA RIVER

In this work, transfer rates of radionuclides and stable elements are being investigated in aquatic systems. Several related aspects of primary productivity are being studied, for example, in relation to soil particle-water exchanges, and in relation to plant and animal structure in the ALE Reserve ecosystem. An understanding of the interaction between water, suspended materials, and the biota is necessary because thermal stress effects, for example on the periphyton community, can ultimately affect fish.

Electron Micrographic Observations
of Particulate Matter Suspended in
the Columbia River

R. E. Wildung and R. L. Schmidt

Previous investigations established the applicability of ultracentrifugation techniques, based on the principal of Stoke's law for viscous flow about a falling spherical body, to the approximate size separation of particulate matter suspended in the Columbia River. The goal was to provide a particle frac-

tionation that would reflect the natural distribution of micron and submicron particles in the river system and therefore harsh chemical treatments were not employed to remove organic matter prior to separation. However, the suspended particulate matter consists of a complex mixture of organic, mineral and organomineral detritus. Size separation was therefore considered to be only approximate because of the necessity for estimation of particle density, a parameter essential to the

selection of appropriate centrifugation parameters, on the basis of known, organic matter-free mineral densities.

To provide an absolute measure of particle size in the various size fractions and insight into the physical configuration of separated particles, an electronmicrographic study of the isolated materials was undertaken. The electron micrographs strongly reflect the criteria employed for separation. The particle size distribution was dependent upon particle density, i.e., the relatively large organic detrital compo-

nents of low density were found to be mixed with smaller mineral particles of higher density (Figure 27). However, the range of particle sizes generally fell within the range defined by the centrifugation parameters employed. Materials in the same fraction may be expected to exhibit similar suspension and transport characteristics. However, larger undecomposed organic particles have lower charge densities and surface areas and therefore contribute less to ion sorption than do smaller mineral particles.

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13,200X

FIGURE 27. Electron Micrograph of Suspended Particulate Matter Isolated and Size Fractionated (0.2 to 0.5 μ) by Ultracentrifugation Techniques. (Particle height equal to one-half shadow length.)

Mineral Composition of Particulate
Matter Suspended in the Columbia
River as Influenced by Watershed
Characteristics and Particle Size

R. E. Wildung and R. L. Schmidt

The chemical nature of suspended particulate matter may exert controlling influence on the behavior of ions soluble in surface waters. The mineralogical composition of suspended solids in the micron and sub-micron size fractions has not been completely elucidated but may be determined by X-ray diffraction techniques, and the concentration range of individual minerals may be expressed as a percentage of total minerals present. Applications of these techniques to intact-suspended particulate matter isolated from the Columbia River over the year and to size-fractionated suspended particulate matter isolated during the spring freshet provided unique insight into the source of these materials and their role in radionuclide sorption.

On a seasonal basis, changes in primary mineral (quartz, feldspar, amphibole) proportions were not pronounced (Table 17), however the proportions of layer silicate minerals (mica-illite, chlorite and montmorillonite) differed significantly during the year. Increases in the layer silicate minerals during the period April to August reflected increases in the quantity of particulate matter

from terrestrial sources. Increases in montmorillonite concentration corresponded to the period in which Columbia Basin irrigation water was returned to the river.

The primary minerals were generally more abundant in the larger size fractions (Table 18). The presence of the less resistant minerals, quartz and feldspar, in the smaller size fractions indicated that the principal weathering mechanism in these systems was mechanical disintegration as opposed to chemical dissolution. Furthermore, the mica-illite and chlorite originated from granitic and metamorphic parent materials characteristic of the upper Columbia River drainage (north-central Washington and southern Canada). Thus, of the minerals identified, only montmorillonite was likely to have originated from soils local to the sampling region.

The layer silicate minerals mica-illite and chlorite which exhibit low cation exchange capacities relative to montmorillonite were generally more abundant in the larger ($>0.5 \mu$) size fraction whereas the opposite situation prevailed in size fractions smaller in diameter ($<0.5 \mu$). The increased cation exchange capacities with decreased particle size previously observed therefore result from relative differences in mineral type and concentration as well as from increased reactive surface area.

TABLE 17. Seasonal Changes in the Relative Abundance of Minerals in Particulate Matter (<53 μ) Isolated from River Water

Time of Sampling	Relative Abundance ^(a) of					
	Quartz	Feldspar	Amphibole	Mica-illite	Chlorite	Montmorillonite
November	2	2	2	3	2	1
February	2	2	2	2	2	1
April	2	1	2	3	2	2
June	2	2	2	3	3	2
August	2	2	2	2	2	2

a. Relative mineral abundance designated as 1, trace (2 to 10%); 2, intermediate (5 to 25%); 3, abundant (>25%)

TABLE 18. Relative Abundance of Minerals in Size Fractions of Suspended Particulate Matter Isolated from River Water^(a)

Approximate Particle Size Range	Relative Abundance ^(b) of					
	Quartz	Feldspar	Amphibole	Mica-illite	Chlorite	Montmorillonite
53 to 2.0	2	3	3	3	3	1
2.0 to 0.5	2	3	3	3	3	1
0.5 to 0.2	2	1	3	2	2	2
<0.2	1	2	3	2	2	2

a. April

b. Relative mineral abundance designated as 1, trace (2 to 10%); 2, intermediate (5 to 25%); 3, abundant (>25%)

Productivity of Rattlesnake Springs

C. E. Cushing and E. G. Wolf

A computer program necessary to process the extensive amounts of data collected from diurnal pH recordings was suitably modified for the estimation of primary productivity. A sample run of data collected on

May 27, 1970, produced a productivity range of 6.1 g CO₂ m⁻²hr⁻¹ at Station 1 to 1.5 g CO₂ m⁻²hr⁻¹ at Station 4.

The variations of dissolved oxygen show the seasonal characteristics of periphyton primary productivity that may be expected once the pH data have been examined. Figure 28 shows

FIGURE 28. Annual Dissolved Oxygen Content of Rattlesnake Springs Stream at Stations 1 and 5. (Station 1 is 440 m upstream from Station 5.)

an increase in dissolved oxygen (D.O.) as the water flows downstream. During late fall through late winter, D.O. increases are related to the decrease in water temperature as water flows downstream. As solar energy increases and the water warms, the lower reaches become suitable for periphyton growth. This results in a bloom and an increased D.O. content at Station 5 in late February, March and early April, as the walls of Dry Creek canyon continue to shade the upper areas of the stream. As a result the periphyton bloom is de-

layed for several months at Station 1.

The principal primary producers in those years with winter floods will be the periphyton until late June or early July; then the watercress (*Rorippa nasturtium-aquaticum*) alters the environment sufficiently and becomes the principal autotroph.

The chemical and physical characteristics of the stream show only slight seasonal variations.

Many data have been collected concerning the consumer biota of the stream. At this time only the generic

names of those organisms most often observed are listed and these are as follows: Archilestes sp. (Odonata); Hesperophylax sp. (Trichoptera), Baetis sp. (Ephemeroptera); Gerris sp. and Notonecta sp. (Hemiptera); Hydaticus sp. and Agabetes sp. (Coleoptera), and Gyrallus sp. (Mollusca).

Chemical Characterization of Columbia River Water and Phytoplankton

C. E. Cushing and L. A. Rancitelli

Complete data on neutron activation analyses of Columbia River water and phytoplankton are presented in Table 19. As might be expected, seasonal concentrations of many of these trace elements are quite variable with little or no seasonal trends discernible in the few data. There

is a tendency toward low values for many elements in the phytoplankton in the 2/12/69 sample. Conversely, winter is usually the period of highest concentration of several elements in the water.

