Department of

OCEANOGRAPHY

SCHOOL OF SCIENCE

OREGON STATE UNIVERSITY

PROGRESS REPORT

Ecological Studies of Radioactivity in the Columbia River Estuary and Adjacent Pacific Ocean

Norman Cutshall,
Principal Investigator

Compiled and Edited by
James E. McCauley

Atomic Energy Commission
Contract AT(45-1) 2227 Task Agreement 12
RLO 2227-T12-10

Reference 71-18

1 July 1970 through 30 June 1971

ECOLOGICAL STUDIES OF RADIOACTIVITY IN THE COLUMBIA RIVER ESTUARY AND ADJACENT PACIFIC OCEAN

Compiled and Edited by

James E. McCauley

Principal Investigator: Norman Cutshall
Co-investigators: Andrew G. Carey, Jr.
James E. McCauley
William G. Pearcy
William C. Renfro
William O. Forster

Department of Oceanography
Oregon State University
Corvallis, Oregon 97331

PROGRESS REPORT
1 July 1970 through 30 June 1971

Submitted to

U.S. Atomic Energy Commission
Contract AT(45-1)2227

Reference 71-18
RLO 2227-T-12-10

July 1971

ACKNOWLEDGMENTS

A major expense in oceanographic research is "time at sea." Operations on the R/V YAQUINA, R/V CAYUSE, R/V PAIUTE, AND R/V SACAJEWEA were funded by several agencies, with the bulk coming from the National Science Foundation and Office of Naval Research. Certain special cruises of radiochemical or radioecological import were funded by the Atomic Energy Commission, as was much of the equipment for radioanalysis and stable element analysis. Support for student research, plus some of the gamma ray spectometry facilities, were provided by the Federal Water Quality Administration. We gratefully acknowledge the role of these agencies in support of the research reported in the following pages.

We also wish to express our thanks to the numerous students and staff who contributed to the preparation of this progress report.

NOTICE

The progress report that follows includes research results ranging from unproved ideas to scientific papers published during the tenure of this contract. The end of the contract year finds several facets of our work in various states of preparation, therefore the reader is cautioned that all except the published papers are subject to revision.

PROFESSIONAL STAFF

Norman Cutshall, Ph.D Research Associate	Principal Investigator Radioecology
Andrew G. Carey, Jr., Ph.D Assistant Professor Of Oceanography	Co-Investigator Benthic Ecology
William O. Forster Assistant Professor of Oceanography	Co-Investigator Radiochemistry
James E. McCauley, Ph.D Associate Professor of Oceanography	Co-Investigator Benthic Ecology
William G. Pearcy, Ph.D. Professor of Oceanography	Co-Investigator Nekton Ecology
William C. Renfro, Ph.D. Assistant Professor of Oceanography	Co-Investigator Radioecology

TECHNICAL STAFF

Norman Farrow Instrument Technician	
Carolyn Kuehlthau, B.S. Assistant in Oceanography	Benthic Ecology
Peter Kalk, B.S. Assistant in Oceanography	Nekton Ecology
Michael Kyte, B.S. Assistant in Oceanography	Benthic Ecology
I. Lauren Larsen, B.S. Research Associate	Gamma Ray Spectrometry
David L. Stein, B.S. Assistant in Oceanography	Nekton Ecology
Gerald Wagner, B.S. Assistant in Oceanography	Atomic Absorption Spectrometry
Julie Weills, B.S. Assistant in Oceanography	Benthic Ecology
Show Wu, B.S. Assistant in Oceanography	Radiochemistry

ECOLOGICAL STUDIES OF RADIOACTIVITY IN THE COLUMBIA RIVER ESTUARY AND ADJACENT PACIFIC OCEAN

TABLE OF CONTENTS

INTRODUCTION

This annual report describes progress in marine radioecological studies under USAEC Contract Number AT(45-1)2227 Task Agreement 12 during the period 1 July 1970 through 30 June 1971. This contract number replaces USAEC Contract Number AT(45-1)1750 which started 1 June 1962. Although the basic report format has not been greatly changed from previous years, a major emphasis is now being given to inclusion of materials that are well along the way toward publication. Papers submitted or accepted for publication during the past year are included in their present form along with reprints of published papers. Research in progress, which has previously been reported in detail, is briefly described without presentation of data. Sections on routine laboratory operations and methodology are much reduced. The thirteen chapters which we have contributed to Bioenvironmental Studies of the Columbia River Estuary and Adjacent Ocean Region (A.T. Pruter and D.L. Alverson, eds.) are not reprinted this year, although some effort has been given to their revision and to the technical problems of getting them published. Hopefully, that book will be published during the next contract period. Consequently, this year's report stresses what has been accomplished somewhat more than what is being accomplished.

The past year has been productive. The reprint/preprint section includes 16 papers. In addition, one Ph.D. and seven master's theses have been completed. Several additional papers are in rough manuscript form, but are not ready for submission to a journal at the time of this report. The final shutdown of the Hanford reactors has stimulated several new research projects which are reflected in the "Research in Progress" section.

Once again we have attempted to categorize our efforts as: Radioecology, Radiobiology, Nekton, and Benthos, although such a classification is somewhat artificial. During the past year our research team and their areas of specialization have been Dr. Cutshall (geochemistry), Dr. Renfro (radiobiology), Dr. Forster (radiochemistry), Dr. Pearcy (nekton ecology), and Drs. Carey and McCauley (benthic ecology). Dr. Cutshall has been responsible for most of the administrative chores and Dr. McCauley has edited this report. Dr. Forster spent two months last summer on the project before returning to the Marine Biological Program at the Puerto Rican Nuclear Center at Mayaguez.

MARINE RADIOECOLOGY AT OREGON STATE UNIVERSITY

CHRONOLOGY

Marine radioecology at OSU began in the early 1960's. In early 1961 Charles Osterberg demonstrated that neutron induced radionuclides from the Hanford plant could be readily measured in marine organisms collected off the Oregon coast. Three Atomic Energy Commission research contracts were soon initiated: Contract AT(45-1)1726, Species Composition and Distribution of Marine Nekton in the Pacific Ocean off Oregon, with Dr. William Pearcy as principal investigator began in September, 1961; In June, 1962, Radioanalysis of Oceanic Organisms in the Pacific Ocean off Oregon, AT(45-1) 1750, was initiated with Dr. Wayne V. Burt as principal investigator and Charles Osterberg as co-investigator; Contract AT(45-1)1758, Ecological and Radioecological Study of the Benthos in the Pacific Ocean off Oregon, began in February, 1963 with Dr. Andrew Carey, Jr. as principal investigator and Drs. McCauley and Osterberg as co-investigators. These three studies comprised a broad marine ecological program with emphasis upon artificial radionuclide cycling. In November, 1964 they were officially combined under the 1750 contract number with Dr. Osterberg as principal investigator. In November, 1970 the contract number was changed to AT(45-1)2227, Task Agreement 12. Since June, 1967 Dr. Osterberg has been on leave from OSU. During this period the program has actively continued with Drs. Forster (1967, 1968), Renfro (1969) and Cutshall (1970) as principal investigators.

PHILOSOPHY

The OSU radioecology program was begun and has continued with three basic tenets:

1. In order to understand the impact that artificial radioactivity may have upon an ecosystem it is necessary to first have a good working knowledge of the mechanics of that ecosystem.

2. Direct determination of radionuclide distribution in an ecosystem is needed in order to test our understanding of the system.

3. Artificial radionuclides themselves provide a most useful tool for learning ecosystem mechanics.

The Columbia River System has thus been considered a "unique natural laboratory for radioecological studies" (1964 proposal). More conventional ecological study of species abundance, distribution, their interactions with one another and with the physico-chemical environment have been facilitated by the presence of radioactive tracers. These principles continue to guide our research.

RESULTS OF THE PROGRAM

Publications resulting from the program have covered a wide range of topics. Together with the papers of other AEC-supported researchers at the University of Washington, the laboratories at Hanford and the US Geological Survey in Portland, Oregon, they embody the great majority of knowledge about the Columbia River System. The list of publications included in this report includes titles on virtually every aspect of the system. In addition, about 400 other Department of Oceanography papers provide a considerable breadth of related knowledge.

Students have provided a considerable resource of manpower and ideas to the program. Forty-one graduate degrees have been awarded to students in or closely associated with the radioecology program. The majority of these are presently employed in oceanographic research with the primary employers being universities and the Federal Government.

RADIOECOLOGY GRADUATES (1962-1971)

MS or MA	PhD
27	14

(2 persons have received 2 degrees)

Present Occupation

Research	Teaching	Military Service	Other or Unknown
24	4	4	7

Present Employer

University or College	Government (Military)	Industry	Other or Unknown
15	11 (4)	4	5

PRESENT AND FUTURE

The last of the production reactors at Hanford was permanently shut down on January 28, 1971. Thus this primary input of radionuclides to the Columbia River System has ceased and radioactive decay plus natural dispersion processes are lowering concentrations of radionuclides. This depletion period is considered one of the most interesting phases in the radionuclide history of the system and efforts in sampling and analysis are presently at a maximum.

Already some interesting observations have been made. As the formerly most abundant nuclides decay, new nuclides are detected. Twelve year ^{152}Eu and 16 year ^{154}Eu are clearly measurable in Columbia River sediment. These nuclides hold considerable promise for further sediment studies and for testing our ideas about sediment-sorbed ^{65}Zn. Short-lived fission products from fallout are becoming more readily visible in gamma-ray spectra. Preliminary measurements of ^{95}Zr-Nb in filtered water and suspended sediments yield provocatively different results than we observed in the early 1960's. Of course, ^{60}Co, with its 5 year half-life is expected to persist at measurable levels for several years. The Trojan nuclear power plant on the Columbia River is not expected to add noticeable quantities of radionuclides to the river although its presence has evoked doubt in some quarters. We expect to analyze samples in the vicinity of the plant.

In the years following shutdown of the Hanford reactors, our program emphasis is expected to change only subtly. As shorter-lived nuclides disappear, our radioecology program will concentrate upon longer-lived nuclides. We expect to continue to emphasize the integration of direct radionuclide measurement in environmental samples with broad ecological studies in the Columbia River, its estuary, and the Northeastern Pacific Ocean.

STABLE ELEMENT ANALYSES

BY Ingvar L. Larsen and J. Wagner

Stable element measurements are made by atomic absorption spectrophotometry, utilizing a Perkin-Elmer model 303 instrument. The recent acquisition of a cadmium lamp has expanded our capability to analyze 23 elements by this method. Zinc was the most frequently analyzed element and accounted for 44 per cent of the total number of analyses. During the 12-month period from July 1970 to June 1971 approximately 9,445 samples of organisms, sediment and water samples were analyzed for various trace elements.

RADIOANALYSIS

by Ingvar L. Larsen

Radionuclides present in samples collected from the marine environment and from laboratory studies are measured by gamma-ray spectrometry. For this purpose, three 12.7 x 12.7 cm NaI (Tl) well-type detectors are used in conjunction with Nuclear Data 512 multichannel analyzers (series 130). In addition to the well-type detectors, a 7.62 x 7.62 cm NaI (Tl) detector is available for counting larger samples. This latter detector can be readily connected to one of the multichannel analyzers when necessary. The well-type crystals are designed for receiving plastic counting tubes holding approximately 12 ml of volume and giving a reproducible geometry.

Data output from the analyzers includes paper punch tape, an X-Y recorder, and typeout of the digital data. Data reduction for spectra containing complex and overlapping photopeaks is accomplished by utilizing a non-linear least squares program in a CDC 3300 computer. For simple spectra containing monoenergetic gamma-emitters such as those of K-40 and Zn-65, a program which corrects for Compton continuum is used. This calculation can be done by a desk calculator or when several samples need to be reduced, and can also be accomplished by the CDC 3300 computer. Samples are compared to standards of known activity and geometry. These standards include the following : $^{56,57,60}Co$, ^{46}Sc, $^{124,125}Sb$, ^{59}Fe, ^{65}Zn, ^{54}Mn, ^{95}Zr-Nb, ^{137}Cs, ^{51}Cr, ^{203}Hg, ^{106}Ru-Rb, ^{144}Ce-Pr, ^{152}Eu, and ^{40}K.

Depending upon the level of activity suspected, samples are counted from 2 to 800 minutes, the shorter time for spiked laboratory studies and longer counting periods for environmental samples. Weekly background determinations of 1,000 minutes duration are made and the appropriate fraction of this background subtracted from the samples.

The analyzers are in nearly continuous operation; 21-22 hours per day, 7 days a week. Time disposition for each analyzer is approximately as follows:

Sample analysis time	0.5
Background and standards measurements . . .	0.1
Instruction usage, data readout calibration, and off time	0.4

During May 1971, one of the 12.7 x 12.7 cm NaI (Tl) well-type detectors exhibited erratic behavior and was discontinued from service.

II. STUDENT PARTICIPATION

We hereby acknowledge the contribution of students who have been associated with the program during the past year. One has earned his doctorate and seven their master's degree. Much of the research has been made possible by the participation of students. Some have written portions of this report or otherwise contributed to research efforts. Some have been supported by AEC funds, some by other federal funds, and a few have been self-supporting. Abstracts of the theses are in the following section.

DOCTOR OF PHILOSOPHY

Gerald A. Bertrand, Jr. — NSF Sea Grant Assistantship

Dr. Bertrand holds a B.S. degree from the University of New Hampshire and an M.S. in zoology from Florida State University. He completed the requirements for the Ph.D. at Oregon State University in December 1970. Mr. Bertrand's doctoral dissertation concerns the effects of seventeen environmental factors on the distribution and abundance of benthic invertebrate infauna on the central Oregon continental shelf. He began duty as a marine ecologist in Washington, D.C., with the U.S. Army Corps of Engineers in February 1971. (Carey)

MASTER OF SCIENCE

John Butler

Mr. Butler received his B.S. from the University of Washington and completed his M.S. at Oregon State University in June 1971. He is currently employed as an assistant in oceanography in the nekton program. (Pearcy)

Ingvar L. Larsen — Research Associate

Mr. Larsen has been in charge of the trace element and radioanalysis labs and is also responsible for data reduction and quality control. He completed his M.S. in December 1970 and continues to work for the radioecology group. (Renfro)

Wen Yuh Lee — Taiwan National Scholar

Mr. Lee has a degree from the National Taiwan University. He completed his M.S. in November 1970 and plans to continue graduate work at Florida State University. (McCauley)

James L. Sumich

Mr. Sumich has a B.S. from the University of Oregon and additional study at the University of Hawaii. He completed his M.S. in August 1970 and is teaching at Grossmont College in San Diego, California. (McCauley)

Harold M. Stanford

Mr. Stanford completed his M.S. in Oct. 1970 and is now employed by Telodyne Isotopes, Inc., Westwood, N.J. (Heath)

Richard T. Tomlinson

Mr. Tomlinson completed his M.S. degree in September 1970 and is now employed as a Research Assistant in Chemical Oceanography at Oregon State University. (Renfro)

Stephen Tonjes — FWQA Trainee

Mr. Tonjes holds a B.A. from the University of Michigan and completed his M.S. in January 1971. He is now an officer in the U.S. Coast Guard (U.S.C.G. RTC, Yorktown, VA 23490) (Renfro)

DOCTORAL CANDIDATES

John Bolen — FWQA Fellowship

Mr. Bolen is completing requirements for his Ph.D. in General Science with a thesis project carried out with the Radioecology Group. His dissertation will be on ^{32}P dynamics in starry flounder of the Columbia River Estuary. He will join the U.S. Atomic Energy Commission in Bethesda, Maryland. (Lyford-Renfro)

Vernon G. Johnson — AEC Graduate Assistant

Following completion of his M.S. degree in 1965, Mr. Johnson worked for four years as a health physicist at the National Reactor Testing Station in Idaho. His thesis research is concerned with the exchange of heavy metals between estuarine water and sediment. (Cutshall)

Margaret S. McFadien — NSF Sea Grant Assistantship

Miss McFadien holds a B.S. from Dickinson College and an M.S. from West Chester State College. She has completed her first year in the Oregon State University Ph.D. program in biological oceanography. Miss McFadien's doctoral dissertation is concerned with sediment reworking and burrowing by invertebrate infauna on the continental shelf, continental slope, and Cascadia Abyssal Plain. A combination of field and laboratory studies will aid in description of burrows, burrowers, and factors influencing the degree and type of burrowing. Miss McFadien is a participant in the annual graduate seminar on animal-sediment interrelationships at the Bermuda Biological Station during the summer of 1971. (Carey)

Janakiram R. Naidu AEC Graduate Assistant

After receiving his M.S. from the University of Washington in 1963, Mr. Naidu worked for six years for the India Atomic Energy Commission. His thesis research concerns the distribution of Zn, Pb, and Hg in hake, *Merluccius productus*, along the west coast of the U.S. (Cutshall)

Henry Vanderploeg AEC Graduate Assistant

Mr. Vanderploeg has his M.S. from the University of Wisconsin. He is working on a model for the uptake of radionuclides, especially as applied to the radioecology of ^{65}Zn in marine benthic fishes. (Pearcy)

MASTER'S CANDIDATES

Carol Bell

Miss Bell is a graduate of Boise State College and is engaged in a study of ^{65}Zn specific activities of Columbia River carp organs. (Renfro)

Jose R. Cañon Chilean National Scholar

Mr. Cañon is here on a fellowship from the government of Chile. He has been working with the Chilean Fisheries Development Institute and is working on an M.S. (McCauley)

David Evans Teaching Assistant

Mr. Evans received a B.S. in Chemistry from UCLA and is currently finishing his thesis research concerning changes in the physical form of Hanford radionuclides upon entering the Columbia River Estuary. (Cutshall)

John Frey NOAA Sea Grant Assistant

Mr. Frey is working on vertical migration and activity patterns of the pink shrimp.