The investigation into the reasons for the discrepancies in analysis for certain elements in phytoplankton by neutron activation and by "standard" methods was completed. As indicated in last year's Annual Report, it was suspected that the pretreatment of samples during analyses by "standard" methods was not dissolving the entire sample. This proved to be the case. Dissolution of phytoplankton by HCl left a residue which contained significant amounts of several elements, including as much as 87% of the sodium. It was found to be necessary

TABLE 19. Elemental Composition of Columbia River Water and Phytoplankton Analyzed by Neutron Activation

Element	Water, ppb					Phytoplankton, ppm dry wt				
	11-24-68	2-12-69	4-24-69	6-11-69	8-24-69	11-24-68	2-12-69	4-24-69	6-11-69	8-24-69
Ag	0.50	<0.01	<0.01	3.03	<0.01	0.93	0.22	0.45	---	0.44
As	2.5	1.4	2.9	2.6	2.4	---	---	---	---	---
Au	0.03	<0.005	<0.005	<0.005	<0.005	---	---	---	---	---
Br	5.6	5.4	5.4	4.9	4.1	17.7	5.43	20.8	6.19	6.35
Co	0.02	0.04	0.22	0.06	0.09	9.11	2.15	10.6	11.0	7.73
Cr	0.4	<0.1	0.1	0.2	<0.1	22.8	5.36	24.3	29.4	19.0
Cs	0.35	0.03	0.02	0.03	0.03	2.11	0.56	2.52	2.18	2.08
Cu	2.6	0.6	1.5	1.0	1.1	---	---	---	---	---
Fe	13	<10	62	24	17	19200	5000	24400	24400	18100
Hg	<0.1	<0.1	0.2	<0.1	0.1	0.56	0.32	2.9	0.35	0.02
K	1190	560	1060	920	990	10700	5600	23000	---	19400
Mn	2.8	5.4	43.8	9.4	11.0	---	---	---	---	---
Na	2200	1365	2900	1880	2100	8000	2100	7100	14700	6600
Rb	3.5	0.4	0.9	1.1	1.3	69.0	17.7	58.9	44.2	138
Sb	0.24	0.43	1.04	0.30	0.43	0.79	0.36	1.50	2.85	1.06
Sc	0.002	0.001	0.015	0.003	0.006	5.98	1.59	7.10	8.01	5.62
Se	0.2	0.2	0.1	0.2	0.1	1.77	0.55	0.73	1.16	1.66
U	0.7	0.5	1.0	1.0	0.7	---	---	---	---	---
Zn	8	44	6	8	6	1310	1170	980	830	1360

to treat algal samples containing diatoms with hydrofluoric acid to insure that the entire sample was dissolved. This information was found by activating a phytoplankton sample, pretreating it as usual with HCl only, and then radioanalyzing both the solution and the residue.

Some Haematozoa of Columbia River Fishes

C. D. Becker

Most parasitic (and infectious) diseases occur in habitats in well-defined ecosystems where the parasite, vectors or intermediate hosts, and the definitive hosts form natural associations or biocenoses within which the parasite circulates. For this reason, the modern approach to parasitology envisages an ecological complex, and the parasites can be considered "ecological labels" that frequently prove to be more responsive to subtle environmental changes than the hosts themselves.

To aid in defining the ecological characteristics of the free-flowing Columbia River at Hanford, sporadic blood smears from resident fishes have been examined for incidence and intensities of haematozoa. To date, 150 fish (of 19 species) have been sampled and 9 infections detected. An intraerythrocytic haemogregarine, Haemogregarina catostomi, occurred in seven of 34 suckers (Catostomus macrocheilus and C. columbianus). An euryxenous biflagellate, Cryptobia salmositica, was identified from one of 19 squawfish (Ptychocheilus oregonensis) and one sucker; both are

new host and locality records. Infection intensities in all cases were low, indicating little or no pathological effects. The piscine haematozoa in the Columbia River have not been previously surveyed. However, the ecological concept dictates that environmental modifications resulting from man's activities, such as occurring in the Columbia in recent decades, may well alter former host-parasite relationships. Habitat modifications usually act indirectly by influencing host and vector systems, as well as the efficiency of transmission, rather than directly upon the parasite or disease organism.

Radionuclide Cycling by Periphyton

C. E. Cushing and L. L. Eberhardt

General uptake patterns of ^{65}Zn by periphyton together with related governing factors have been presented in the past annual reports. One of the serious problems in defining the exact mechanisms involved in various uptake and retention phenomena is that in virtually all field experiments, and in most laboratory studies, it is not possible to obtain sufficient data points for fitting the nonlinear mathematical models usually involved.

The periphyton cycling apparatus makes it possible to circumvent this problem by taking observations every few minutes if desired, so that it is feasible to define deviations from a given model very precisely. New experiments are now in progress to fit known models to cycling data generated by the system. We can thus

obtain accurate estimates of rate parameters for intercomparing different experiments, and we can also locate and define deviations from expected behavior within a given experiment on a rather fine time scale. Computer routines for fitting non-linear models are available, and permit rapid analysis of the data, with estimates available during the course of an experiment if necessary.

Cycling of Zinc-65 in a Simple Food-Web

D. G. Watson and C. E. Cushing

The present experiment was designed to investigate the cycling of a single radionuclide, ^{65}Zn , in a simple water-algae-fish food-web under constant flow, light, and ambient radionuclide concentration. Water temperature followed the seasonal pattern of the Columbia River. Replicate troughs containing periphyton and young carp (*Cyprinus carpio*) were contaminated continuously to maintain ^{65}Zn concentrations in the water of approximately 1 and 10 pCi/ml--about 20 times and 200 times that of the river water. Periphyton and fish were sampled at intervals to ascertain the time necessary to reach equilibrium. Subsequently, the radioactivity was cut off and retention of the ^{65}Zn was followed.

Cycling of ^{65}Zn by the periphyton and fish is shown in Figure 29. Concentrations of ^{65}Zn in periphyton

approached equilibrium in about 28 days at levels of 17 and 90 nCi/g wet weight in the low and high level troughs, respectively. These represent concentrations of about 23 and 150 times that of the control periphyton and are very close to the differential spike levels in the water. This means that, under the conditions of this experiment, periphyton concentrate ^{65}Zn in nearly direct proportion to ambient concentrations. The specific activity (pCi ^{65}Zn /mg total Zn) of the periphyton at equilibrium was 35 and 210 pCi/mg in the low and high level troughs, respectively. Again, the difference is of the same order of magnitude as that of the spike concentrations. The estimated effective half-life was about 15 days.

Data on the fish were more variable due to the influence of temperature on metabolic rates. Approximate equilibrium was reached in about 40 days at concentrations of 0.25 and 1.3 nCi per gram wet weight in the low and high level troughs, respectively. This represents concentrations of 6 and 9 times that of the control fish. Specific activities at this time were 3 and 20 pCi/mg. These last two sets of data do not approximate the differential ambient spike levels and probably mean that true equilibrium had not been reached. Water temperatures varied from 6 to 18 °C during the experiment which ran from January to July.

FIGURE 29. Uptake and Retention of ^{65}Zn in Laboratory Stream Ecosystems

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● EFFECTS OF MODIFICATION ON COLUMBIA RIVER ECOSYSTEMS

These studies are closely related to the foregoing group concerned with quantification or description of food base and abiotic interactions. They are, however, primarily concerned with biological effects of warm water effluents, as from reactor operation, rather than with ecological relationships. Such effects may take place at several different trophic levels of the aquatic ecosystem, and the studies here deal with periphyton communities, invertebrates, and juvenile salmonids (which are particularly sensitive to thermal shock). Hydrographic modeling and certain fish mortality parameters were reported on previously (see 1969 Annual Report).

Growth of Juvenile Chinook Above and Below Reactor Discharges

C. D. Becker

Young salmonids are able to detect small changes in ambient temperatures (0.5 °C), and their metabolism responds to temperature increases. This response is shown by increases in feeding activity and digestive rates that result in more rapid growth. However, ultimately a point is reached at rising temperatures where a fish expends more energy than it replaces, despite a superabundance of food, and weight gain is stabilized or even reduced. Activity at high

but still sublethal temperatures requires that a high proportion of the food intake is burned merely in maintaining body functions.

In order to investigate the phenomena of temperature and growth in juvenile chinooks at Hanford, samples of fish were collected periodically at stations above and below the heated effluent discharges from April through July, 1969. Length-weight data were compiled from over 700 fish in the 35 to 80 mm size range and compared by a nonlinear least squares fitted power function. Some nonrandom deviations of points from the fitted line were evident

but "eyeball fit" was excellent for practical purposes (Figure 30). No significant statistical difference was found for the fitted lines. Thus, proportionate allometric develop-

ment was a conclusion consistent with all data. Length-weight relationships of juvenile chinook collected above and below the Hanford discharges were approximately equal.

FIGURE 30. Length-Weight Relationships of Juvenile Chinook Collected Above and Below the Hanford Effluent Discharges, 1969

The coefficient of condition (Q) was also applied to compare the general physical status of fish in the contrasting areas. The equation is $Q = \frac{W(10^5)}{L^3}$ where W is the weight (g) of the fish, L is the length (mm) and the factor 10^5 brings the value of Q near unity. Q was found to be low and equal (1.08) for both 36 to 45 mm size groups (Table 20); these fish had recently emerged from the gravel of the river bed and were beginning to feed at low seasonal temperatures. Q was nearly equal for the larger size groups above and below the effluent discharges, ranging from 1.29 to 1.39. No major differences were evident, even for the largest fish presumably dwelling and feeding for the longest time under somewhat dissimilar thermal conditions. Comparison of these data with reported Q values for young salmon in other areas indicates that conditions in the central Columbia are quite favorable for growth of juvenile chinook.

TABLE 20. Coefficients of Condition (Q) for Different 10 mm Size Groups of Juvenile Chinook Collected Above and Below the Hanford Effluent Discharges, 1969

Size Group, mm	Above		Below	
	No. Fish	Q	No. Fish	Q
36-45	120	1.08	291	1.08
46-55	74	1.33	103	1.29
56-65	27	1.35	30	1.33
66-75	13	1.34	14	1.37
76-85	2	1.39	6	1.31

Effects of Effluent Discharges on Juvenile Salmonids

C. D. Becker, C. C. Coutant and E. F. Prentice

Discharges of heated reactor effluent constitute an ecologically important thermal modification for seaward migrating salmonids at Hanford. Juvenile fish passing involuntarily through the effluent mixing zones may be expected to receive thermal shocks of either sublethal or lethal intensities, depending on the temperature increase and duration of exposure (= thermal dose). The possibility of substantial mortalities among that portion of the migrating population entering the mixing zones was investigated in situ in 1968 and 1969. The experimental approach involved drifting test fish retained in live-boxes through the areas of maximum thermal increment while monitoring thermal dose.

Following final analysis in 1970, the results of this study are now available. A summary of the data is presented in Figures 31 and 32, where the maximum temperatures encountered by test fish are compared with the preferred temperature (12 to 14 °C) and an arbitrary upper incipient lethal level of 25 °C.

Midriver drifts through the main discharge plumes resulted in insignificant mortalities except under unfavorable late summer conditions of high base river temperatures and low discharges. But shoreline drifts through a few areas receiving heated water via intragravel seepage from retention basins resulted in some

FIGURE 31. Maximum Thermal Exposure of Juvenile Salmonids During Live Box Drifts Through Effluent Discharges in 1969. A, B, and C in the figure refer to Brett's (1952) zones of "preferred temperature", "thermal tolerance", and "thermal resistance." The uppermost line is an incipient lethal temperature.

mortalities. Contrasting effects between the two sites were due to differences in current flow and resulting effluent mixing patterns. Ambient environmental features regulating thermal dose in the central

Columbia River, which varied during the migration season, were base river temperatures (4 to 19 °C) and discharges (40,000 to 270,000 ft³ per second). Four combinations occurred in sequence with increasing

FIGURE 32. Maximum Thermal Exposure of Juvenile Salmonids (Test) During Livebox Drifts Through Effluent Discharges in 1969. Legend is the same as Figure 31.

potential for thermal damage: low temperature-low discharge (early spring, low temperature-high discharge, (late spring), high tempera-

ture-high discharge (early summer), and high temperature-low discharge (late summer). Most juvenile chinook salmon are produced in the Hanford

area migrate seaward from April to July under protective conditions of favorable temperature and high discharge.

Vulnerability of Juvenile Salmonids to Predation Following Thermal Shock

M. J. Schneider

In the Hanford stretch the many immature emigrant salmonids may be involuntarily swept through the warm water of reactor outfalls. Field studies have shown that such exposures are not usually lethal. It is possible, however, that such exposure renders the juvenile migrants more vulnerable to predation due to subtle, temporary effects.

To investigate this aspect, an experiment was designed in which juvenile fish were exposed to predators following a thermal shock. Juvenile rainbow trout, *Salmo gairdneri*, were used as prey according to the regime indicated in Figure 33. Juveniles acclimated to 15 °C water were cold branded to facilitate identification as experimentals or controls. Then 25 fish from the two stocks were exposed for a timed dose at elevated temperature for the experimentals and at acclimation temperature for the controls. The 50 fish were then transferred in a common tank to the predator tanks which contained 8 to 12 adult rainbow trout. When about

Neg 704714-1

FIGURE 33. Flow Diagram, Predator Tests

half of the initial charge of small fish remained, the small fish were removed and the percentages of treated and untreated prey were determined.

While the final statistical analyses of the results have yet to be completed, Table 21 summarizes the available results.

In addition to the results presented in the table, it can be stated that the effect (that is, the degree of vulnerability) becomes more pronounced with increased duration of exposure to any one temperature.

TABLE 21. Temperature and Exposure Duration Required to Render Fish More Vulnerable to Predation

Temperature, °C	Duration, min
30	1.0
28	4.0
27	2.5
25	6.0
23	12.0
22	12.0
21	No effect

Response of Columbia River Invertebrates to Thermal Stress

C. D. Becker

Many poikilothermous invertebrates dwelling in the central Columbia River are exposed to thermal increments from the release of heated

effluent from the Hanford reactors. These increments may be beneficial, by enhancing developmental rates, or they may be sublethal or lethal, depending on inherited thermal tolerance and prior thermal acclimation of individual species. Thermal stress from elevated temperatures theoretically may occur in two ways. The first is from brief exposure to relatively high increments in the mixing zones of midriver effluent plumes; this applies to organisms occurring normally in the river drift and passing downriver on collision course with the plumes. The second is from prolonged exposure to relatively low increments existing below the primary mixing zones; this applies to organisms living and completing their life cycles in the river below Hanford.