Jay Gile OSU Teaching Assistant

Mr. Gile, a general science student, is looking at Zn, Cu, and Mg in razor clams. He expects to complete his M.S. this summer and will be employed by EPA in Rockville, MD. (Cutshall)

Priscilla J. Harney FWQA Trainee

Miss Harney is a graduate of the University of California, Berkeley, is in the process of completing her M.S. thesis research. Her project concerns the uptake of ^{65}Zn by Alder Slough isopods. She is also engaged in a study of ^{65}Zn and ^{54}Mn turnover rates in freshwater clams. She expects to continue for her Ph.D. degree. (Renfro)

William M. Lenaers FWQA Trainee

Mr. Lenaers holds a B.S. degree in Chemistry from the University of Santa Clara. He is presently investigating the role of organic material in the fixation of ^{65}Zn by Columbia River sediment. He will complete his degree this summer and enter the U.S. Army Chemical Corps as an officer in September 1971. (Cutshall)

Harold Longaker FWQA Trainee

Mr. Longaker is a graduate of the U.S. Naval Academy and spent several years following his navy tour as an electronics engineer. He is now completing a M.S. thesis project which involves the uptake of ^{57}Co by marine phytoplankton. He plans to continue his studies for the Ph.D. (Renfro)

Paul Longueville

Mr. Longueville holds a B.S. degree from LaCrosse University, Wisconsin. He is currently finishing his thesis research concerning pesticide concentrations in marine biota. (Cutshall)

Lynn Tucker McCrow

Mrs. McCrow obtained a B.A. from Oberlin and has done additional study at the Marine Biological Laboratory at Woods Hole, Massachusetts and at the University of New Hampshire. She is investigating the larval dynamics of *Callianassa* in Yaquina Bay. (McCauley)

Ronald C. Scheidt FWQA Trainee

Mr. Scheidt holds an A.B. degree in Chemistry from Fresno State College. Prior to coming to O.S.U., he worked for the U.S. Naval Radiological Defense Laboratory for ten years as a radiochemist. He is presently investigating retention and diffusion of ^{51}Cr in Columbia River sediment. (Cutshall)

Michael Schonzeit NOAA Sea Grant Assistant

Mr. Schonzeit has a B.S. from CCNY, New York and is working on lower trophic levels and oceanographic conditions during the summer of 1969. (Pearcy)

Douglas R. Squires

Mr. Squires is a student in General Science working on the biology of predation by oyster drills in Netarts Bay, Oregon. (Carey)

III. THESES

One student has completed his doctorate and seven the masters degree. Abstracts of these theses are included below and complete copies will be submitted as supplements to this progress report.

A COMPARATIVE STUDY OF THE INFAUNA OF THE CENTRAL OREGON CONTINENTAL SHELF*

by Gerard Adrian Bertrand

Abstract of Ph.D. Thesis

One hundred and sixty 0.1 meter^2 Smith-McIntyre grab samples were taken on the Oregon Continental Shelf at eight seasonal stations between 75 and 450 meters depth. The five replicate grab samples per season per station were analyzed for macrofauna (>1.0 mm). Particular attention was paid to shelled Mollusca, Cumacea, and Ophiuroidea. The samples were analyzed for total species, number of specimens, wet weight, and ash free dry weight. Seventeen environmental parameters were measured at each station at each season.

Results showed no seasonal variation in either the infaunal composition in total species, numbers, or biomass, or in the sediment environmental parameters. The average values for all stations over the year-long study were 597 individuals per meter^2 , 36.5 grams wet weight per meter^2 , and 2.57 grams ash free dry weight per meter^2. These values are lower than those reported for Southern California and for the Northeast coast of the United States.

Four species groups which were the dominant fauna in beach sand, silty sand, sandy silt, and glauconite sand were extracted by R mode factor analysis. The Q mode factor analysis showed two distinct sand communities in glauconite sand and beach sand. The silty sand stations had high loading to two factors while the sandy silt stations had high loading to no factors. A fourth community of organisms was described for the Oregon continental shelf in addition to the three previously described off Washington.

The results of regression analysis on nine major environmental factors showed no meaningful correlation that accounted for more than 39 percent of the total variation. Only seven of the 21 most abundant molluscan species showed meaningful significant correlation to one or more of the environmental variables. This may be an indication of biotic interdependence.

---

* Dr. Andrew G. Carey, Jr., major professor

SWIMBLADDER MORPHOLOGY AND BUOYANCY OF NORTHEASTERN PACIFIC MYCTOPHIDS*

by John Lawton Butler

Abstract of M.S. Thesis

Of the common adult lanternfishes found off Oregon, two species have fat-invested swimbladders (*Stenobrachius leucopsarus* Eigenmann and Eigenmann 1890 and *Stenobrachius nannochir* Gilbert 1891), two species have reduced swimbladders (*Lampanyctus ritteri* Gilbert 1915 and *Lampanyctus regalis* Gilbert 1891), two species have gas-filled swimbladders (*Protomyctophum thompsoni* (Chapman 1944)) and (*Protomyctophum crockeri* (Bolin 1939)). Adult *Diaphus theta* Eigenmann and Eigenmann 1891 and adult *Tarletonbeania crenularis* Jordan and Gilbert 1880), however, have either gas-filled or reduced swimbladders. Small individuals of all the above species have gas-filled swimbladders.

The primary buoyancy mechanism is lipids for large *S. leucopsarus*, *S. nannochir*, *L. ritteri* and *D. theta*, is reduction of dense material for large *L. regalis*, and is gas for all juveniles and for *P. thompsoni*, *P. crockeri* and some adult *T. crenularis* and *D. theta*.

DETERMINATION OF ^{65}Zn SPECIFIC ACTIVITY IN VARIOUS TISSUES OF THE CALIFORNIA SEA MUSSEL, *MYTILUS CALIFORNIANUS***

by Ingvar Lauren Larsen

Abstract of M.S. Thesis

The specific activity of ^{65}Zn (nanocuries ^{65}Zn/g total Zn) was determined in various organs of the common coastal mussel, *Mytilus californianus* Conrad, collected from six locations along the Pacific Coast. These organs included the gills, mantle, foot, reproductive organs, adductor muscle, and viscera. After ashing and dissolving with nitric acid (8 M), each tissue was analyzed for ^{65}Zn by gamma-ray spectrometry. The determination of total zinc concentrations of the various organs was accomplished by atomic absorption spectrophotometry as well as by neutron activation analysis.

---

* Dr. William G. Pearcy, major professor
** Dr. William C. Renfro, major professor

Variable amounts of both stable zinc and radioactive ^{65}Zn were observed within the specific tissues from a given location. The ^{65}Zn specific activities of the tissues of organisms from a particular station however, tended to be uniform, at least within the uncertainty of the measurements. Both radiozinc and ^{65}Zn specific activity decreased with distance from the Columbia River mouth, whereas the stable zinc tended to remain uniform for a specific tissue. Tissues high in radiozinc were also high in stable zinc and conversely.

An estimate of the input specific activity from the mussel's environment (food and/or water) was calculated from a simple model resulting in a value similar to zooplankton values sampled from within the Columbia River plume.

Comparison of the concentrations of zinc determined by neutron activation with those determined by atomic absorption spectrophotometry indicated a linear relationship between the two methods. Results of atomic absorption measurements were approximately 27% larger than the results of neutron activation analysis, indicating the presence of a systematic error. The higher values attained by atomic absorption are attributed to evaporation during storage of the ash solution which would lead to an increase in zinc concentration. In considering the two methods of analysis, economy of both time and expenses favors the atomic absorption method over that of neutron activation.

THE COPEPODS IN A COLLECTION FROM THE SOUTHERN COAST OF OREGON, 1963*

by Wen-Yuh Lee

Abstract of M.S. Thesis

Plankton samples for this present study were collected from an area off the southern Oregon coast, extending westward to about 83 kilometers offshore. Over this sampling area, 41 species of adult copepods were identified, including representatives of 26 genera and 17 families. The total abundance averaged 550/m^3.

Population densities of copepods as a group were found higher inshore than offshore and this distribution was largely determined by four dominant species, that is, *Oithona similis*, *Pseudocalanus minutus*, *Acartia longiremis*, and *Acartia clausi*. They accounted for approximately 81% of the total copepod abundance.

Species diversity had a tendency to increase with distance from the coast. This could be due to the possibilities that the sampling depth was increased offshore, or that the living environment was more stable offshore than inshore.

---

* Dr. James E. McCauley, major professor

Rank-correlation analysis of the four dominant species, fish eggs, copepod nauplii, euphausiids, and *Eucalanus bungii* suggest that the positively correlated category includes several pairs, *Oithona similis* to *Pseudocalanus minutus*, *O. similis* to *Acartia clausi*, *A. longiremis* to *P. minutus*, fish eggs to *O. similis*, *A. longiremis* to *A. clausi*, *O. similis* to copepod nauplii, and fish eggs to copepod nauplii. The negatively correlated category includes three pairs, euphausiids to copepod nauplii, euphausiids to fish eggs, and euphausiids to *O. similis*.

Results from the correlation analysis of the dominant species relative to temperature, salinity, and distance from shore show that no significant relationship was apparent except that the occurrence of *P. minutus* was negatively correlated to distance from shore.

GROWTH OF A SEA URCHIN, *ALLOCENTROTUS FRAGILIS*, AT DIFFERENT DEPTHS OFF THE OREGON COAST*

by James Larry Sumich

Abstract of M.S. Thesis

Allocentrotus fragilis (Jackson) was obtained from six stations at depths of 100 to 1,260 m on the continental shelf and upper slope off Newport, Oregon.

Ages and growth rates of *A. fragilis* were determined by two methods: 1) A procedure was developed to make growth zones of the skeletal test plates visible. Alternating light and dark growth zones were found to be formed semi-annually. The total number of growth zones was used to indicate the urchin's age. 2) Age and growth rate values were also determined from analyses of size-frequency distributions of trawl collections from 200 m. Collections from other depths were not adequate for size-frequency analyses.

Gonad indices of *A. fragilis* from 200 m were used to determine spawning periodicity and frequency. A semi-annual frequency was found, with spawning occurring in early spring and early autumn. No *A. fragilis* specimens collected below 400 m were reproductively mature.

The growth curve of *A. fragilis* from 200 m, which was plotted from the mean test diameter of age groups defined by test plate growth zones, shows a good least-squares fit with von Bertalanffy's growth equation. Growth rates were similar for *A. fragilis* from 100-600 m, but decreased for specimens from 800 and 1260 m. The maximum test diameter decreased with increasing depth below 200 m.

---

* Dr. James E. McCauley, major professor

Variation of magnesium content of the calcareous skeletal plates was due largely to variation with age. Little skeletal Mg variation was found at different depths for specimens of the same age. Greater Mg content differences occurred between young and old specimens from the same depth, and between young and old test plates of the same individual.

The effects of several environmental factors on the growth rate and maximum size of A. fragilis are discussed. Of these factors, food availability, water temperature, and oxygen tension form gradients with depth or distance offshore; and were considered to be important in affecting the growth of A. fragilis.

THE CONCENTRATION AND OXIDATION STATE OF CHROMIUM IN SEA WATER*

by Harold Milford Stanford

Abstract of M.S. Thesis

The partitioning of chromium (III) and chromium (IV) between the dissolved and particulate phases of surface sea water off the coast of Oregon was examined. Independent measurements made on two aliquots of sea water allowed the determination of chromium (VI), and total chromium (the sum of chromium (VI) and any chromium (III)). Chromium (VI) was extracted and concentrated from one aliquot using a methyl isobutyl ketone extraction procedure, after acidification with hydrochloric acid. Total chromium was extracted and concentrated from the second aliquot using a similar procedure, after oxidation of any chromium (III) to chromium (VI) with potassium peroxydisulfate and a copper (II) catalyst. Both filtered and unfiltered samples were examined using these procedures. The chromium content of the ketone extracts was determined using neutron activation analysis.

Mean values for chromium (VI) and total chromium in filtered sea water were determined to be $0.189 \pm 0.102 \mu g/l$ and $0.246 \pm 0.127 \mu g/l$ respectively. For unfiltered sea water, mean values for chromium (VI) and total chromium were found to be $0.156 \pm 0.144 \mu g/l$ and $0.194 \pm 0.186 \mu g/l$, respectively. The precision of the analytical data proved to be poor, due to compounding of counting errors.

At the 68% confidence level, the presence of soluble chromium (III), particulate chromium (III), or particulate chromium (VI) could neither be confirmed nor disproved.

* Dr. Ross G. Heath, major professor. Mr. Stanfords research was only minimally associated with this research contract and the full thesis is not included.

NON-BIOLOGICAL UPTAKE OF ZINC-65 FROM A MARINE NUTRIENT MEDIUM*

by Richard Douglas Tomlinson

Abstract of M.S. Thesis

The nature and magnitude of experimental errors due to ^{65}Zn adsorption by inorganic surfaces was examined in a laboratory system designed to measure ^{65}Zn uptake by marine phytoplankton. In the pH range, 6.3 ±.1 to 7.5 ± .1, a precipitate formed in the algal nutrient medium selected for the system. To this seawater-base medium, zinc was added only as carrier-free ^{65}Zn. The precipitate increased in both volume and tendency for ^{65}Zn uptake as the pH increased. At a pH of 7.5 ± .1, the particles, predominantly orthophosphates, accumulated 70 percent of the ^{65}Zn in the medium in 24 hours. It was therefore concluded that ^{65}Zn adsorption by undetected precipitates could result in serious errors in measurements of ^{65}Zn uptake by marine phytoplankton.

Equilibrium of ^{65}Zn adsorption by Pyrex glass surfaces was attained between .50 and 2.0 hours elapsed time. Found to be negligible at pH levels less than 6.0 ± .1, such uptake was a linear function of the hydrogen ion concentration in the pH range, 6.7 ± .1 to 8.2 ± .1. Pretreatment of the glass surfaces with dimethyldichlorosilane (General Electric "Dry Film") reduced ^{65}Zn adsorption by over 80 percent.

The relationship between percent ^{65}Zn sample adsorption and wetted glass surface area/pipette sample volume was shown to be linear for volumetric pipettes of the size range, 1-15 ml. At a pH of 7.5 ± .1, ^{65}Zn adsorption was negligible for most laboratory glassware, but increased with increased pH. At a pH value of about 8.0, glassware having surface area/sample volume ratios as small as those of 15 and 20 ml volumetric pipettes adsorbed 7 to 11 percent of the contained sample activity. Two prerinses with the sample liquid were required to reduce such errors by a fraction of one half.