Studies on the response of Columbia River invertebrates to thermal stress were intensified in 1970. Experiments with representative river organisms were designed to test 1) thermal tolerance, 2) resistance to thermal shock, and 3) development under elevated temperature regimes.

Data on the thermal tolerance of larval caddisflies (*H. cockerelli*) acclimated to maximum summer temperatures of 19.5 °C are given in Figure 34. Temperatures 10 °C above ambient (ΔT 29.5 °C) resulted in 50% mortality in 68 hr, whereas mortalities at 7.5 °C above were insignificant. Resistance to thermal shock of young crayfish (*P. leniusculus*), a nondrifting organism, is illustrated in Figure 35. At an acclimation of 17 °C, exposures of 1 hr to temperatures of 32.5 °C (ΔT 15.0 °C) was

FIGURE 34. Thermal Tolerance of Larvae *Hydropsyche cockerelli* (Diptera: Trichoptera) Acclimated to 19.5 °C (± 0.5)

FIGURE 35. Effects of Thermal Shock on Young Crayfish *Pacifastiscus leniusculus* Acclimated to 17 °C (± 0.5)

required to produce significant (i.e. 50%) mortality. Limited studies completed in 1970 indicate that, for most typical river invertebrates, the upper incipient lethal limit is well above maximum temperatures existing in the Columbia below the mixing zones. For the species tested, thermal increases at successive steps of 2.5 °C (up to ΔT 10 °C) result in well-defined increases in rates of development and growth.

Columbia River Periphyton Communities
Under Thermal Stress

B. B. Owen, Jr.

Production and community structure of primary producers are essential elements that require understanding before conclusions concerning the effects of thermal stress on river ecosystems can be made. Periphyton communities, representing the lowest trophic level, form a vital link in the aquatic food chain, leading to production of fishes.

To evaluate the potential effects of thermal additions on Columbia River periphyton, artificial stream channels were constructed. A flow-through design was used, with each stream receiving four gallons of river water per minute. The control channel received river water at ambient temperatures, while the other four received river water, at 2.5, 5.0, 7.5, and 10 °C increments above ambient. Each stream developed a community of periphyton characteristic of its temperature regime.

The streams were sampled monthly

for standing crop, pigment content and species composition. Data were collected from October 1969 to October 1970. During this period, nets were used continuously to collect the export of each stream. A portion of each stream was cleaned, and allowed to recolonize briefly, each season. Collections of standing crops were made periodically during colonization and growth, until a stable climax community developed. Although the data have not been completely analysed, several general conclusions may be drawn.

The standing crops and pigment contents of mature periphyton communities did not differ greatly among streams on any collection date, regardless of temperature level. Moreover, 1 yr totals of algae export were similar for all five streams (about 12% variation). Each season revealed a different relationship of temperature to export among the five streams. There was a range from 0.30 gram export per square meter per day in midwinter, to 8.0 g/m²/day in early fall.

The data from seasonal colonization studies indicate that the rate of growth or colonization of periphyton was directly related to temperature (Figure 36). Light appears to be an insignificant factor at the temperatures tested. Light conditions were similar for the spring and summer periods, as they were also for the fall and winter. This section of the study bears considerable significance, as Columbia River periphyton

FIGURE 36. Seasonal Productivity of Artificial Streams with Added Thermal Increments

is undoubtedly maintained in a sub-climax condition, similar to that studied. Grazing and erosion are two factors that maintain the natural river community in an almost constant state of recolonization and growth.

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EFFECTS OF MODIFICATION OF COLUMBIA RIVER ECOSYSTEMS - RELATED STUDIES

These studies (supported by service assessment funds) are closely interrelated with Division of Biology and Medicine programs outlined previously. While some of the studies reflect the uniqueness of the Columbia River, i.e., emphasis on anadromous fish, it is important to note that the techniques developed are applicable to other aquatic systems. The scope of the studies concerns not only lethal effects on the developmental stages of fish, but also potential problems caused by concomitant disease and gas supersaturation. Behavioral aspects of fish migration are being assessed by sonic tracking.

Studies have shown that Columnaris disease has reached a critical level in the Columbia River above the Hanford area. A slight change of conditions in the river may be sufficient to trigger an epidemic. Many factors contribute to disease conditions, but the combined seasonal stresses of lower than normal river flow and warmer river temperatures were probably most important during 1970.

Analysis of data in a 20-year study of salmon spawning indicates that the establishment of additional dams on the Columbia River and the associated destruction of main stem spawning areas were more influential on size of the local stock than river temperature, river flow, or reactor operation.

Effects of Temperature Increments on Juvenile Steelhead*

P. A. Olson and E. G. Tangen

Studies to evaluate the effects of thermal increments on the development, mortality, hatching and growth of salmonid eggs and young have been conducted at BNW facilities for several years. The central Columbia

is heavily utilized as a spawning area by adult salmonids, and operating Hanford reactors discharge heated effluent into the river. These studies, therefore, provide some assurance that the normal increments from reactor effluents will not cause excessive mortality or growth depression, and permit estimates of critical thermal levels.

Past work has emphasized artificial propagation of fall chinook salmon, rainbow trout and steelhead.

* Supported by Service Assessment Funds

Rearing is conducted in Columbia River water receiving controlled thermal increments, with temperatures ranging above and below ambient levels in response to normal seasonal changes. Of necessity, these are long-term experiments that correspond to the inflexible inherited period that each species must spend in the freshwater environs prior to seaward migration.

The effects of increased temperatures on survival and growth of juvenile steelhead have been studied since July 1969. At the start, the fish averaged 0.8 g in weight and were allocated to rearing in four groups: normal river temperatures, $\Delta 3^{\circ}\text{F}$ (1.7°C), $\Delta 4^{\circ}\text{F}$ (2.2°C), and $\Delta 5^{\circ}\text{F}$ (2.6°C). Average daily temperatures in the warmest group averaged slightly over 21.1°C during the warmest part of the summer and tended to depress growth rates. Mortalities could not be correlated with temperatures, but resulted primarily from columnaris disease. During the winter when river temperatures were low, growth in the warmest group was favored.

Maximum temperatures during the summer of 1970 again slowed growth rates in the warmest group and growth in the coldest (base river temperature) was greatest. With decreasing fall temperatures, the relative growth of the warmest group increased in comparison with the coldest. On October 1, 1970, the average weight of the surviving fish in the four groups were 187.8, 201.3, 206.5 and 185.5 g, respectively.

Fall Chinook Salmon Population Studies*

D. G. Watson, G. J. Paulik, and R. O. Gilbert

Estimates were made of the numbers of fall chinook salmon spawning near Hanford through aerial census of their redds. This is a continuation of yearly observations begun in 1947 to evaluate the effects of the reactor effluents on this locally spawning population.

Spawning started on October 8, reached a peak during the second week in November and was completed by November 19. A total of 3825 redds was counted, the second highest number observed during the 24 years that surveys have been conducted. By application of a 1:7 ratio of redds to salmon, the estimated spawning population was about 26,800. This is approximately 43% of the fall run passing McNary Dam, the nearest dam downstream, or about 12% of the fall chinook that moved over Bonneville Dam, the dam nearest to the river mouth.