ZINC-65 UPTAKE BY A BACTERIUM ISOLATED FROM ALDER SLOUGH, COLUMBIA RIVER ESTUARY**

by Stephen Dodd Tonjes

Abstract of M.S. Thesis

Bacteria were isolated from water at Alder Slough, Oregon. Of 15 isolates grown successfully in the medium employed, 100% showed measurable uptake of Zn-65. A growth curve was established for one isolate, a gram-negative rod designated AS-1. Increasing Zn-65 uptake was found generally

---

* Dr. William C. Renfro, major professor
** Dr. William C. Renfro, major professor

to correspond with increasing growth of AS-1. The optimum growth temperature for this isolate was 31°C, with very little growth at 37.5°C and 6.7°C. Growth and Zn-65 uptake occurred in a 35 ppt medium from a temperature of 31.0°C to 13.9°C but little growth and no Zn-65 uptake was observed at 8.6°C and 4.4°C. Growth and Zn-65 uptake in a 0 ppt medium occurred from 31.0°C to 5.0°C, with little growth but measurable Zn-65 uptake at 8.9°C and 5.0°C.

It was found that 200 ppm Mg added to a culture which had already taken up Zn-65 failed to displace the zinc from the cells. An interaction of the energy source, Casamino Acids, with the Zn-65 spike influenced the results. When cells were lysed, spiked with Zn-65, and the debris removed by centrifugation, 84.8% of the Zn-65 remained in the supernatant. But when cells grown first in Zn-65 spiked medium were lysed and centrifuged, 74.4% of the Zn-65 was found in the debris.

It was concluded that bacterial uptake of Zn-65 and other metal cations must be considered in determining the fates of these materials released into the environment. Chemical adsorption phenomena were determined to be a major factor controlling this uptake, with other chemical and biological factors, such as competitive binding by the medium and active uptake or exclusion by the cells, exerting a significant influence that requires further investigation to characterize.

IV. PAPERS PRESENTED AND MEETINGS ATTENDED

ANDREW G. CAREY, JR.

Zoological Museum, University of Copenhagen, Denmark. Visiting Scientist, March 1-August 31, 1970.

University of Massachusetts, Marine Sciences Program, Amherst, Massachusetts, Tuesday, March 2, 1971. Title: "Ecology of the Sea Floor off Oregon."

U.S. Naval Base, Long Beach, California. Western Beaufort Sea Ecological Cruise 1971 Planning Conference. January 19-21, 1971.

Third National Symposium on Radioecology, Oak Ridge, Tennessee. May 10-12, 1971.

Scripps Institute of Oceanography, Benthic Ecology Group, La Jolla, California. June 18-19, 1971. Title: "Research on Benthic Ecology off Oregon."

AAAS-ASLO-ESA (Pacific Divisions) Meetings, University of California, San Diego. June 21-24, 1971. Title: "A Comparison of Benthic Infaunal Abundance on Two Abyssal Plains in the Northeast Pacific Ocean."

Abstract: The benthic infauna was sampled in the Northeast Pacific Ocean at twelve stations on an east-west transect across Cascadia and Eastern Tufts Abyssal Plains to determine the effects of continental influences and depth. The two plains, separated by the East Pacific Rise, differ in depth, distance from the continental margin, and presumably therefore in the supply of food material available to organisms on the sea floor. Tufts Plain lies to the west; primary production in the overlying water masses and the amount of organic carbon in the surface sediments are lower than for the Cascadia Plain region.

Five benthic ecological zones were distinguished: Cascadia Plain Slope Base, Eastern Cascadia Plain, Cascadia Deep-Sea Channel, Western Cascadia Plain, and Eastern Tufts Plain. These differ in faunal biomass, numerical density, and gross composition of the fauna by phyla. The Slope Base environment supports the most abundant fauna; undoubtedly because of its proximity to the continent. The numerical density of infauna on Eastern Tufts Plain is similar to that on Eastern and Western Cascadia Plain; however, the biomass is significantly lower in the deeper, more distant environment. It is concluded that these differences in the benthic fauna are caused by different levels of food supply.

NORMAN CUTSHALL

Mercury in the Western Environment, February 25-26, 1971. Portland, Oregon.

Northeastern Oregon Nuclear Power Educational Conference, February 16, 1971, Hermiston, Oregon. Oral presentation: "Release of Chemical Additives in Cooling Water" (with Richard S. Caldwell).

Third National Radioecology Conference, May 10-12, 1971, Oak Ridge, Tennessee. Papers presented: "Zinc-65 in Oregon-Washington Shelf Sediments" (with W.C. Renfro, D.W. Evans and V.G. Johnson), "^{65}Zn Specific Activity in *Mytilus californianus* Tissues" (with I.L. Larsen and W.C. Renfro) manuscripts included in this report.

JAMES E. McCAULEY

Northwest Estuarine and Coastal Zone Symposium, Portland, Oregon. October 28-30, 1970.

WILLIAM G. PEARCY

Tuna Conference, Lake Arrowhead, California. October, 1970. (paper presented)

California Cooperative Fisheries Conference. Palm Springs, California. October 1970. (Paper presented)

Symposium on Remote Sensing in Marine Biology and Fishery Resources. College Station, Texas. January 1971. (paper presented)

NASA Annual Scientific Review. Houston, Texas. November 1970. (paper presented)

National Shellfish Association. Seattle, Washington. June 21-22, 1971. (paper presented)

WILLIAM C. RENFRO

Gordon Research Conference on Chemical Oceanography, Santa Barbara, California, 18-22 January 1971.

Third National Symposium on Radioecology, Oak Ridge, Tennessee, 10-12 May 1971. "Seasonal radionuclide inventories in Alder Slough on ecosystem in the Columbia River Estuary." (manuscript included in this report)

Beginning in September 1971, W.C. Renfro will be on a two-year leave of absence from Oregon State to work for the International Atomic Energy Agency at the Laboratory of Marine Radioactivity at Monaco.

V. RESEARCH IN PROGRESS

A. RADIOCHEMISTRY

ZINC-65 SPECIFIC ACTIVITY IN MUSSELS FROM THE OREGON COAST

by Ingvar L. Larsen

With the gradual withdrawal and final termination of the plutonium production reactors at Hanford, Washington, the major contribution of ^{65}Zn to the Columbia River has diminished and finally ceased. Since this radionuclide is widely distributed in marine organisms inhabiting the Oregon Coast, an opportunity arose to study decreasing levels of ^{65}Zn in marine organisms in their natural habitat.

A sampling program was initiated in January of 1971 to collect mussels (*Mytilus californianus*) bi-monthly from Yaquina Head and observe the change in ^{65}Zn specific activity. Samples have been analyzed for both ^{65}Zn and total zinc concentration. Recent values of ^{65}Zn specific activity are approximately an order of magnitude lower than for values of previous years (Larsen, Ingvar L., 1971, M.S. Thesis, OSU).

SORPTION OF RADIONUCLIDES ON SEDIMENT

by D. W. Evans

The fractionation of radionuclides between dissolved and particulate phases is important in determining their fates in aquatic environments. The radionuclides carried down the Columbia River are likely to change their distribution between the dissolved and suspended particulate phases when they experience the new environment of the river's estuary.

Research underway will determine whether the changing conditions of salinity and secondarily of temperature, pH, Eh, and biological activity leads to a net transfer of the gamma-emitting radionuclides Zn-65, Mn-54, Co-60, Cr-51, Sc-46 and Sb-124 from suspended particles to water or vice versa. The experimental approach includes direct mixing of Columbia River water and filtered sea water, leaching of filter collected suspended matter with seawater, transfer of Columbia River bottom sediments to oceanic sites for long-term leaching and surveying of dissolved radionuclide activities at various salinities in the Columbia River Estuary.

SEDIMENT ORGANIC MATTER AND Zn-65 IN SEDIMENT

by W. M. Lenaers

The sediments of the Columbia River form the major reservoir for Zn-65 formerly released from the Hanford reactors. Several modes of Zn-65 fixation by the sediment have been suggested, the most prominent implicating (1) clay minerals, (2) hydrous oxide coatings of Mn and Fe, and (3) organic material and coatings.

The relative quantitative importance of Zn-65 sorption by organic material is being investigated using ultra-violet irradiation to selectively destroy organic material so that this phase of the system can be studied independently of the clay minerals and hydrous oxide coatings.

Zn-65 UPTAKE BY ESTUARINE ISOPODS

by Priscilla Harney

In order to predict how radionuclides will distribute themselves in an ecosystem, it is important to find the major uptake mechanisms of the organisms within it. Some second trophic level organisms, estuarine isopods, are being examined for the important routes of Zn-65 uptake. The routes of uptake under different conditions are being determined with laboratory tracer studies. The conditions include sterilized and non-sterilized systems of sediment and water, and water only.

RADIONUCLIDES IN DETRITUS

by Priscilla Harney and Hank Longaker

To gain further insight into the cycling of radionuclides in an ecosystem, studies are being conducted to determine rates of loss of some radionuclides from certain of their reservoirs. After the shutdown of the Hanford reactor, Alder Slough detritus was gathered, put in net bags and placed in different regions of that area. Differences in the rate of loss of Zn-65 and Cr-51 are observed when the detritus bags are buried in the sediment, placed on the sediment surface or put in the water column.

RADIONUCLIDE RETENTION IN FRESHWATER CLAMS

by Priscilla Harney

The freshwater mollusc, Anodonta, is an ideal biological monitor. It is widely distributed and strongly concentrates Zn-65 and Mn-54, two nuclides commonly found in atomic power plant effluents. It is necessary to determine the biological turnover time of these nuclides in a natural system. Several groups of Anodonta have been transferred from the Columbia River to the Willamette River, and are being counted live monthly. The biological turnover time will be determined by watching the rate of loss of the nuclides with time.

Another group of Anodonta, which has remained in the Columbia River, is also being counted live monthly. The loss rates and turnover times will be compared for the two locations.

Some molluscs from the Willamette River will be transferred to the Columbia River at McNary Reservoir. The uptake of Zn-65 and Mn-54 with time will be observed. Periodic sacrifices will be made, and the specific activities of those molluscs will be compared to that of the sediment, of filtered water, and of the particulate component of the water. From this, the source(s) of radioactivity for Anodonta should be identifiable.

EUROPIUM-152 IN COLUMBIA RIVER SEDIMENT

by V.G. Johnson and R.C. Scheidt

In the course of radioanalysis of sediment cores from the upper Columbia, the persistent presence of a 0.345 MeV photopeak with depth was noted. A half-life determination carried out over a one-year period as well as persistence at depth in cores suggested a half-life of much greater than one year. Energy and half-life considerations pointed strongly to Eu-152 ($T_{1/2}$ 12.4 years). Radiochemical confirmation was made by fluoride precipitation of rare earth carrier from 12 N HCl sediment extract. (On the basis of energy assignment using a low background, high resolution gamma-ray spectrometer; Battelle workers found that Eu-154 as well as Eu-152 was present in sediment below Hanford; personal communication, R.W. Perkins and D. Robertson). Both Eu-152 and 154 standards have been obtained and are now included in our least squares program library. This will permit determination of actual concentrations in sediment cores and in other samples.

The abundance of Eu-152 relative to Zn-65 (approximately 1:3) in upper core sections, suggest that europium should also be detectable, with prior extraction-concentration, in shelf sediment. A scheme for rare earth extraction and concentration from marine sediment is being developed.

CONCENTRATION OF RADIUM-228 BY CALCAREOUS BENTHIC ORGANISMS

by R.C. Scheidt

Considerable data have been published on the uptake of magnesium, strontium and barium by calcitic organisms. However, there is a paucity of information on the distribution and transport of natural radioactive ^{228}Ra within the ecosystem and its concentration by calcareous benthic organisms. The present hypothesis is that calcium carbonate secreting organisms incorporate ^{228}Ra into thin shells or tests by coprecipitation, ion exchange or complex formation.

Southern Oregon beaches contain placer deposits, high in heavy mineral assemblages. The continental shelf in this area is also suspected to contain placer deposits. Since ^{232}Th, the parent of ^{228}Ra, is normally associated with dense minerals, it is expected that ^{228}Ra will be very unevenly distributed on the shelf. Hypothetically, ^{228}Ra diffusing from these deposits into the overlying waters is incorporated **into** the calcium carbonate shells of benthic organisms.

Direct determination of ^{228}Ra, by measurement of its β^- activity, is complicated by the presence of ^{226}Ra. Therefore, ^{228}Ra is usually determined by measuring the activity of its ^{228}Th daughter. This method requires considerable time after the initial radium separation, before the daughter has accumulated in sufficient amount to determine its α activity. A more rapid method for determining ^{228}Ra is being developed using extraction and liquid scintillation counting of 6hr ^{228}Ac. Radium-228 will be measured in shells of calcareous organisms and ^{232}Th (daughters) will be measured in adjacent sediment in order to determine whether or not the organisms reflect sediment radioactivity.

MERCURY AND ZINC IN PACIFIC HAKE

by J.R. Naidu

Pacific hake, collected synoptically from the Columbia River plume have been analyzed for ^{65}Zn specific activity. The same samples are being analyzed for Hg using flameless atomic absorption. By using ^{65}Zn specific activity as an index of exposure to Columbia River water, it should be possible to learn whether or not the river has been a significant Hg source off Oregon. Primary effort during the past year has been given to the Hg analytical technique and to intercalibration on and off the OSU campus.

Water samples from the Columbia River are also being analyzed for total Hg. The samples are filtered through .45 μ Gelman filters and the filtrate is being used for Hg determination. The filter paper will also be tested for Hg content. The method used for the filtered water samples is by extraction with dithizone in chloroform and then a quantitative back extraction is done using 5N hydrochloric acid. An aliquot of this extract is used to determine Hg by the flameless method of the AAS. Another aliquot is being tested for Hg by neutron activation. The results are not yet finalized.

FALLOUT OBSERVATIONS

by V.G. Johnson and R.C. Scheidt

The conspicuous presence of ^{95}Zr-Nb in the $Fe(OH)_3$ precipitates of our 0.45μ filtered water samples from both the upper and lower Columbia has renewed our interest in transport and behavior of fallout radionuclides. Past fallout studies have shown that ^{95}Zr-Nb is predominantly particulate in natural waters. Thus its predominance in filtrates rather than in filters was unexpected. Passage of this nuclide through our membrane filters suggests it is present either in anionic form, as particles smaller than 0.45μ filters can remove, or perhaps as a negatively charged radiocolloid. Whatever its physical and/or chemical form, its current behavior appears to be distinctly different than that observed in the past. For this reason, further characterization of the nature of this apparently "new" type of fallout is underway.

SORPTION OF RADIONUCLIDES ON SEDIMENT: COMPARISON OF FIELD AND LABORATORY PROCESSES

by V.G. Johnson

The seawater releasability of Hanford Co-60 and Zn-65 in Columbia River sediment has been compared with the releasability of lab spiked subsamples of the same sediment. Laboratory uptake variables included effect of uptake contact time on seawater releasability, initial pH of sorptive media, suspended load, and substrate type (river suspensoids as well as fractionated and unfractionated bottom sediment). Results of this study have important implications regarding the use of laboratory tracer studies to simulate the interaction of seawater with sediment-sorbed trace metals as well as radioactive wastes. A manuscript is in preparation.

POST SHUTDOWN RADIONUCLIDE TRANSPORT STUDY

by Vernon G. Johnson

Bottom sediment, especially in the upper river, has been the major sink for most of the Hanford produced radionuclides in the Columbia River system. Although incorporation of radionuclides into bottom deposits via sedimentation is generally treated as depletion, under certain conditions such deposits may act as a source for additional transport or dispersal. The present study was designed to take advantage of the increased sensitivity to the "source function" provided by the final reactor shutdown. That is, in the absence of new input,bottom sediment is the only source of transported Hanford activity.