River temperatures were approximately 16°C at the start of spawning but had dropped to around 12°C at peak of spawning. This is within the acceptable upper temperature tolerance limits for incubation of salmon eggs.

Mathematical analysis of salmon spawning data** from 1947 through 1969 shows no apparent relationship between size of the locally spawning

* Supported by Service Assessment

** See Manuscript Listing, p. 2.35.

the locally spawning population and population and numbers of reactors operating at Hanford. The establishment of additional dams on the Columbia River, and the associated destruction of main stem spawning areas, seemed more influential on the size of the local stock than river temperature, flow, or reactor operation.

Feeding Habits of Juvenile Chinook in the Central Columbia

C. D. Becker

Juvenile chinook salmon in the central Columbia River feed upon various stages of aquatic insects, primarily adult and larval midges (Diptera: Tendipedidae). Within aquatic habitats, the production of various insects is influenced by numerous environmental variables including water temperatures, water quality, current velocity and discharge, type of substrate, water depth, and predation. Insects are but one link in the aquatic food chain and they, in turn, feed upon other insects, algae or detritus. Production of these smaller food organisms at a lower trophic level is, in turn, influenced by a complex of environmental factors including temperature regimes.

Studies on the food habits of juvenile chinook at Hanford were conducted during the spring of 1968 and 1969, in order to evaluate feeding in the vicinity of heated discharges from operating reactors. Food organisms utilized were essentially similar each year, indicating no major shifts in feeding activity or

availability of aquatic insect groups. The extended sampling program in 1969 permitted a more critical evaluation of monthly changes in feeding habits, in relation to the normal seasonal increases in water temperature and size of the growing fish (Table 22), as well as to the rise and fall of river volume. The major insect orders utilized were the Diptera, Hemiptera, Trichoptera and Collembola, but relatively few species were taken within each group. Midges were heavily utilized each month. Small emerging chinook (39 mm long) in March selected small midges almost exclusively. The Hemiptera (mainly Notonecta nymphs) and Collembola (Hypogastruridae), small forms associated with the shoreline and mud-water interface, were captured during the annual spate when rising water levels inundated shoreline zones. The large adult Trichoptera (mainly Hydropsyche cockerelli), a univoltine form emerging in June and July, were utilized by larger chinook (45 to 65 mm long). Mean numbers of insects per feeding chinook showed an increasing trend in correlation with fish growth.

It is known that young salmonids are largely opportunistic feeders, that organisms utilized are subject to limitations imposed by fish size, and that food selected by larger individuals can be very diverse. However, diversity is clearly restricted to what is available in the ecosystem.

Perusal of all data collected in this study indicates that the distinctive features of chinook feeding

TABLE 22. Monthly Changes in Feeding Habits of Juvenile Chinook at Hanford in 1969, All Sampling Stations Combined

Category	Percent Consumption Per Month				
	March	April	May	June	July
<u>Insect Group</u>					
*Diptera	99.5	88.8	70.2	77.2	84.8
Tendipedidae, adults	67.1	62.4	50.4	52.4	77.2
Tendipedidae, larvae	31.8	24.6	17.4	22.8	6.3
*Hemiptera	---	3.2	13.2	2.6	T
Coleoptera	T	T	T	T	T
Lepidoptera	---	T	T	3.3	T
*Trichoptera	---	T	T	10.2	13.0
Ephemeroptera	---	T	---	T	T
Homoptera	---	T	T	3.4	T
Hymenoptera	---	T	T	T	T
*Collembola	T	5.6	13.8	1.4	---
Unknowns	---	---	T	T	---
All other insects	---	T	T	1.3	T
Total Insects (%)	99.5	97.6	97.2	99.4	97.8

<u>Number Fish Examined</u>	46	275	160	199	89
<u>Fish Size (mm)</u>					
Mean	39.4	39.9	44.1	49.4	58.7
Standard Deviation ($\pm$)	2.8	2.3	4.8	7.7	11.2
<u>$\bar{X}$ Insects/Feeding Fish:</u>	15.9	13.2	32.7	28.9	43.9

Note: "T" = "Trace," or less than 1% by number in stomach contents.

* = Major insect groups utilized.

in the central Columbia are fourfold: first, relatively few insect species are utilized; second, the fish have a high dependence on drifting, floating or swimming forms; third, they usually select organisms moving independently on or in the water; and fourth, they are indeed opportunistic to a high degree. No evidence was obtained that either food orga-

nisms or feeding activity were adversely affected by heated effluent discharges.

Sonic Tracking of Adult Salmonids M. J. Schneider*

The Columbia River serves as a migratory route for anadromous fishes

* Supported by Service Assessment Funds

to and from the spawning grounds in the river and its tributaries. Any effective blockage of the upstream migrations could have disastrous results on the species. Hydroelectric dams could present such a blockage were it not for fish ladders. A more subtle but equally effective block could be formed by a discharge of thermal water such as the reactor outfalls of Hanford. Thermal water entering and mixing with the river waters potentially could elevate the river temperature locally to a level avoided by fish. To evaluate the behavior of migrating adult salmon in the Hanford reach of the Columbia, the paths of individual fish have been plotted for the past three fall runs. Individual salmon were caught as they passed through the fishways of Columbia River dams and implanted with an ultrasonic tag. After release, the fish were followed by a boat equipped with hydrophones and receiving gear. The sonic tag used was developed by the National Marine Fisheries Service (formerly Bureau of Commercial Fisheries) at Seattle. Two types of sonic tags have been developed, one simply emits a "beep" which can be used to locate the fish. The second type of tag emits a tone; the frequency of the tone telemeters the ambient temperature. The study has been conducted with the cooperation of Mr. James Johnson and Mr. Gerald Monan of N.M.F.S.

In the past the fish were tagged at McNary Dam. This year, however, the fish were obtained at Priest Rapids Dam and delivered to a site down river of the Hanford reactors

where the sonic tags were implanted and the fish were released. Two series of tracking studies were performed in 1970.

The former series of tracks was made from late August to early September. During this time period the thermal discharge at Hanford was at the absolute minimum as both functioning reactors were not operating. For the first time since the beginning of the sonic tracking studies this allowed tracks to be made through the reactor area without the influence of discharge. Heretofore, it had been found that fish used the side of the river opposite the reactors exclusively. This year, however, three of the eight fish, released on the north side of the river crossed to the south, reactor side, during their passage and two of the remaining five were released on the south shore and remained there throughout their passage. The final three were released on the north shore and stayed there. Two of the eight fish had been implanted with the newly developed temperature tags. Seven of the fish used were chinook salmon (*Oncorhynchus tshawytscha*) and one was a steelhead trout (*Salmo gairdneri*).

The second series of tracks was made from late September to early October. At this time the reactors were again operating and all seven Chinooks used were implanted with the temperature telemetering tags as the river now offered a temperature challenge to the fish. Difficulty was encountered during this series possibly due to the lateness of the season,

i.e., the fish were those of the end of the fall run and may have been too weak to withstand the trauma of trapping, transportation, implantation, and release in an area they had already negotiated. Two of the fish eventually went down river, one fish moved up the north shore very slowly, one fish died before release, and the remaining three Chinooks remained in the area of release. Although only one track, per se, was obtained it was learned that the new temperature tags were sufficiently sensitive and durable. Further, they can be used successfully in the sonically "noisy" river.

Bionomics of Columbia River Limpets
in Normal and Reactor-Warmed Water*

C. D. Becker and C. C. Coutant

The limpet snail, Fisherola nuttalli (Haldeman) contributes to the biomass of invertebrate organisms forming benthic communities in the Columbia River between Priest Rapids Dam and Richland, Washington. Since the metabolism of poikilothermic invertebrates is regulated by relatively slight changes in ambient temperatures, it may be expected that developmental rates of organisms living in the thermally altered zone below the Hanford reactors will show a detectable response. Observations on the growth and reproduction of Columbia River limpets in 1969-70 were made by collecting samples above and below the heated effluent discharges.

* Supported by Service Assessment Funds

Although temperatures of the mixed water were increased about 0.5 to 2.5 °C, limpet sizes and growth rates at any collecting period did not differ significantly between the two areas (Figure 37). However, development clearly corresponded to normal seasonal changes in water temperatures. Growth of young limpets was most rapid from July to October when temperatures were high (17 to 20 °C). Growth rates stabilized during the fall and winter when temperatures dropped and became minimum (4 to 6 °C), then increased with the warming trend of early spring. All populations sampled exhibited essentially the same growth pattern through the year, but there were some size variations between stations because of habitat peculiarities.

Mature limpets established in laboratory troughs receiving heated river water reproduced successfully. Deposition of egg capsules averaging 6.5 embryos (range: 1 to 12) occurred on rising temperatures in April, May and June during the period of maximum river flows. High mortality occurred among mature limpets following the reproductive period. Thus the Columbia River limpet, an endemic form, has a predominantly 1 year life cycle (as do most other gastropod molluscs) with population abundance peaking in the summer after hatching. Thermal modifications experienced at Hanford appear to be less than the sensitivity of developmental responses of this species, and well below any upper incipient lethal limit.

FIGURE 37. Water Temperatures Above and Below Reactor Discharges and Means of Combined Lengths and Widths (with 95% Confidence Limits) of Limpets (*Fisherola nuttalli*). (Thirty limpets per sample: A = above reactors, B = below reactors).

Gas Bubble Disease of Salmonid Fishes*

M. J. Schneider

The large volume of runoff water which flows down the Columbia River each spring far exceeds the hydraulic capacity of the hydroelectric dams. As a result much of this water is released over the spillways. This falling water entrains air which is subsequently driven into solution in the depths of the plunge basin creating air-supersaturated water downstream. Since the gas can be lost only at the air-water interface, the supersaturated condition persists from the first upriver dam that is spilling to the ocean.

Fish, being gill breathing organisms, are in gas equilibrium with their medium. If the water is supersaturated their tissues become supersaturated and if the level of gas is sufficiently great, the symptoms of gas bubble disease develop. Typically, the symptoms include emboli forming in the circulating blood, blisters and gas pockets forming subcutaneously in the head region and in the membranes between fin rays.

The physiology of the affliction is poorly understood, especially the initial stages of the disease.

The site of formation of the first bubbles is probably the circulating blood. To determine this, 2 yr old rainbow trout (*Salmo gairdneri*) were exposed to gas-supersaturated water and the circulatory system monitored for emboli. The means employed to

monitor the blood is a Doppler Telemetering Flowmeter. The probe of the flowmeter is surgically implanted on the conus arteriosus of the heart. The main result of this work to date is that the individual susceptibility to gas-supersaturated water seems to be highly variable. As a result no statement can yet be made about the level of supersaturation or the length of exposure required for gas emboli formation in the circulating blood.

A second aspect of gas bubble disease physiology that is being studied concerns the mechanism of formation of the subcutaneous blisters in the head region. In an attempt to gain information concerning this process, fish are exposed to gas-supersaturated water until these external symptoms develop. The gas within the blisters is sampled by gas tight syringe and analyzed by gas chromatography. The results of these analyses appear in Table 23. In the table, the source indicates the location of the blister.

TABLE 23. Ratio of Nitrogen to Oxygen in Blisters on Rainbow Trout (*Salmo gairdneri*) Afflicted with Gas Bubble Disease. (Percent saturation of dissolved gas: N₂ = 125.00%, O₂ = 118.27%, water temperature = 10 °C.)

Source	N ₂ :O ₂
Operculum	3.64:1
Periorbital	6.82
Eye, right	6.39
Eye, left	9.00

* Supported by Service Assessment Funds

The results indicate that the disease symptoms are caused by supersaturation of air, not just nitrogen which is so often alleged. The sites where the nitrogen-to-oxygen ratio varies significantly from that of air are also sites of high metabolic activity, e.g., the eye socket. Here the oxygen has been depleted by metabolism of the surrounding tissues. The composition of the gas at the site of passage into the blister is probably very close to that of air.

Studies of Furunculosis and Columnaris Disease in Fishes*

M. P. Fujihara

The incident of exposure (not infection) and infection of the endemic microbial fish diseases (Chondrococcus columnaris and Aeromonas salmonicida) in coarsefishes and adult salmonids was examined during seasonal changes in river temperature.

Furunculosis Disease - Studies on the incidence of furunculosis disease in coarsefishes was continued at Hanford and Wenatchee sites on the Columbia River and at one site on the Snake River. During the last half of FY-1970, the winter temperature increased from 2.8 to 13.3 °C (Table 24). Depending on sampling site, the disease incidence generally decreased through March and/or April, and started to increase during May when temperatures reached 8.3 to 13.3 °C. Incidence of the disease at Hanford (29.6 to 56%), Wenatchee (16.6 to 45.8%) and at one site on

the Snake River (20.7 to 54.3%) was generally the same; the incidence at the Keokuk site (downstream from Wenatchee), however showed a greater increase in disease incidence (17.5 to 69.4%). It is possible that this increase in incidence resulted from the warm water released from the smelting plant in this area.

The increase in 'heavy infection' during the sampling period at Hanford was 1.7 to 22.0%, Wenatchee, 2.0 to 8.3%, Snake River, 0 to 26% and Keokuk 1.8 to 41.7%. Although large numbers of furunculosis organisms were prevalent throughout the winter and summer months (Annual Report, 1969), typical septicemic conditions of active infection were lacking in coarsefishes. It is likely that these fish were immune-carriers of the disease, and that infection in the population was sufficient to cause noticeable mortality.

Columnaris Disease - C. columnaris organisms were isolated from coarsefishes at Hanford and near Wenatchee, Washington, during the initial sampling periods when the seasonal river temperatures were the coolest (2.8 to 3.3 °C). Preliminary data suggest that psychrophilic strains of columnaris are being selected. Psychrophilic strains of C. columnaris have not previously been observed in the Columbia River.