Supply mechanisms involving bottom deposits can be classed as 1) resuspension or "scour", and 2) dissolution or desorption. To determine the importance of these mechanisms our sampling efforts have been organized into two parts, Upper River and Lower River.

Upper River Bi-weekly water samples are collected below McNary Dam and analyzed for filterable and non-filterable radionuclides. These data will allow us to evaluate and distinguish between scour and dissolution, and, along with discharge data, will permit approximation of net radionuclide removal from McNary Reservoir. Sediment grab and core samples are also being collected in the lower reservoir at monthly intervals for radioanalysis. These measurements are being used to determine loss rate from bottom sediment in the lower reach of the reservoir. Changes in radionuclide concentrations in sediment will provide an additional test for dissolution. That is, if decay corrected radionuclide ratios vary in time, one can infer that dissolution occurs.

Lower River Input rate to the estuary is being determined by a combination of bi-weekly grab samples of water at Harrington Point (RM 21) and Beaver Army Terminal (RM 54) and a daily composited sample from Prescott (Environmental Research Lab, NMFS). Bi-weekly surface and depth integrated water samples (200 liters) are also being collected near the mouth of the estuary at ebb tide. A few of the estuary water samples are filtered for soluble and particulate distribution. With these data, together with previous estimates of radionuclide retention in the estuary (USGS), we hope to estimate post shutdown oceanic supply. (A more refined oceanic input number is needed since we can no longer assume a quasi-steady state). In addition to an oceanic supply term, it is hoped that our estuarine sampling efforts can be used to observe bottom sediment response in the estuary as well as the river to the spring runoff event.

SEAWATER LEACHING OF RADIONUCLIDES FROM SEDIMENT

by Vernon G. Johnson

Study of radionuclide release from lower river sediments is centered around the dynamics of seawater desorption of radionuclides from new sediment laid down during the Spring freshet. The extensive mud flats in Youngs Bay are being studied for this purpose. Youngs Bay is essentially a freshwater environment during high river runoff. As discharge declines, seawater intrusion occurs. Thus fresh sediment laid down on tidal mud flats during high runoff can be expected to release exchangeable ions as the bay is transformed from a fresh water to a saline environment. To test this possibility, surficial sediment (top 1-2 mm) and high-tide salinity samples are being collected from four representative mud flat sites around Youngs Bay. Seawater extractable radionuclides and stable manganese will be determined on these samples. There should be a sharp decline in extractable manganese and/or radionuclides as the salinities increase.

COBALT ASSIMILATION BY MARINE PHYTOPLANKTON

by Hank Longaker

The purpose of this project is i) to determine how much cobalt becomes associated with a marine phytoplankton for a given cobalt concentration in an artificial seawater medium and, ii) to determine how much cobalt is required by a vitamin B_{12} producing marine phytoplankton. Each component of the artificial seawater will be stripped of cobalt by first chelating the cobalt with 1-Nitroso-2-napthol and then extracting the excess 1-Nitroso-2-napthol and the chelated cobalt with chloroform. This chelation and extraction will be done at least twice using cobalt-58 as a tracer to determine the completeness of extraction. The phytoplankton will be grown in batch cultures with varying concentrations of stable cobalt with cobalt-58 being added as a tracer. Following innoculation of a single species of Coccolithophore, the cultures will be sampled at periodic intervals. An aliquot of the sample will be filtered and the cobalt-58 activity on the filter will be determined using a gamma ray spectrometer. This will indicate how much cobalt is associated with the phytoplankton. A Coulter Counter Model B will be used to determine the number of phytoplankton per unit volume of the culture. Comparing the growth rates of the various cultures will determine the levels of cobalt required by the phytoplankton.

B. RADIOBIOLOGY

CYCLING OF RADIONUCLIDES IN THE COLUMBIA RIVER ESTUARY

by William C. Renfro and Norman D. Farrow

Seasonal inventories of ^{65}Zn, ^{51}Cr, and ^{46}Sc in Alder Slough continued at a greatly increased frequency. Begun in 1968, these estimates of the total activities of the radionuclides were carried out in April, July and December. When the last plutonium production reactor at Hanford was shut down in late January 1971 it was decided to carry out the inventories on a biweekly basis. This study should provide much insight into the rates of loss of radionuclides from the sediments, detritus, plants, and animals of this small ecosystem.

Detritus bag experiments were carried out over a second fall-winter-spring season in Alder Slough. These experiments, designed to follow the changes in radioactivity of decaying plant materials, involve anchoring fine mesh nylon bags of chopped vegetation to the slough bottom. Periodically, samples of the decaying material is radioanalyzed to determine changes in the levels of ^{65}Zn, ^{46}Sc, and ^{51}Cr. Results of two such experiments can be seen in Figure 3 of the preprint entitled: "Seasonal radionuclide inventories in Alder Slough, an ecosystem in the Columbia River Estuary," and included below.

Periodic measurement of the specific activity of ^{65}Zn in Alder Slough sediments continued this year. Briefly, this project involves leaching ^{65}Zn and stable Zn atoms from 100-200 g samples of the top cm of sediment using $CuSO_4$ solution. After filtration of the $CuSO_4$ solution, a small volume is taken for total Zn analysis by atomic absorption spectrophotometry and the remainder is evaporated and counted for ^{65}Zn activity. These measurements will permit us to follow the loss of ^{65}Zn from slough sediments over a long period.

Sampling of water, fishes, and crustaceans from three stations in the Columbia River Estuary continued. This program, which began in late 1963, provides an accurate historical record of radionuclide concentrations in the biota of the estuary. With the shutdown of the last important source of neutron activation, radionuclides, the plutonium production reactor, "ecological half-lifes" of a number of radionuclides in several species of animals can now be measured. Ecological half-life, the time required for the specific activity of a radionuclide in an organism to be reduced by one half when radioactivity input to its ecosystem ceases, is an important parameter. In the case of estuarine food webs, it is expected that ecological half life of a radionuclide is at least partially dependent on the trophic level of the organism. In the months ahead it will be possible to examine the relationship of ecological half-lifes to trophic level, size, species, and location.

C. NEKTON ECOLOGY

^{65}Zn SPECIFIC ACTIVITIES OF NERITIC ANIMALS

by William G. Pearcy

During July 1971, on a cooperative cruise between O.S.U. and National Marine Fisheries Service, Seattle, numerous organisms were collected for radioanalysis off the Washington and northern Oregon coasts using a variety of sampling devices from pumps to large universal trawls. Sixty-four samples representing 18 species collected on this cruise are being analyzed for gamma emitting radionuclides and total trace elements. Specific activities of ^{65}Zn calculated to date for samples off the mouth of the Columbia River indicate the following ranking (from high to low):

Copepods
Thysanoessa spinifera
Parophrys vetulus
Glytocephalus zachirus
Isopsetta isolepis
Thalichthys pacifica
Microstomus pacificus
Eopsetta jordani
Medusae (*Chrysaora*)
Citharichthys sordidus
Sebastodes entomelas
Merluccius productus
Atheresthes stomias

Thus most fishes have a higher specific activity than hake, *Merluccius productus*, probably because the hake are migratory and had just moved into these waters, whereas most other species are year-around residents. In general, highest specific activities are expected and were found in lower trophic levels. Radioanalysis of stomach contents should help to determine feeding habits of some of these fishes.

D. BENTHOS

BENTHIC ECOLOGY AND RADIOECOLOGY

by A.G. Carey, Jr.

On-going AEC research is in four main areas: (1) radioecology of benthic fauna on the continental shelf adjacent to the Columbia River, (2) ecology of macro-epifauna on Cascadia Abyssal Plain, (3) a detailed statistical analysis of all radioecological data accumulated to date, and (4) systematic and ecological studies of selected animal groups.

(1) During the past contract year the large epibenthic fauna have been sampled on the continental shelf off northern Oregon and southern Washington on three cruises undertaken in cooperation with Drs. Renfro and Cutshall. The objective of these integrated studies is primarily to determine the budget of ^{65}Zn in the marine environment in the sediments and to determine the relationship of ^{65}Zn specific activity in the benthic fauna to that in the sediments. Common species of benthic invertebrates have been sampled at four stations on each of four transects across the continental shelf from Tillamook Head to the south of the Columbia to the Raft River to the north. We are continuing to occupy these stations and radioanalyze the samples to determine the rate of decline of ^{65}Zn in the fauna as the levels in the environment decrease owing to the shut-down of the plutonium production reactors at Hanford. A variety of ecological types of abundant fauna have been radioanalyzed for gamma-emmitters and analyzed for stable zinc for computation of specific activities at varying distances from the river and varying depths across the continental shelf.

(2) The ecology of macro-epifauna on Cascadia Abyssal Plain has been under study (see Figure 1) to determine the effects of various features of the environment on the abundance and species and ecological composition of the fauna. Paired quantitative beam trawl samples taken with a 1/2" stretch mesh net have been obtained and are undergoing sorting, identification, and quantification in the laboratory. Of particular interest is the effect of distance from shore and from the Columbia River on the abundance of fauna; these factors influence the supply of organic food material to the benthic environment.

(3) All benthic fauna radioecological data collected to date are being summarized and analyzed statistically with the assistance of Dr. Roger Peterson of the Oregon State University Statistics Department and Dr. Lynn Scheurman of the OSU Computer Center. Approximately two thirds of the data are on file on magnetic tape in the computer system, the remainder are in the process of being coded and entered. The data including rare species and radioisotopes will first be summarized by presence or absence of the radioelements to determine the effects of species, ecological type, depth distance, season, and year on the distribution pattern of radioisotopes. Then the abundant data on the more common species will be analyzed in more detail by pCi of the detected radioisotopes per gram ash-free dry weight and by ^{65}Zn specific activity.

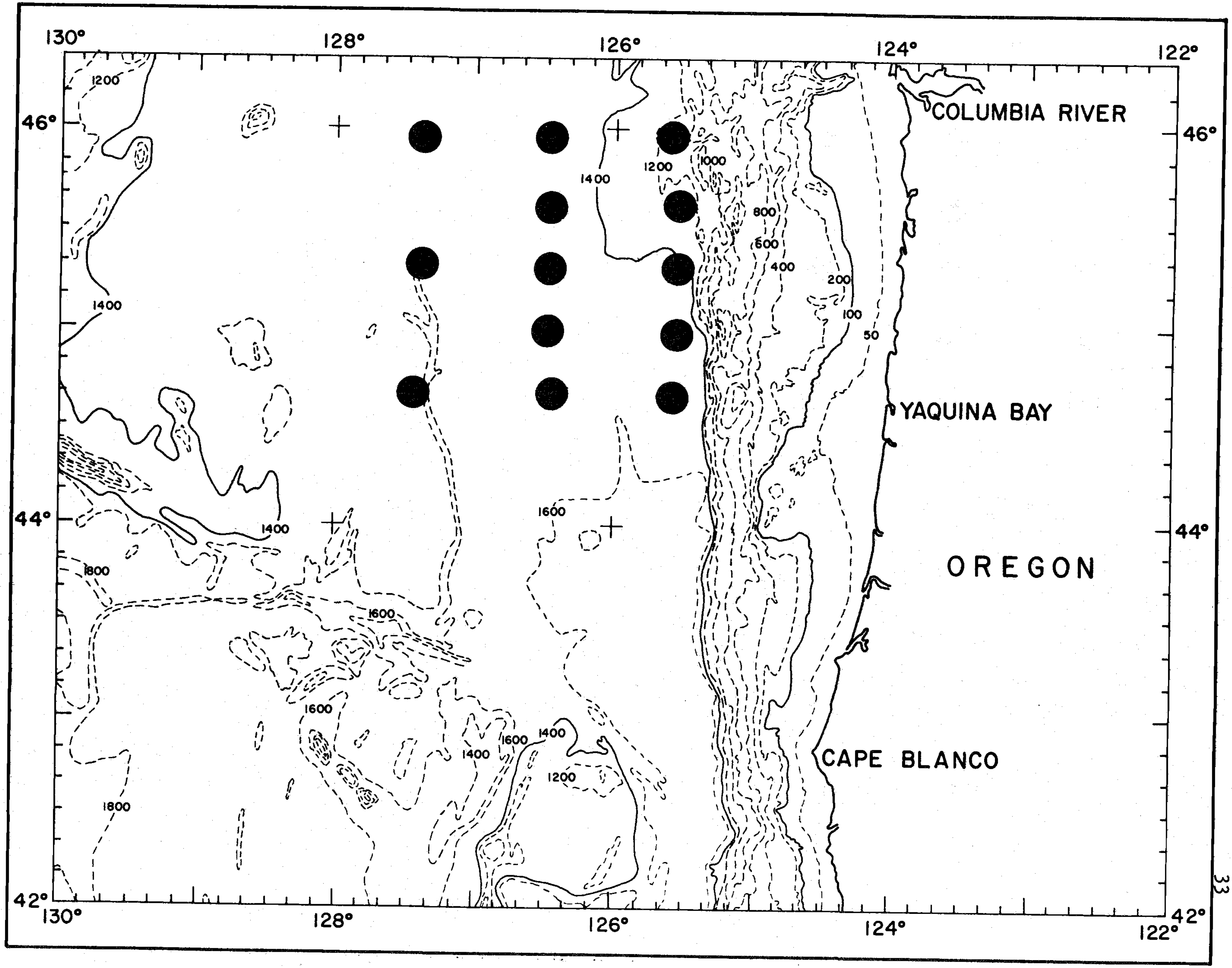


Figure 1 The three north-south Cascadia Plain Station lines occupied while undertaking an ecological study of the macro-epifauna.

(4) A variety of studies on the fauna have been underway during this period of the systematics of various fauna groups and on summarizing ecological and biological features of several taxa. Two papers on ophiuroid (brittle star) systematics are included in this progress report (Kyte), and one of the ecological aspects of opiuroids distributions is underway (Carey and Kyte). Other papers in progress include the following topics: reproduction of an abyssal holothurian (Hufford, Carey, and Pearse), an introduction to the central Oregon infauna on the Newport Transect (Carey), infaunal communities on the central Oregon continental shelf (Bertrand and Carey), and the galatheid crabs off Oregon (Weills and McCauley).

CALLIANASSA CALIFORNIENSIS IN YAQUINA BAY, OREGON

by Lynne T. McCrow

The life cycle of *Callianassa californiensis* Dana, 1854 has been studied in the estuary of the Yaquina River. At this latitude it is largely restricted to intertidal sandy mud flats under predominantly marine influence. Salinity and temperature appear to determine its distribution to a greater extent than does sediment type. Vertical movement within the sediment is related to the tides on a day to day basis and to temperature on a seasonal basis. Large-scale breeding generally begins in the spring, and ovigerous females may be plentiful in the cooler layers of the mud until August. It is not clear what triggers larval release, but temperature and tidal conditions seem to be important. All five zoeal stages are found in the plankton from the mouth of the bay to three miles offshore during late spring and summer. Nearshore waters appear to act as a larval reservoir along this part of the coast, and successful larval settlement may depend upon high tide transport into the bay.

A master's thesis is nearing completion on this work.

V. RESEARCH COMPLETED

NON-BIOLOGICAL UPTAKE OF ZINC-65 FROM A MARINE ALGAL NUTRIENT MEDIUM

by Richard D. Tomlinson and William C. Renfro

ABSTRACT

The nature and magnitude of experimental errors due to ^{65}Zn adsorption on inorganic surfaces were examined in a laboratory system designed to measure ^{65}Zn uptake by marine phytoplankton. In the pH range, 6.3 to 7.5, a precipitate formed in the algal nutrient medium and accumulated up to 70% of the ^{65}Zn in the medium within 24 hours. It was concluded that ^{65}Zn adsorption by undetected precipitates could result in serious errors in measurements of ^{65}Zn uptake by marine phytoplankton.

The relationship between percent ^{65}Zn sample adsorption and wetted glass surface area/pipette sample volume was shown to be linear for volumetric pipettes of 1-15 ml. At a pH value of 8.0, glassware with surface area/sample volume ratios as small as those of a 20 ml volumetric pipettes adsorbed 7-11% of the contained sample activity. Use of polypropylene apparatus reduced zinc adsorption during experimental transfers.