Field sampling at the above sites in 1970 showed a direct correlation between unusually high C. columnaris disease incidence among coarsefishes and the potential for a columnaris epidemic among adult migrating

* Supported by Service Assessment Funds

TABLE 24. Furunculosis Infection Coarsefishes During 1970

Location	Sampling Month	Temp, °C	No. Fish	Disease Incidence	
				Light Inf., (a) %	Heavy Inf., (b) %
Hanford	January	3.3	54	22.4	7.4
	February	5.0	41	41.5	17.0
	March	4.4	44	18.2	4.5
	March	6.1	60	11.6	1.7
	May	8.3	50	32.0	20.0
	May	12.2	50	34.0	22.0
Wenatchee	February	2.8	31	45.1	6.45
	March	2.8	30	13.3	3.3
	April	4.4	51	19.6	2.0
	May	8.9	50	42.0	8.0
	June	12.2	24	37.5	8.3
Keokuk	March	6.7-15.6	57	15.7	1.8
	April	8.3-17.8	49	44.9	4.1
	May	17.2-19.4	50	30.0	34.0
	June	18.9-21.1	43	30.2	30.2
	July	18.9-25.0	36	27.7	41.7
Snake River	January	3.5	18	44.0	0
	March	6.7	29	17.3	3.4
	April	8.3	50	26.0	8.0
	May	13.3	46	28.3	26.0

Arbitrary Definitions

- a. 1 to 50 surface isolates/fish - light infection
 b. >50 surface isolates/fish or 1 or more internal isolate - heavy infection.

salmonids. The average monthly exposure and infection, after the start of the columnaris season, at these two sites was approximately 5.1 and 2%, respectively, during 1965 and 1969 and increased to 19.8% exposure and 5.2% infection at Hanford and 38% exposure and 34% infection at Wenatchee during 1970 (Table 25).

The large number of infected coarsefishes present in fish ladders

during migration of Jack chinook salmon (Table 26), demonstrated that these physical confines were major focal points of C. columnaris cross-infection. The data suggest that repetitive exposure at successive upstream ladder sites contributed to the high disease incidence among migrating salmon. When coarsefishes and salmon were confined in a collection pond (Tables 26 and 27), with considerably lower water volume and

TABLE 25. *Chondrococcus columnaris* Exposure and Infection in Coarsefishes During 1970

Location	Sampling Month	Temp, °C	No. Fish	Percent Exposed(a)	Percent Infected(b)	Percent with Isolates(c)
Hanford	January	3.3	54	3.7	0	3.7
	February	5.0	41	0	0	0
	March	4.4	44	0	0	0
	March	6.1	60	0	0	0
	May	8.3	50	2.0	0	2.0
	May	12.2	50	4.0	0	4.0
	July	20.0	44	27.3	4.5	31.8
	September	20.0	82	29.3	8.5	37.8
	October	16.7	43	30.3	11.6	41.9
Wenatchee	January	(No sampling)				
	February	2.8	31	16.1	0	16.1
	March	2.8	30	3.3	0	3.3
	April	4.4	51	0	0	0
	May	8.9	50	0	0	0
	June	12.2	24	0	0	0
	July	18.9	42	35.6	42.9	78.5
	July	18.3	50	48.0	36.0	84.0
	August	20.6	59	37.0	39.0	76.0
	September	18.3	41	34.1	43.9	78.0
	September	17.5	36	30.2	25.3	55.5
	October	16.7	49	32.7	16.3	49.0
	October	14.5	55	27.2	16.4	43.6

a. 1 to 10 surface isolates/fish - exposed but not infected

b. >10 surface isolates/fish or 1 or more internal isolates/fish - infected

c. Includes exposed and infected fish

TABLE 26. *Chondrococcus columnaris* Exposure and Infection in Coarsefishes and Jack Chinook Salmon

Location	Sampling Date(a)	River Temp, °C	Number Fish	Percent Exposed(b)	Percent Infected(c)	Percent with Isolates(d)
<u>Coarsefishes</u>						
Priest Rapids Ladder	9/23/70	16.6	8	12.5	37.5	50.0
Rocky Reach Ladder	9/9	17.8	12	8.4	41.6	50.0
	10/14	15.6	23	17.3	34.8	52.1
	10/22	15.6	6	16.7	33.3	50.0
Wells Dam Collection Pond	9/11	17.3	28	35.7	60.7	96.4
	9/25	17.3	17	11.8	82.3	94.1
	10/9	15.6	15	0	100.0	100.0
<u>Jack Chinook Salmon</u>						
Priest Rapids Ladder	9/3/70	19.4	12	25.0	50.0	75.0
	9/23	16.6	23	29.7	30.4	60.1
Rocky Reach Ladder	9/9	17.8	4	0	50.0	50.0
	10/7	16.7	7	57.1	28.6	85.7
	10/14	15.6	18	38.9	38.8	77.7
	10/22	15.6	5	20.0	60.0	80.0
Wells Dam Collection Pond	9/11	17.3	12	49.7	33.3	83.0
	9/25	17.3	23	43.5	17.4	60.9
	10/9	15.6	35	3.0	97.0	100.0

a. Coarsefishes and salmon were not sampled at ladders and the collection pond prior to September

b. 1 to 10 surface isolates/fish - exposed but not infected

c. >10 surface isolates/fish or 1 or more internal isolates/fish - infected

d. Includes exposed and infected fish

TABLE 27. Distribution of *C. columnaris* in Water Samples from Priest Rapids and Rocky Reach Ladders, Priest Rapids and Wells Spawning Channels and the Wells Fish Collection Pond

Location	Sampling Date	River Temp, °C	Forebay Isolates/ml	Inlet ^(a) Isolates/ml	Middle ^(a) Isolates/ml	Outlet ^(b) Isolates/ml
<u>Ladders</u>						
Priest Rapids	9/3/70	19.4	0.3	0.28	----	2.8
	9/23	16.6	0.12	0.24	----	1.32
	10/2	17.8	0.04	0.12	----	0.96
Rocky Reach	8/14	18.9	----	----	7.2	----
	8/28	19.4	0.2	----	2.96	1.04
	9/9	17.8	0.12	----	3.0	2.64
	9/26	17.3	0	----	0.65	1.25
	10/7	16.7	0	----	0.76	1.52
<u>Spawning Channels^(c)</u>						
Priest Rapids	10/2	17.8	----	----	----	10.56
Wells	9/11	17.3	----	----	----	5.36
	10/9	15.6	----	----	----	6.56
<u>Collection Pond^(d)</u>						
Wells	10/9	15.6	----	----	----	21.2
a. Approximately 70-75 cfs water b. Approximately 3,000 cfs water c. Approximately 140 cfs water d. Approximately 20 cfs water						

flow than occurs in ladders, infection reached up to 100%. Thus, crowding, whether in fish ladders or a collection pond, increases the hazard of columnaris exposure.

The presence of large numbers of infected coarsefishes and/or salmonids in fish ladders was also indicated by the high distribution of organisms released into the water, and by positive isolates from the forebay of the dams (Table 27). During 1966, forebay water samples were negative (Annual Report, 1966). Prespawning mortality of chinook salmon confined at Priest Rapids was considered normal, but mortality at

Wells spawning channel through September 30 was at least three times higher than during 1969 (personal communication - fisheries biologists).

Studies on the spawning grounds at Okanogan showed evidence of a *C. columnaris* epidemic among spawned but living sockeye salmon. Similar studies at Leavenworth suggested that large numbers of prespawning coho salmon were infected with the disease. As shown in Table 28, sockeye salmon exposure was 18% and infection 57%. The 5% exposure and 6% infection of the Leavenworth Hatchery coho salmon was not anticipated because river temperatures were down to 1.2 °C. The

TABLE 28. Chondrococcus columnaris Exposure and Infection in Sockeye Salmon and Coho Salmon

Location	Sampling Date	Species	River Temp, °C	No. Fish	Percent Exposure ^(a)	Percent Infected ^(b)	Percent with Isolates ^(c)
Okanogan River	10/20/70	Sockeye	10.0	53	18.0	57.0	75.0
Leavenworth, Wenatchee River	10/28	Coho	1.2	83	4.8	6.0	10.8

a. 1 to 10 surface isolates/fish - exposed but not infected

b. >10 surface isolates/fish or 1 or more internal isolates/fish - infected

c. Includes exposed and infected fish

data indirectly suggest that disease incidence during migration in the warmer Columbia River was high before the salmon entered the cold Wenatchee River spawning area.

Estimates of total prespawning mortality from the spawning grounds and spawning channels will be available after tabulation of the data accumulated by the Washington State Fisheries Biologists, Wenatchee, Washington.

Field studies have provided evidence that columnaris disease in the Columbia River has reached a critical stage. A slight change of conditions in the river, in a manner favorable for increased growth of C. columnaris and proliferation of the disease may be sufficient to trigger an epidemic disease situation. Although many factors undoubtedly contributed to the columnaris disease condition in the Columbia River in 1970, the combined stresses of lower than normal river flow and higher river temperatures (1 to 2 °C) were probably the most important contributors. The presence

of higher percentages of infected coarsefishes in ladders implicates these structures as focal points for the transmission of C. columnaris to migrating adult salmonids.

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- EFFECTS OF SHORT RANGE PARTICLE IRRADIATION ON EMBRYOGENESIS OF MARINE TELEOST FISH
- FIXATION AND LONG-TERM ACCUMULATION OF TRITIUM IN AN EXPERIMENTAL AQUATIC ENVIRONMENT

Tritium as tritiated water will be a major contributor to the radioactivity in the effluents from nuclear power plants, and it cannot be removed by conventional technology. Two new research programs were initiated to determine the ultimate concentration in and its effect upon segments of the aquatic food web. Experiments on the aquatic food web have just commenced, and the aquatic ecosystem has been established. In the other groups of experiments, preliminary consideration of data indicates no significant degree of detriment in embryogenesis, as resulting from exposure to levels of 0.01, 0.1 and 1.0 μCi of tritium per milliliter. However, the present effort treats only a portion of the early life stages. Longer term studies will be necessary to investigate the problem fully, to examine first embryonic mitosis (four-cell blastomere stage), and to examine time of reabsorption of yolk sac.

Effects of Short Range Particle
Irradiation and Embryogenesis of
Marine Teleost Fish

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

Most available studies with aquatic organisms are concerned with the effects of acute exposures of radiation. While these data indicate that fish and other aquatic species are relatively radioresistant in comparison with terrestrial mammals,

few pertinent data are available for assessment of the effects of low-level and chronic exposure regimens. Furthermore, in no known situations have similar studies with tritium been conducted with aquatic species. It is agreed, however, that embryonic and larval life stages appear to be more radiosensitive than other ontogenetic forms, indicating that primary emphasis should be placed at this level of organization.

In May 1970, eggs of rainbow trout, *Salmo gairdneri*, were spawned artificially in the laboratory, water hardened, and at 6 hr after fertilization were immersed in 0.01, 0.1 and 1.0 $\mu\text{Ci/ml}$ tritium (biological grade) contaminated spring water. Rearing throughout embryogenesis, 25.5 days at $10.5 \pm 0.5^\circ\text{C}$, was facilitated within a recirculating drip incubation system of 150-liter capacity. Combustion of samples for liquid scintillation counting was accomplished using the Model 300 Tri-carb Sample Oxidizer. Distinction between volatile or body water tritium and nonvolatile or "bound" tritium was emphasized. The effects of each treatment were assessed in terms of the proportions of eggs hatching and the numbers of obviously abnormal larvae produced. Additionally, selected behavioral and physiological tests were applied to detect sub-lethal effect.

Accumulation and Incorporation

A rapid uptake of tritium during the first 1 to 2 days was indicated for all three concentrations; this was followed during the ensuing 23 to 24 days of exposure by maintenance of equilibrium levels. The patterns of uptake for both volatile and bound fractions at the 0.1 $\mu\text{Ci/ml}$ level are illustrated in Figure 38. The "bound" tritium accounts for approximately 20% of the total label in each egg, a level not exceeded as determined over the duration of exposure.

The loss of tritium upon transfer to inactive free-flowing water after

exposure for 20 days at an initial level of 1.0 $\mu\text{Ci/ml}$ is shown in Figure 39. For both volatile and bound fractions, fast and slow components of turnover are indicated. Initially both volatile and bound fractions elute rapidly with estimated half-times of ~ 1.0 , and ~ 2.0 hr, respectively. A slower component of the volatile fraction persists for ~ 17 days, as determined in hatched fry. The slow component of the bound fraction, for comparison, persists at approximately 0.6% of the initial bound equilibrium level at 17 days. Even after 6 months in juveniles there exists a trace but measurable level of this fraction.

FIGURE 38. Accumulation of Tritium in Eggs of *Salmo gairdneri*

FIGURE 39. Retention of Tritium in Eggs of Salmo gairdneri

Irradiation Dose

Autoradiographs were prepared by dipping slides in Ilford K.5 liquid emulsion, exposing for 12 weeks and processing in Kodak D-19b developer. These slides were stained through the emulsion with hematoxylin and eosin. From such techniques it was evident that exposure to tritiated water resulted in essentially a uniform distribution of the isotope in all tissues of the embryo and subse-

quently all tissues and organs of the larvae. No localization within either nuclear or cytoplasmic organelles was demonstrated. A final estimation or prediction of dose will be based on refinement of presently used methods and additionally, of application of cytochemical techniques directed at determining the microdistribution of beta particles within the more sensitive macromolecules of the cell nucleus, specifically nucleic acids.

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compared with body water. Furthermore, it is suggested that under chronic exposure conditions there may occur a greater binding to certain long-lived organic molecules resulting in overall slower turnover rates. Under equilibrium conditions, this could result in higher concentrations than would be predicted from concentrations in water alone. Additionally, the ingestion of food organisms with tritium bound in an organic form may enhance incorporation and hence accumulation, in comparison with absorption of tritium from water alone.

It was then proposed to simulate a chronic exposure situation within an experimental aquatic ecosystem, measure the rates of accumulation in selected aquatic species, and to determine whether enhanced incorporation occurs in tissues and selected subcellular fractions.

For this purpose, an experimental aquatic ecosystem was established

within a 30 ft diameter concrete pond located at the K-East reactor hatchery. The pond was stocked with appropriate segments of the freshwater environment indigenous to the Columbia River inclusive of: sediments, emergent plants, invertebrates and fish.

Commencing July 15, 1970, tritiated water was introduced to the system, with replacement water at a concentration of 1.0 $\mu\text{Ci/liter}$ or 10 mCi/day; this concentration has been maintained for a period of 5 months. Samples of biological material are being analyzed for volatile and nonvolatile or "bound" tritium. Autoradiographic and cytochemical techniques directed at assessment of dose to specific subcellular fractions are being performed. After 8 or 9 months, the system will be maintained on nonactive replacement waters for an additional 6 months to determine the rate of elimination of tritium from the system.

20 days during embryogenesis) and untreated control juvenile (5 months) fish to predation was determined using the method of Bams, 1966. For other groups of tritium-stressed fish, equilibrium loss and thermal death times were determined. A statistically significant difference was not indicated in any of the procedures applied.

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

The few available studies with aquatic organisms have emphasized acute exposures carried out over short durations and have demonstrated that incorporation of tritium into body water occurs at a rate corresponding to a half-time of 15 minutes. However, it is known from studies with mammalian systems, that tritium can be incorporated into organic molecules where it turns over slowly as

The relative performance of tritium-treated (1.0 μ Ci/ml exposure for

[illegible]

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