INTRODUCTION

Laboratory studies of ^{65}Zn uptake by marine algae have generally shown large zinc concentration factors, where concentration factor is counts min $^{-1}$g^{-1} fresh tissue/counts min $^{-1}$ml^{-1} medium. Gutknecht (1965) observed concentration factors of 30 to 3,300 for ^{65}Zn accumulated by nine species of seaweed. On a tissue volume basis, Chipman, Rice *et al*. (1958) found a ^{65}Zn concentration factor of 5×10^4 in cultures of the marine diatom, *Nitzschia closterium*. Through the use of carrier-free ^{65}Zn, they obtained evidence that cell surface adsorption accounted for most of the zinc uptake.

Adsorption of zinc from algal culture media is not restricted to tissue surfaces alone. The formation of precipitates in artificial nutrient media may also contribute to the adsorptive uptake of zinc from solution. Nutrient media frequently contain abnormally high levels of nutrients in comparison to the natural environment (Fogg, 1966). Although chelating agents such as sodium ethylenediamine tetraacetate (Na_2EDTA) are often added to help maintain these nutrients in solution, various workers (Chipman, Rice *et al*., 1958; Polikarpov, 1966; Bernhard and Zattera, 1967) have indicated that EDTA renders zinc less available for algal uptake. Therefore, any serious attempt to duplicate environmental conditions for the study of zinc

---

To be submitted to Environmental Science and Technology.

RLO-2227-T12-9

uptake rates in the laboratory must use environmental zinc concentrations and avoid the addition of chelating agents to the artificial nutrient medium. Unfortunately, omission of the chelator may engender chemical precipitation, resulting in an increase of inorganic surfaces available for adsorption of metallic cations such as zinc.

There has been some concern that laboratory glassware might adsorb significant amounts of ionic zinc. Adsorption of zinc by glass surfaces has generally been found negligible by workers using ^{65}Zn as a tracer in relatively large containers such as 125 ml Pyrex glass bottles (Schutz and Turekian, 1965) and 250 ml Pyrex glass bottles (Robertson, 1968). However, it has not previously been determined whether adsorption is significant when aqueous media having oceanic zinc concentrations are transferred to containers with high surface area to volume ratios, such as pipettes.

The work presented here represents an attempt to evaluate the extent of non-biological uptake of ^{65}Zn from a marine algal nutrient medium and the consequent effect on the accuracy of a common method of measuring zinc uptake by marine phytoplankton.

METHODS AND MATERIALS

Algal Nutrient Medium

The algal nutrient medium used in these studies was similar to that first characterized by Davis and Ukeles (1961). The only alterations made in the original nutrient concentrations were the elimination of Na_2EDTA and $ZnSO_4$, and the reduction of the $FeCl_3$ concentration from 6.88 mg/l to 1.28 mg/l. The medium base consisted of seawater filtered through a 0.45 μ pore membrane filter. In all experiments, sufficient carrier-free ^{65}Zn was added to the medium to give an initial activity of approximately 4μCi ^{65}Zn/l. Table I lists the final concentrations of the various chemical components added to the seawater base, for which the concentration of total zinc was determined by atomic absorption spectrometry to be 12.4 ± 0.6 μg/l at one standard deviation.

Physicochemistry of the Nutrient Medium Precipitate

When the newly made algal nutrient medium was exposed to air, an increase in pH from 6.3 ± 0.1 to 7.5 ± 0.1 was observed. This change in pH was accompanied by the formation of a flocculent precipitate. Because the extent of ^{65}Zn adsorption was found to be dependent on the pH of the medium, the effect of the pH on the physicochemical nature of the precipitate was also examined. For this purpose, four 2-liter Pyrex glass beakers were filled with freshly made non-radioactive nutrient medium and sealed tightly to permit the adjustment of the pH to four values held constant throughout the experiment: 6.3 ± 0.1, 6.7 ± 0.1, 7.1 ± 0.1, and 7.5 ± 0.1.

Table I. Algal Nutrient Medium

Component	Concentration	
	Davis Medium	* Modified Davis Medium
KH_2PO_4	200 mg/l	200 mg/l
Thiamine HCl	.2 mg/l	.2 mg/l
Biotin	1.0 μg/l	1.0 μg/l
Vitamin B_{12}	2.0 μg/l	2.0 μg/l
Na_2EDTA	7.3 mg/l	---
$FeCl_3$	6.88mg/l	1.28mg/l
$NaNO_3$	150 mg/l	150 mg/l
$CuCl_2 \cdot 5H_2O$	19.5 μg/l	19.5 μg/l
$ZnSO_4 \cdot 7H_2O$	44.0 μg/l	---
$CoCl_2 \cdot 6H_2O$	22.0 μg/l	22.0 μg/l
$MnCl_2 \cdot 4H_2O$	360 μg/l	360 μg/l
$(NH_4)_2MoO_4$	12.5 μg/l	12.5 μg/l
NH Cl	25 mg/l	25 mg/l

* Medium base: seawater filtered through a .45 μ pore membrane filter.

The set pH values were initially attained by bubbling air or pure CO_2 through the medium.

Homogeneity of the suspended solids was maintained by continuous stirring. Samples were withdrawn through small, otherwise-stoppered ports in the vessel lids. The relative volume of precipitate in the sample containers was determined by centrifuging 50 ml samples and transferring the solid portions to capillary tubes which had been sealed at one end and calibrated with mercury at successive 1 μl intervals. The capillary tubes were then centrifuged again, at 1,500 rpm for 10 minutes, and their relative packed volumes were recorded. The precipitate formed at a pH of 7.5 ± 0.1 was analyzed for chemical composition using a variety of methods which are listed with the accompanying results in Table II. Prior to analysis, the precipitate was collected by filtration, washed with deionized distilled water, and dried at 110°C.

Zinc-65 Uptake studies: Adsorption by the Nutrient Medium Precipitate

The uptake of ^{65}Zn by the nutrient medium precipitate was studied using four 1.5-liter cultures having initial pH values of 6.3 ± 0.1, 6.7 ± 0.1, 7.1 ± 0.1, and 7.5 ± 0.1. The medium was spiked with ^{65}Zn and kept in sealed containers. The pH of each was monitored throughout the experiment.

For each sampling period, the radioactivity associated with the precipitate was calculated as the difference in ^{65}Zn activity measured for equal volumes of the homogeneous medium and its centrifugate. To minimize loss of ^{65}Zn through adsorption to the equipment, polypropylene centrifuge tubes and radioanalysis counting tubes were used. Pipetting was done with a 500μl Eppendorf push-bottom microliter pipette with disposable polypropylene tips (Brinkmann Instruments, Westbury, N.Y.). Adsorption of ^{65}Zn to the polypropylene surfaces in each case was found by direct measurement to be less than 1% of the contained sample. The accuracy of the pipette was given by the manufacturer as ± 0.3% at three standard deviations.

All samples were radioanalyzed in a 13 cm x 13 cm NaI(Tl) well crystal coupled to a Nuclear Data Series 130 multichannel analyzer.

Zinc-65 Uptake Studies: Adsorption by Laboratory Glassware

Adsorptive uptake of ^{65}Zn by Pyrex volumetric pipettes was measured indirectly by determination of the decrease in the value of nCi ^{65}Zn/g solution, from the stock solution to the pipetted sample. The value of nCi ^{65}Zn/g for the stock solution was established as an average for seven decay-corrected standards taken over a period of several days. Losses of ^{65}Zn through adsorption to the walls of the stock solution container were found to be negligible. The standards were individually dipped out of the

Table II. Qualitative and quantitative analysis of the algal nutrient medium precipitate.

A) Physical characteristics of the precipitate as a function of pH

pH	Relative packed volume (μl ppt/50 ml suspension)	Color	Consistency	Crystalline structure
6.3 ± .1	1.5	red-brown	gelatinous	---
6.7 ± .1	2.0	red-brown	gelatinous	---
7.1 ± .1	4.0	orange-brown	gelatinous to particulate	---
7.5 ± .1	4.0	yellow-brown	particulate	amorphous

B) Chemical composition of precipitate formed at pH = 7.5 ± .1

Component	Percent (by weight) of total precipitate	Method of Analysis
PO_4^{3+} - P	54.3 ± 3.3 †	*spectrophotometry
Ca	14.4 ± 1.4	**AAS
Mg	6.8 ± .3	AAS
Fe	1.7 ± .1	AAS
Zn	.2 ± .01	AAS
Mn	not detectable	AAS
Unknown	22.6 ± 5.1	

* Strickland and Parsons (1965)
** Atomic Absorption Spectrometry
† All error values represent estimates at one standard deviation

stock container using a polypropylene tube, and poured into a preweighed second tube. This aliquot was then weighed and radioanalyzed, the volume having been adjusted to standardize the counting geometry. The samples were pipetted into preweighed polypropylene counting tubes, weighed and radioanalyzed. In each case, the sample liquid was not allowed to rise above the volume mark on the pipette, so that only the surface area associated with the sample volume was involved in the adsorptive uptake process. The pH of the stock solution was 8.0 ± 0.1. It was stirred throughout the experiment. For comparison of adsorptive potential, the geometric inner surface area of each pipette was approximated as a combination of cylinders and cones.

RESULTS AND DISCUSSION

Physicochemistry of the Nutrient Medium Precipitate

The results of the qualitative and quantitative examinations of the algal nutrient medium precipitate are summarized in Table II. The precipitate consisted primarily of orthophosphates. On the basis of its composition, low solubility, amorphous form and white color, calcium orthophosphate ($Ca_3(PO_4)_2$) is one possible constituent. The ferric ion was apparently responsible for giving the precipitate its red-brown to yellow-brown color, since the particles were found to be white when $FeCl_3$ was not added. The color and consistency suggest that an iron compound, perhaps hydrated ferric oxide, predominates at pH values of 6.3 to 6.7.

The concentration of added nutrients in algal nutrient media is generally planned according to desired culture densities (Fogg, 1966). For some purposes, then, it may be possible to avoid precipitation by using lower nutrient concentrations such as those specified for Chu medium no. 10 (Chu, 1942). High levels of phosphate are not unique to the modified Davis medium used in the present studies, but seem to be relatively common in many nutrient media used for algal culture. Accordingly, the utility of these observations is not strictly limited to the single medium used in this study.

Figure 1 completes the picture of the role of the nutrient medium precipitate in ^{65}Zn adsorption. Figure 1 (a) indicates that precipitation in the medium at pH = 6.3 ± 0.1 results in very little depletion of soluble zinc levels. However, in an open container the pH of the nutrient medium rose to a value near 7.5 in a relatively short period of time. Table II shows that the relative packed volume of the precipitate increased by a factor of 2.7 between pH values of 6.3 and 7.5. Simultaneously, the physicochemical nature of the precipitate changed and its capacity to absorb ^{65}Zn increased. In an open culture of the yellow-green alga, <u>Isochrysis galbana</u>, pH values remained within the range 7.5 ± 0.1 from inoculation to senescence.

Figure 1 shows an increase in adsorption of ^{65}Zn by the precipitate, with increases in pH over the range, 6.3 ± 0.1 to 7.5 ± 0.1. These are initial pH values in each case. The plots of pH vs time in each figure give pH changes in the closed containers due to addition of the ^{65}Zn in acidic solution at time zero. The decrease in pH seen in Figure 1 (c-d) gives evidence that the associated measurements of the particulate fraction ^{65}Zn activity are conservative in comparison to projected results for ^{65}Zn uptake at a constant pH equal to the initial value. Even so, the culture having an initial pH of 7.5 ± 0.1 shows an equilibrium adsorption level of about 70% of the added ^{65}Zn (Figure 1(d)). The pH of this medium is near that of the growing culture of _Isochrysis galbana_. It is clear that such a precipitate can compete with a marine alga in the accumulation of zinc from an aqueous medium.

Using similar levels of zinc, i.e., 10 µg/l, Boroughs, Chipman (1957) found that the marine diatom, _Nitzschia closterium_, removed nearly 90% of the zinc from a culture in four hours. At a pH of 7.5 ± 0.1, the present studies show that a nutrient medium precipitate is capable of taking up over 50% of the zinc in the same length of time. This comparison is somewhat limited, due to lack of pH and particle density data for the alga, but it is not unreasonable to suggest that the precipitate and the alga could be present in a single culture, each accumulating zinc. Under such conditions considerable error could result from the assumption that loss of zinc from the solution was due to uptake by the alga alone.

Zinc-65 Uptake Studies: Adsorption by Laboratory Glassware

Two relationships were examined--adsorbed ^{65}Zn activity vs geometric glass surface area exposed to the ^{65}Zn solution, and percent sample adsorption vs exposed glass surface area/pipette volume (Figure 2). In each case the linear relationship between the two parameters was obtained by the method of least squares, with no attempt to force the line through zero. The low correlation of values of percent sample adsorption with measurements of glass surface area/pipette volume, and the failure of this plot to intercept the theoretical value of zero was attributed to the varied adsorptive history of the pipettes. To give this experiment a practical aspect, these pipettes were chosen at random from a stock of previously used laboratory equipment. They were prepared by rinsing with 6 N HCl, distilled deionized water and acetone. Figure 2(b) indicates that this treatment, a common glassware cleaning technique, was inadequate to remove previously adsorbed substances from the glass surfaces.

The relationships depicted on Figure 2 were reexamined by pretreating a similar set of pipettes with dilute HF prior to exposure to the radioactive solution. Tomlinson (1970) showed that pretreatment of Pyrex glass surfaces with .3N HF had no significant effect on the time required to establish equilibrium of zinc uptake from solution. Quantitatively, however, the equilibrium level of adsorbed zinc was increased by a factor of five under these conditions. The Pyrex glass surfaces used in his experiments had not previously been exposed to an aqueous medium.

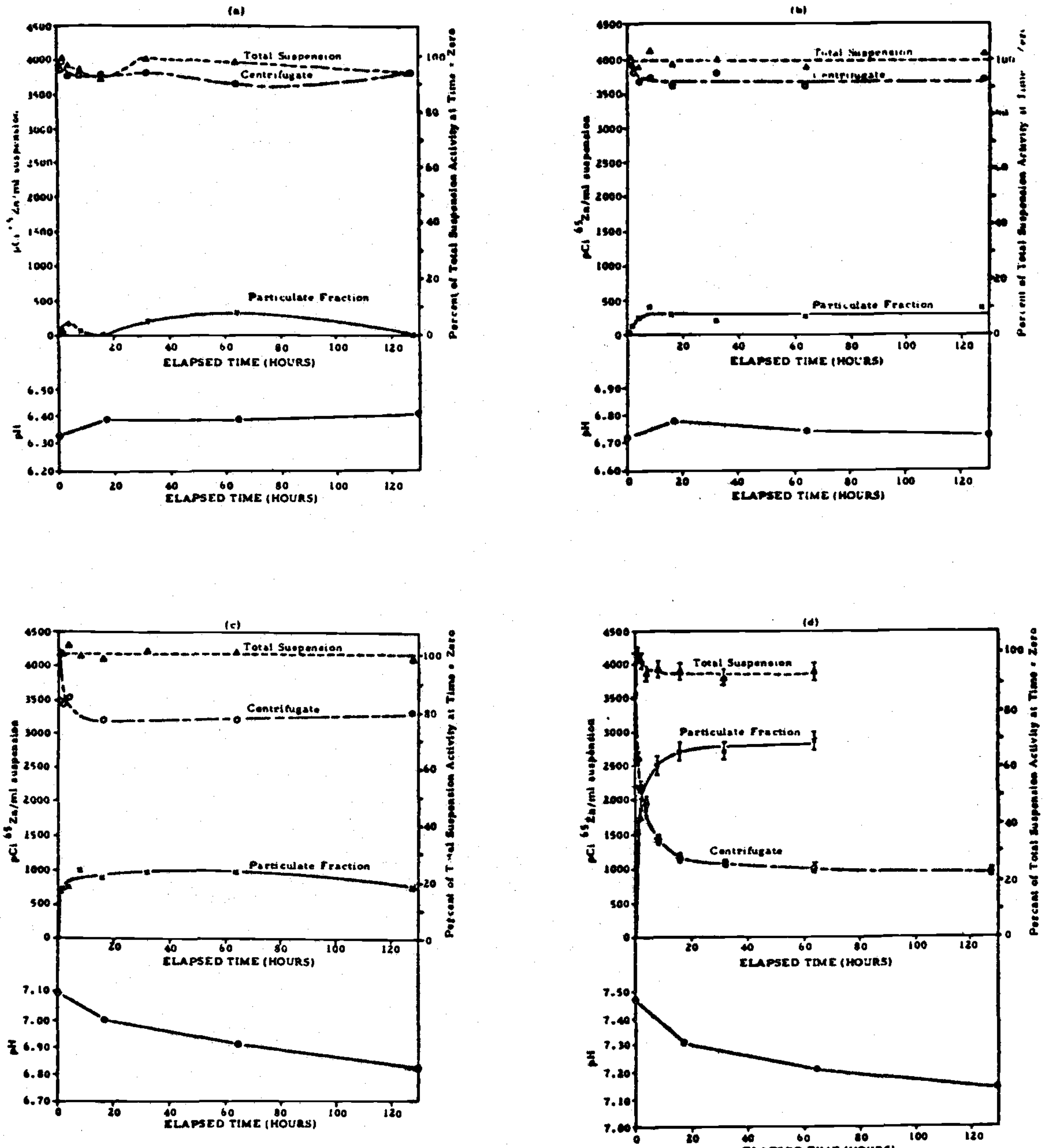


Figure 1 The zinc-65 activity of the total suspension, the centrifugate and the particulate fraction at four pH levels as a function of time. The pH of each culture is also shown as a function of time. The error brackets around the values in part (d) represent a range of $\pm$ three standard deviations of the mean, weighted according to the inverse of the individual sample variances (Harley, 1967)

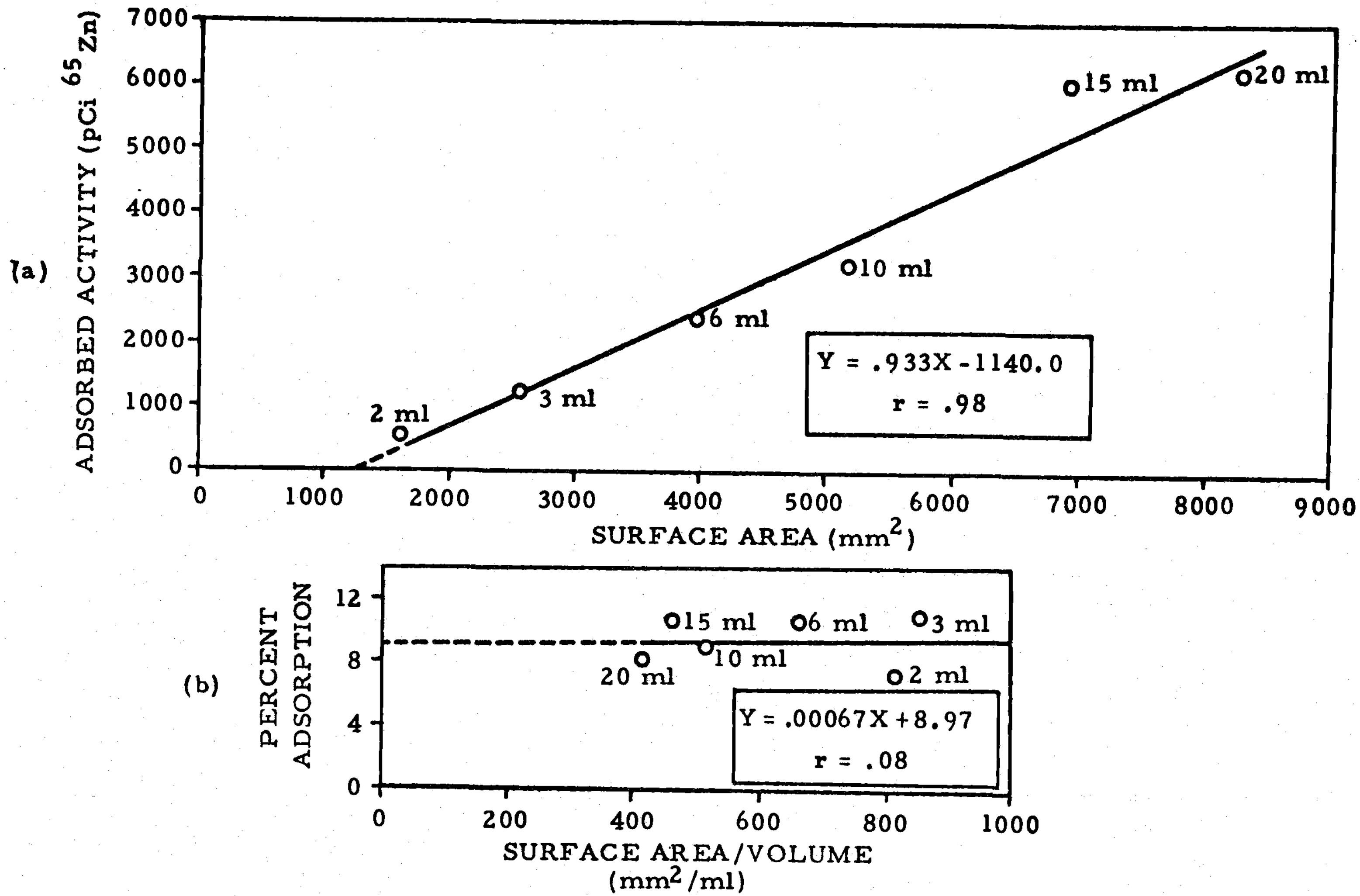


Figure 2 Zinc-65 uptake by acetone-pretreated Pyrex volumetric pipettes.
(a) Zinc-65 uptake as a function of exposed glass surface area.
(b) Percent adsorption of ^{65}Zn in the contained sample as a function of pipette surface area/sample volume.

The effect of pretreatment of the pipettes with dilute HF may be seen in a comparison of the results of this experiment (Figure 3) with the results previously examined (Figure 2).

With respect to adsorptive uptake of zinc by Pyrex volumetric pipettes, the following observations can be made on the basis of data presented in Figures 2 and 3:

1) HF pretreatment of previously used pipettes helped to eliminate individual pipette surface variations (arising from varied adsorption histories) and permitted collection of adsorption data on a standard basis (Figure 3). For each of the two ar relationships examined, adsorbed ^{65}Zn activity vs glass surface area and percent sample adsorption vs glass surface area/sample volume, HF pretreatment increased the correlation of X-Y values (in comparison to acetone pretreatment) and placed the Y-intercept nearer to the theoretical zero value.
2) For the conditions used (12 μg total zinc/l, pH = 8.0 ± 0.1), zinc adsorption by previously used pipettes of the size range, 2 ml to 20 ml, amounts to 7-11% of the zinc in the contained sample [Figure 2(b)].
3) The relationship, percent sample adsorption vs glass surface area/sample volume, is confirmed as linear for the range of values tested, with a Y-intercept at or near zero [Figure 3(b)]. In this light, sample volume is directly proportional to total available zinc. Zinc adsorption by borosilicate glass is therefore shown to be a function of the available zinc and the glass surface area contacted by the liquid.

From a practical viewpoint, these results show that zinc adsorption from a seawater medium is negligible for glass laboratory apparatus having a low surface area to volume ratio. This includes large beakers, flasks, graduated cylinders, etc. This observation agrees with the results obtained by Robertson (1968) for 200 ml Pyrex glass bottles. However, adsorption of zinc by small glassware such as pipettes may result in serious error. At a pH of 7.6, which was the average value measured for the growing algal culture of Isochrysis galbana, zinc adsorption by the 10 ml pipette in Figure 2(b), for which the pH was 8.0, would amount to only about 2%. This can be determined by examination of the linear pH-adsorption relationship outlined by Tomlinson (1970). For smaller pipettes this error would be potentially larger, and would increase for all Pyrex glassware with an increase in pH. At natural oceanic pH values of about 8.0, zinc adsorption errors may be of the order of 7-11% for even relatively large pipettes. Such errors can be reduced considerably by a minimum of two pre-rinses with the sample liquid and/or treatment of the glass surfaces with various commercial chemicals which produce hydrophobic effects (Tomlinson, 1970). It should be observed that the latter method may necessitate recalibration of volumetric glassware due to alteration of the shape of the liquid meniscus and the reduction of surface wetting.

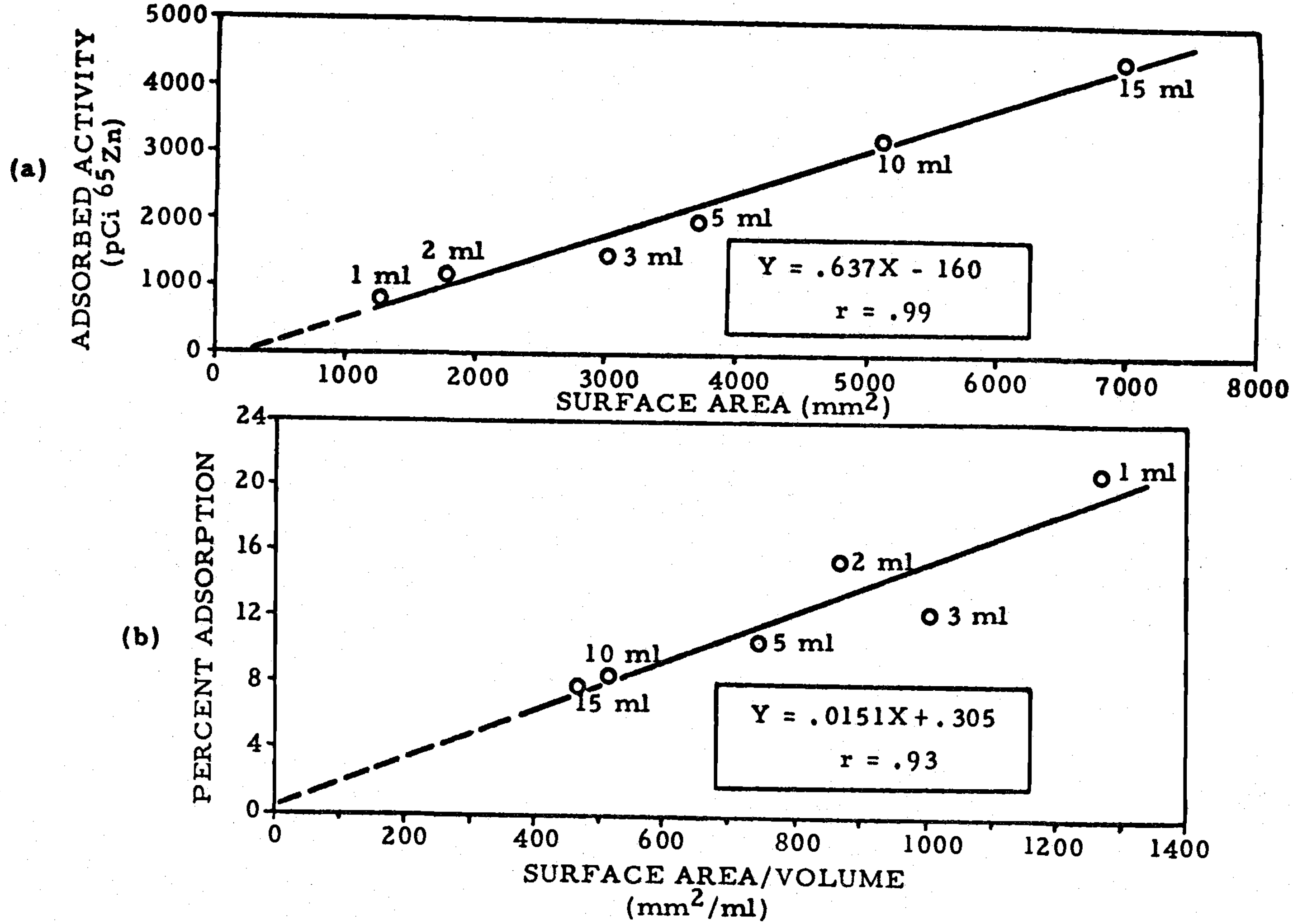


Figure. 3 Zinc-65 uptake by HF-pretreated Pyrex volumetric pipettes.
(a) Zinc-65 uptake as a function of exposed glass surface area.
(b) Percent adsorption of ^{65}Zn in the contained sample as a function of pipette surface area/sample volume.

SUMMARY

Analysis of ^{65}Zn uptake in a batch-type marine algal culture system indicates that under certain conditions significant amounts of zinc may be removed from solution through adsorption to inorganic surfaces. In particular, culture medium precipitates and the walls of small glassware can adsorb zinc in quantities sufficiently large to cause significant errors in analyses of ^{65}Zn uptake by marine phytoplankton.

ACKNOWLEDGMENTS

The authors wish to thank Drs. Kendall L. Carder, Norman H. Cutshall, William O. Forster and Lawrence F. Small for the time and effort that they devoted to this work.

This work was supported by funds made available under Atomic Energy Commission Contract no. At(45-1)2227, Task Agreement 12 (RLO-2227-T12-9) and Federal Water Pollution Control Administration Grant no. WP 111-04.

REFERENCES

Bernhard, M. and A. Zattera, "Proceedings of the Second National Symposium on Radioecology", Ann Arbor (USAEC CONF-670503), 1967.

Boroughs, H., W. A. Chipman and T. R. Rice, The effects of atomic radiation on oceanography and fisheries. NAS-NRC, Washington, D. C. NAS-NRC Publication No. 551, p. 80-87, 1957.

Chipman, W. A., T. R. Rice and T. J. Price, U. S. Fish and Wildlife Service, Fishery Bulletin 135, p. 279-292(1958).

Chu, S. P., J. Ecol. 30, 284-325 (1942).

Davis, H. C. and R. Ukeles, Science 134, 562-564 (1961).

Fogg, G. E., "Algal cultures and phytoplankton ecology", Univ. of Wisconsin Press, Madison, 126 p., 1966.

Gutknecht, J., Limnol. Oceanog. 10, 58-66 (1965).

Harley, J. H., Ed. Manual of standard procedures, 2d ed., New York, USAEC (NYO-4700), 1967.

Polikarpov, G. G., "Radioecology of aquatic organisms", North-Holland, Amsterdam, 314 p., 1966.

Robertson, D. E., Anal. Chim. Acta 42, 533-536 (1968).

Schutz, D. F. and K. K. Turekian, Geochim. Cosmochim. Acta 29, 259 (1965).

Strickland, J. D. H. and T. R. Parsons, A manual of sea water analysis, 2d ed., Ottawa, 203 p. (Fish. Res. Bd. Canada, Bulletin No. 125), 1965.

Tomlinson, R. D., M.S. thesis, Oregon State University, Corvallis, Oregon, 1970.

FOOD SOURCES OF SUBLITTORAL, BATHYAL, AND ABYSSAL ASTEROIDS IN THE NORTHEAST PACIFIC OCEAN OFF OREGON

by Andrew G. Carey, Jr.

ABSTRACT

Sea stars from the sublittoral to the abyssal zone at 4260 meters depth in the northeast Pacific Ocean were examined for food source. A total of 491 specimens of 29 species were dissected for stomach content analyses. Six species are carnivores; seven, deposit-detritus feeders; thirteen, omnivores; and the feeding habits of four remain unknown. There are changes in feeding type with increasing depth; the relative abundance of predators decreases from 66.6 to 0.0%, and the deposit-detritus feeders, from 33.3 to 14.3%. The omnivores increase from 0.0% on the inner continental shelf at a depth of 50 meters to 71.4% on the abyssal plains. It is concluded that in the near-shore abyssal environment on Cascadia Plain off Oregon the deep-sea asteroids are generally facultative feeders and obtain food energy from the sediments as well as prey or animal remains, while in the food-rich shallow waters of the inner continental shelf the asteroid fauna are generally specialized carnivores.

INTRODUCTION

Observations have been made on the feeding of asteroids for a long time (see Hyman, 1955 and Feder and Christensen, 1966 for reviews), but the food sources of many species, particularly the deep-sea forms, have remained unclear. It is necessary to observe the animals feeding directly (Mauzey, Birkeland, and Dayton, 1968) or to obtain a large series of stomach content analyses to unravel this segment of the benthic food web. This study describes the major sources of food for certain sublittoral, bathyal, and abyssal asteroids off the coast of Oregon by analyzing a large series of asteroid stomachs. The range of depths and the types of environments covered is broad and should allow generalizations concerning the changes in food source with depth.

One of the major areas of interaction between organisms in the sea is in their search for, and ingestion of, food. The food web is a complex set of interactions that links the flora and fauna of the ocean into a functional whole. The utilization of energy by the benthic animals and their role in the cycling of elements in the marine ecosystem can be understood only when the food sources of each dominant species are known. As an initial step in linking the Oregon benthic fauna together in a functional manner, the feeding patterns of sea stars have been studied. These

---

To be submitted to Ophelia.

RLO 2227-T12-13

organisms are ubiquitous in their distribution and are dominant members of the macro-epifauna.

The species composition and depth distribution of the asteroid fauna from the sublittoral and bathyal zones of northern Oregon have been reported and summarized by Alton (1966). McCauley (in press) has summarized the species collected during Oregon State University oceanographic cruises and has listed their depth distributions. The feeding habits and behavior of shallow subtidal asteroids in the Pacific Northwest have been well characterized by Mauzey, Birkeland, and Dayton (1968) in a large series of direct observations by SCUBA diving. The present paper adds to the northeastern Pacific asteroid literature by increasing the depth range covered and by describing the major trends in food sources with increasing depth and distance from shore.

The field assistance of D. R. Hancock and R. R. Paul and the laboratory assistance of Mrs. G. S. Alspach and G. L. Hufford are gratefully acknowledged. Miles Alton, M. Downey, F. J. Madsen, and J. E. McCauley kindly undertook some of the identifications. Helpful comments on the manuscript were made by J.E. McCauley. Several asteroid collections were provided by W. G. Pearcy and J. E. McCauley.

MATERIALS AND METHODS

The specimens analyzed came from otter trawl samples obtained off central and northern Oregon during benthic radioecological and ecological studies at Oregon State University (Carey, 1968, in press). Seven stations off central Oregon from 50 to 2860 meters depth were seasonally sampled from 1962 to 1968. Other stations further from shore, at intermediate depths, and off northern Oregon were occupied from time to time. A 7-meter semi-balloon Gulf of Mexico shrimp trawl was the standard sampling gear. The 3.8 cm stretch mesh usually was fished with a 1.3 cm stretch mesh liner in the cod-end.

Samples were sorted on the ship into major taxonomic categories, and asteroids for the stomach analyses were separated out and preserved in 10% formalin neutralized with sodium borate. Concentrated neutralized formalin was injected into the stomach when possible. Some specimens deep-frozen at sea for radioecological research were later thawed and dissected in the laboratory. We have collected 70 or more species of Asteroidea in the northeastern Pacific Ocean (McCauley, 1971), but only the more common species and those not needed for other research projects were analyzed for stomach contents.

A circular incision was made on the dorsal side of the starfish into the stomach cavity, and the contents were carefully washed from the animal and stored separately in glass vials in 70% isopropyl alchol. The contents were examined later under a dissecting microscope and enumerated for each

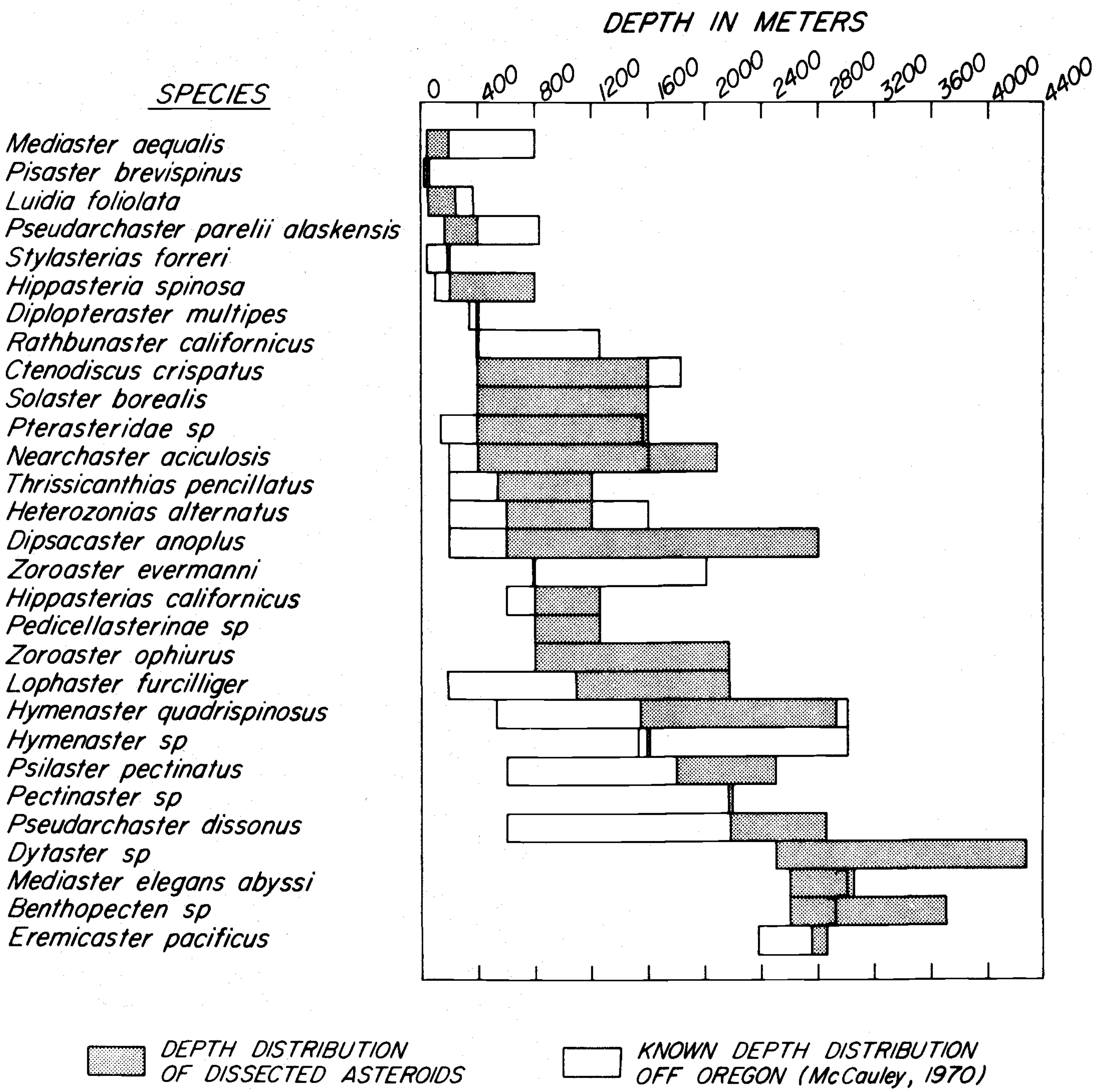


Figure 1. Depth distribution of asteroid species off Oregon studied for food source. The depth range of the dissected specimens and the known range off the Oregon coast (McCauley, 1970) are indicated.

specimen. A rough volume scale was used to note the volume of the food item in the stomach: trace = very small amount; some = ≤ 1/4 full; much = > 1/4 to 3/4 full; and maximum = ≥ 3/4 to full. The starfish were weighed and measured. Stomach contents were summarized for each species, and conclusions drawn about the major source of food. Though data from pertinent literature have been included, the review is probably not complete.

RESULTS

The 29 species (491 specimens) of asteroids cover a broad depth range from 46 to 4260 meters (Figure 1). The number of species is greatest on the upper continental slope. Though in general there is a continuous change in the species composition with depth, the upper slope is a transition zone in the asteroid distributions; a number of bathyal species reach up to 200-400 meters depth, while much of the shallow water fauna is limited to the continental shelf or just beyond.

The stomach contents and feeding types are summarized by species; the sea stars are classified to feeding type by synthesizing the present results with those obtained from the literature. The dominant food sources for each species have been underlined.

1. *Mediaster aequalis* Stimpson. Depth range of specimens: 46 to 200 meters. Number dissected is 9, and the number with material in stomach 5. Stomach contents: faecal pellets and trace to much sediment. [Literature: sponges and ectoprocts on rocky substrate; sea pens and drift algae on sandy substrate; sediment on muddy substrate (Mauzey *et al*., 1968)] Feeding type off Oregon is DEPOSIT-DETRITUS.

2. *Pisaster brevispinus* Stimpson. Depth range of specimens: 50 meters. Number dissected is 4, and the number with material in the stomach 2. Stomach contents: some sediment. [Literature: pelecypods on sandy substrate; barnacles on rocky substrate. (Mauzey *et al*., 1968; Feder and Christensen, 1966)1. Feeding type off Oregon is PREDATOR.

3. *Luidia foliolata* Grube. Depth range of specimens: 56 to 245 meters. Number dissected is 26, and the number with material in stomach 24. Stomach contents: pelecypod, echinoids, holothurian, ophiuroids, polychaete, crustacean, and some sediment. [Literature: pelecypods, holothurians (Mauzey *et al*., 1968); ophiuroids and scaphopods (Fisher, 1911)]. Feeding type off Oregon is PREDATOR.

4. *Pseudarchaster paralii alaskensis* Fisher. Depth range of specimens: 165 to 400 meters. Number dissected is 12, and the number with material in the stomach 9. Stomach contents: gastropods, ophiuroids, crustacean, foraminiferan, and trace to maximum sediment. [Literature: none]. Feeding type off Oregon is OMNIVORE.

5. *Stylasterias forreri* de Loriol. Depth range of specimens: 200 meters. Number dissected is 1, and the number with material the stomach 1. Stomach contents: gastropods (5) and some sediment. [Literature: none]. Feeding type off Oregon is PREDATOR.

6. *Hippasteria spinosa* Verrill. Depth range of specimens: 200 to 800 meters. Number dissected is 3 and the number with material in the stomach 3. Stomach contents: trace to some sediment. [Literature: none]. Feeding type off Oregon is DEPOSIT-DETRITUS.

7. *Diplopteraster multipes* Sars. Depth range of specimens: 400 meters. Number dissected is 2, and the number with food material in the stomach 2. Stomach contents were: ophiuroid-like fragments and some sediment (sand). [Literature: none]. Comments: the stomach was partially everted in both; this species could be a predator with extra-oral digestion. Feeding type off Oregon is UNKNOWN.

8. *Rathbunaster californicus* Fisher. Depth range of specimens: 400 meters. Number dissected is 2, and the number with material in the stomach 1. Stomach contents: echinoid fragments, crustacean fragments, and sediment. [Literature: crustaceans in the laboratory (Fisher, 1928)]. Feeding type off Oregon is PREDATOR.

9. *Ctenodiscus crispatus* Retzius. Depth range of specimens: 400 to 1600 meters. Number dissected is 27 and the number with material in the stomach 26. Stomach contents: pelecypod, foraminiferan, spicules, worm tubes, and some to maximum sediment. [Literature: mud (detritus) Fisher, 1911; Gislen, 1924; and Mortensen, 1927)]. Comments: most specimens had much to maximum sediment in the stomach. Feeding type off Oregon is DEPOSIT-DETRITUS.

10. *Solaster borcalis* Fisher. Depth range of specimens: 400 to 1600 meters. Number dissected is 23, and the number with material in the stomach 14. Stomach contents: echinoid fragments, crustacean, trace to some sediment. [Literature: none]. Comments: most specimens had sediment in the stomach. The mouth was wide open in 2, and there was unidentified material in 3. Feeding type off Oregon is OMNIVORE.

11. Pterasteridae. Depth range of specimens: 400 to 1600 meters. Number dissected is 6, and the number with material in the stomach 6. Stomach contents: ophiuroid and echinoid fragments, faecal pellets, and trace to maximum sediment. [Literature: none]. Feeding type off Oregon is OMNIVORE.

12. *Nearchaster aciculosis* Fisher. Depth range of specimens: 400 to 2086 meters. Number dissected is 32, and the number with material in the stomach 25. Stomach contents: fish scale, crustaceans, ophiuroids, faecal pellets, and trace to much sediment. [Literature: none]. Comments: the mouth was open in 2, and there was unidentified organic matter in 4. Feeding type off Oregon is OMNIVORE.

13. Thrissicanthias penicillatus Fisher. Depth range of specimens: 540 to 1200 meters. Number dissected is 31 and the number with material in the stomach 26. Stomach contents: pelecypods, echinoids, ophiuroids, crustaceans, scaphopod, gastropods, and trace to much sediment. [Literature: none]. Comments: gonads were mature in 2 specimens from a June sample. Feeding type off Oregon is PREDATOR.

14. Heterozonias alternatus Fisher. Depth range of specimens: 600 to 1200 meters. Number dissected is 21, and the number with material in the stomach 15. Stomach contents: a crustacean, foraminiferan, sea pen stalk (?), and trace to some sediment. [Literature: none]. Comments: 11 specimens contained sediment. Feeding type off Oregon is DEPOSIT-DETRITUS.

15. Dipsacaster anoplus Fisher. Depth range of specimens: 600 to 2800 meters. Number dissected is 44, and the number with material in the stomach 41. Stomach contents: pelecypods, gastropods, ophiuroids, crustacean, polychaete, some to much sediment. [Literature: none]. Comments: specimens from 600 to 800 meters contained more animals. Feeding type off Oregon is OMNIVORE.

16. Zoroaster evermanni Fisher. Depth range of specimens: 800 meters. Number dissected is 2 and the number with material in the stomach 2. Stomach contents: echinoderm fragment, spicules, crustacean, isopod, and sediment. [Literature: none]. Feeding type off Oregon is OMNIVORE.

17. Hippasterias californica Fisher. Depth range of specimens: 800 to 1260 meters. Number dissected is 9, and the number with material in the stomach 3. Stomach contents: trace to some sediment. [Literature: none]. Feeding type off Oregon is DEPOSIT-DETRITUS.

18. Pedicellasteridae. Depth range of specimens: 800 to 1260 meters. Number dissected is 18, and the number with material in the stomach 11. Stomach contents: faecal pellets and trace to some sediment. [Literature: none]. Comments: mouth open in 5; sediment coagulate in some. Most animals had some sediment. Feeding type off Oregon is DEPOSIT-DETRITUS.

19. Zoroaster ophiurus Fisher. Depth range of specimens: 800 to 2176 meters. Number dissected is 5 , and the number with material in the stomach 3. Stomach contents: ophiuroid and crustacean fragments, and some to maximum sediment. [Literature: none]. Feeding type off Oregon is OMNIVORE.

20. Lophaster furcilliger Fisher. Depth range of specimens: 1097 to 2176 meters. Number dissected is 29, and the number with material in the stomach 20. Stomach contents: echinoid and ophiuroid fragments, worm tube, foraminiferan, and trace to maximum sediment. [Literature: none].

Comments: mouth open in 3, stomach partially everted in 4. Feeding type off Oregon is OMNIVORE.

21. Hymenaster quadrispinosus Fisher. Depth range of specimens: 1540 to 2926 meters. Number dissected is 47, and the number with material in the stomach 27. Stomach contents: crustacean and echinoid fragments, gastropod, and trace to much sediment. [Literature: none]. Comments: amorphous organic material in 9; mature gonads in 1 from a June sample. Feeding type off Oregon is OMNIVORE.

22. Hymenaster sp. Depth range of specimens: 1600 meters. Number dissected is 2, and the number with material in the stomach 2. Stomach contents: echinoid and ophiuroid fragments and some to much sediment. [Literature: none]. Feeding type off Oregon is OMNIVORE.

23. Psilaster pectinatus Fisher. Depth range of specimens 1800 to 2500 meters. Number dissected is 16, and the number with material in the stomach 11. Stomach contents: some to maximum pelecypods, scaphopods, gastropod, polychaetes, echinoid, holothurian, and trace to much sediment. [Literature: pelecypods and scaphopods (Sokolova, 1957)]. Feeding type off Oregon is CARNIVORE.

24. Pectinaster sp. Depth range of specimens: 2176 meters. Number dissected is 9, and the number with material in the stomach 1. Stomach contents: trace of sediment. [Literature: none]. Comments: amorphous material in 1; mouth open in 6. Feeding type off Oregon is UNKNOWN.

25. Pseudarchaster dissonus Fisher. Depth range of specimens 2176 to 2850 meters. Number dissected is 18, and the number with material in the stomach 9. Stomach contents: ophiuroid fragments, echinoderm and sponge spicules, and trace to maximum sediment. [Literature: none]. Comments: mouth open in 6, stomach everted in 4. Feeding type of Oregon is OMNIVORE.

26. Dytaster sp. Depth range of specimens: 2500 to 4260 meters. Number dissected is 24, and the number with material in the stomach 11. Stomach contents: echinoid and ophiuroid fragments, sponge spicules, and some to maximum sediment. [Literature: none]. Comments: most with much sediment. Feeding type off Oregon is OMNIVORE.

27. Mediaster elegans abyssi Ludwig. Depth range of specimens: 2600 to 3050 meters. Number dissected is 19, and the number with material in the stomach 5. Stomach contents: silicious sponge spicules, tube, and trace to some sediment. [Literature: none]. Comments: mature gonads in 2 (December and February samples). Feeding type off Oregon is UNKNOWN.

28. Benthopecten sp. Depth range of specimens: 2600 to 3700 meters. Number dissected is 44; and the number with material in the stomach 15. Stomach contents: ophiuroid fragments, isopod, and trace to some sediment. [Literature: none]. Comments: Mouth open in 3; stomach everted in 4. Feeding type off Oregon is OMNIVORE.

29. Eremicaster pacificus Ludwig. Depth range of specimens: 2772 to 2860 meters. Number dissected is 6, and the number with material in the stomach 6. [Literature: none]. Comments: some amorphous material in stomachs. Feeding type off Oregon is DEPOSIT-DETRITUS.

Five species, mostly sublittoral forms, are clearly predators, as they almost always contain plentiful small prey or fragments of larger animals. A sixth species, Pisaster brevispinis, is classified as a predator from data available in the literature (Feder and Christensen, 1966; Mauzey, Birkeland, and Dayton, 1968) but there were no significant stomach contents in those specimens studied here.

Seven species are deposit-detritus feeders. These consistently contain sediment; some have only a small amount while others are packed full. Meiofauna and animal fragments were mixed with the sediment in about the same proportion as found in the surrounding surface sediments. When a small amount of fine sediment was consistently present in the stomach, particularly if it was coagulated with a mucous-like material, it was inferred that the organisms had been feeding on detrital organics on the sediment surface.

Thirteen species appear to feed upon sedimentary organics plus other organisms. They have been classified as omnivores because the stomachs generally contain sediment with a considerable number of animal fragments. They may be scavengers rather than active predators, but their diet is a varied one in any case. They appear to feed on whatever organic material that is available. Although I have classified Zoroaster evermanni Fisher and Z. ophiurus Fisher as omnivores, Alcock (1894) noted that another species from the deep-sea, Z. carinatus Alcock, feeds largely on mollusks and crustaceans. Data from the present studies indicate that Solaster borealis Fisher is probably an omnivore; it generally contains sediment as well as animal fragments. However, four other species of Solaster have been classified as carnivores by other workers: S. dawsoni Verrill and S. stimpsoni Verrill eat mainly asteroids (Christensen, unpublished); S. endeca Linnaeus feeds on sea anemones, asteroids, and occasionally holothurians (Grieg, 1913; Blegvad, 1914; and Bull, 1934); and S. paxillatus Sladen feeds on holothurians (Fisher, 1911). In the northeastern Pacific Ocean Hymenaster quadrispinosus, an omnivore, feeds on sedimentary organics as well as some organisms; whereas, H. blegvadi Madsen eats small snails and possibly clams (Madsen, 1956) and H. pellucidus Wyv. Thomson ate an ophiuroid (in one case (Mortensen, 1927).

Four species are categorized as unknown. Their stomachs either contain so little material or the sample number of starfish was so small that determination to feeding type was difficult. It is possible that they digest prey extra-orally with an everted stomach; a type of feeding that is very difficult to detect by stomach content analyses. Eight specimens out of nine of Pectinaster sp. examined for stomach contents were empty; the remaining one contained but a trace of sediment. Alcock (1893) has reported that P. hispidus, Alcock and Wood-Mason another deep-sea species, feeds mainly on mollusks and crustaceans. It may be that the species of Pectinaster studied here is a predator digesting prey extra-orally or feeding infrequently, but the data are too few to permit conclusions.

Depth trends are evident in the food sources of Oregon asteroids (Figure 2). Predators, relatively more abundant on the continental shelf, become increasingly less with depth. No pure predators are present among the species studied from the abyssal environment. Deposit and detritus feeders comprise a fairly constant portion (29-40%) of the asteroid fauna from the inner shelf to a depth of 1200 meters on the upper slope. Beyond this depth the organisms living solely on food materials associated with the sediment decline to 14-18% of the sea star fauna. In contrast, though the omnivores are not present on the inner shelf, they are at the 20% level on the outer shelf and continuously increase to a maximum of 71% on the abyssal plains.

DISCUSSION

The species composition of the asteroid fauna off Oregon changes with depth, species continuously replacing one another (Figure 1 and McCauley, in press). Many characteristics of the bottom environment are correlated with depth of water; therefore, there are gradients of temperature, salinity, dissolved oxygen, pressure, and sediment particle size that change together with increasing depth. These gradients would affect the distribution of individual species, but would not act as a barrier to a large portion of the sea star fauna. There is, however, a large change in the species composition in the depth interval between the outer continental shelf and the upper continental slope. The transition from the shallow seasonally controlled sublittoral environment to the more stable deeper environment of the bathyal and abyssal zones probably accounts for the marked change in species composition off Central Oregon (Sanders and Hessler, 1969). Alton (1966) has reported a similar increase in the number of species of sea stars on the northern Oregon continental slope.

The general trend noted in the diet the Oregon asteroids with depth has been reported by Thorson (1957) for other benthic organisms; the incidence of predation decreases with depth. Sokolova (1959) has reported similar trends over very broad depth ranges (from sublittoral to hadal depths); she relates the trophic structure of the faunal assemblages to sediment type, detrital food supply in the sediment and bottom water, and the character of near-bottom currents. When there is sufficient detrital and sedimentary organic material, the benthic fauna is composed of trophic groups that feed upon these materials. When there is insufficient food material associated with the sediments, selective detritus feeders are absent and filter feeders predominate. Based upon the predominance of deposit-detrital and omnivorous feeders and of deposit-feeding infauna (Carey, 1965), the nearshore Cascadia Abyssal Plain corresponds to the eutrophic abyssal structure described by Sokolova (1966).

As food is probably limiting in the abyssal environment and as it probably reaches the sea floor as particulate material (Ekman, 1953; Sanders and

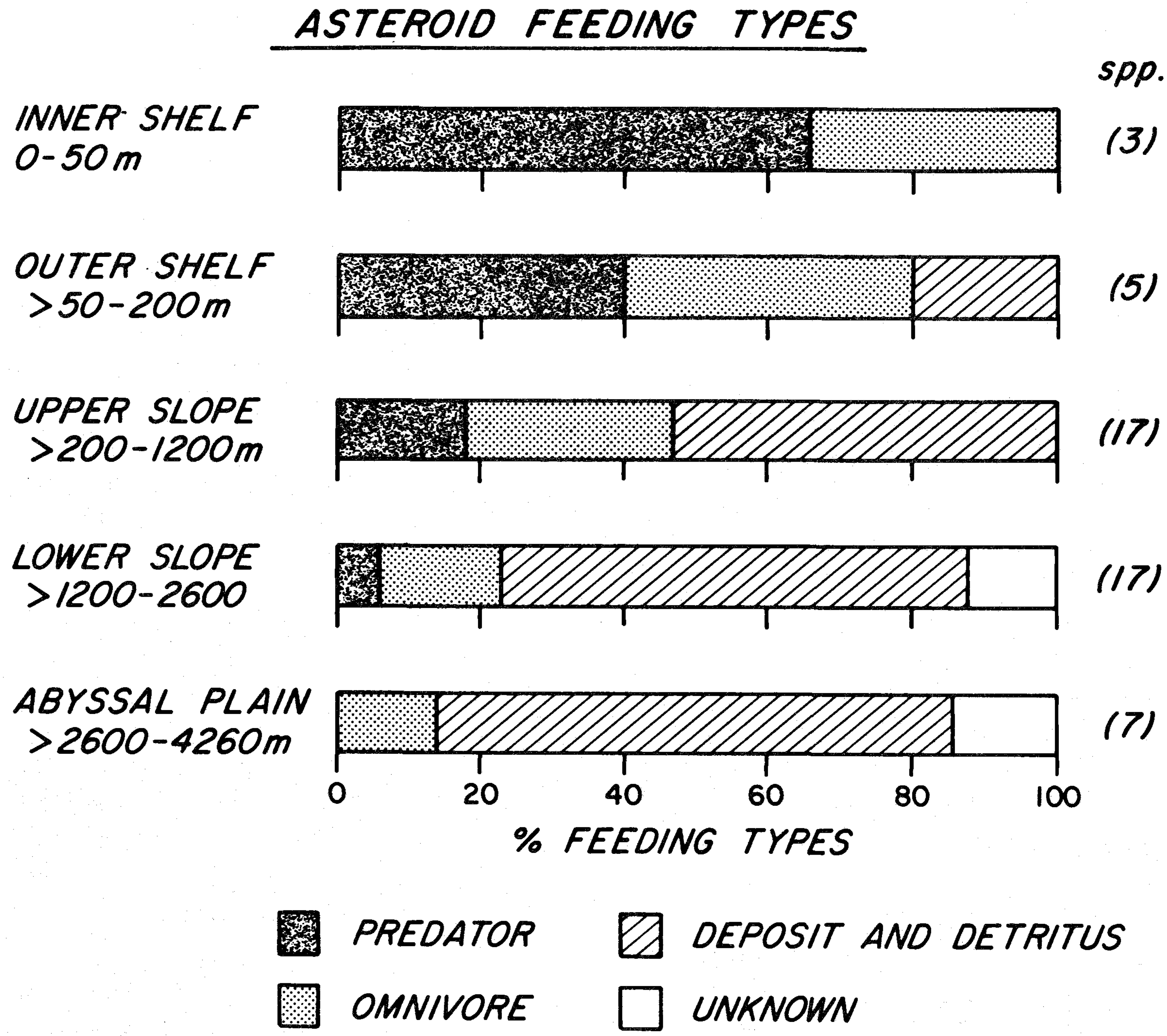


Figure 2. Summary of trends with depth of asteroid food source in the Northeast Pacific Ocean. When a species is present in more than one depth zone, it has been included in both areas.

Hessler, 1969; and Carey, unpublished), it is likely that organisms will become less specialized feeders and will tend toward deposit-detrital and omnivorous feeding. They will feed on whatever utilizable organic materials they can get. Thus, food quality and supply is a regulator of faunal abundance and energy use in the deep-sea. The availability of types of food, prey or nonliving organics, appears to influence the trophic structure at depth; when prey is not available, the omnivores eat what they can get.

Feder and Christensen (1966) state that the majority of sea stars studied are carnivores that only occasionally act as scavengers. Data from the present study indicate that 13 of the 29 species resort to ingestion of sediment in significant quantities as well as animals and/or their remains; it is concluded that these should be characterized as omnivores rather than predators. A number of starfish have been reported as omnivorous scavengers and feed by flagellary mucoid means (MacGinitie and McGinitie, 1949; Anderson, 1959; and Pearse, 1965). These distinctions between carnivore, omnivore, and omnivorous scavenger in many cases are probably more a matter of degree and interpretation than clear-cut categories.

The deposit-detritus category of feeding combines in the present paper at least two types of feeder, the ingesters of whole sediment and those which feed exclusively on the detritus found on the sediment surface. Turpaeva (1953) and Sokolova (1958) separate the non-selective detritus feeders (i.e. deposit feeders) from the detritus feeders collecting detritus from the sediment surface. In the present study, the two types could not be clearly distinguished.

For reconstructing the food web, stomach content analyses present a number of problems. Though in many cases deductions can be made concerning the major food sources, nothing can be determined about the rates of ingestion and assimilation. Deterioration of food items in the stomach from digestive processes during sample retrieval and before preservation of the specimen can also cause problems. Luidia sarsi Duben and Koren digests its ophiuroid prey in 16 to 24 hours at 12-13°C (Fenchel, 1965), leaving ample time for collection and preservation. However, Christensen (1970) has demonstrated that a shallow water carnivorous asteroid Astropecten irregularis Pennant can prefer particular molluscan prey species over others and that rates of digestion are correlated with the palatibility of the food species. Digestion can be accomplished in several hours to several weeks, depending on the resistance of the prey to aneerobic aonditions in the asteroid stomach. Whether species in the food-limited bathyal and abyssal environments exhibit such specific dietary preferences and food manipulations is not known, but such possible complex behavior must be considered when drawing conclusions about food sources from stomach content analyses of field collections.

During retrieval of the trawl sample drom the sea floor, some species may undergo muscle spasms from thermal or pressure shock and empty their stomach. Exterior feeding processes by extrusion of the stomach with extra-oral digestion can also create difficulties; this mode of feeding is most difficult to detect by stomach content analysis. Other types of behavior such as ciliary or flagellar mucoid feeding on small particles (Anderson, 1960) would yield only traces of material in the stomach.

Though direct observation in situ and subsequent retrieval and laboratory experimentation would solve many of these problems (Mauzey, Birkeland, and Dayton, 1968), such procedures are not yet feasible on a broad scale with the deep-sea fauna. Bottom photography should show certain types of behavior that would aid in interpreting the stomach content data, but a series of photographs from the Oregon sampling stations have been studied by the author without results. In spite of these and other difficulties, a study of diet by stomach content analyses can yield valuable results that add to our knowledge of the interactions of the benthic fauna.

Trends in the feeding type of asteroids off Oregon have been correlated with increasing depth. There is a shift in food source from animal prey to sedimentary organics and animal remains; the animals change from a specialized to a more generalized diet. Asteroids like many other abyssal fauna probably ingest and assimilate whatever utilizable food materials are available in the food-limited deep sea.

FOOTNOTE

The financial assistance of the Atomic Energy Commission (Contract AT(45-1)2227-Task Agreement No. 12) and the National Science Foundation (Grants GB-4629 and GB-531) are gratefully acknowledged. The National Science Foundation (Grant GD) provided partial support for ship operations. The manuscript (RLO-2227-T12-13) was completed at the Zoological Museum of the University of Copenhagen in 1970 under partial support of a George C. Marshall Memorial Fellowship of Denmark.

REFERENCES

Alcock, A. 1893. An account of the collection of deep-sea Asteroidea. Natural History notes from H.M. Indian Marine Survey Steamer INVESTIGATOR. Ann. Mag. nat. Hist., Ser. 6, 11:73-121.

Alton, M.S. 1966. Bathymetric distribution of sea stars (Asteroidea) off the Northern Oregon coast. J. Fish. Res. Bd. Can. 23:1673-1714.

Anderson, J. M. 1959. Studies on the cardiac stomach of a starfish, *Patiria miniata* (Brandt). Biol. Bull. mar. biol. Lab., Woods Hole. 112:185-201.

Anderson, J. M. 1960. Histological studies on the digestive system of a starfish, *Henricia*, with notes on Tiedermann's pouches in starfishes. Biol. Bull. mar. biol. Lab., Woods Hole. 119:371-398.

Blegvad, H. 1914. Food and conditions of nourishment among the communities of invertebrate animals found on or in the sea bottom in Danish waters. Rep. Danish biol. Sta. 22:41-78.

Bull, H. O. 1934. Aquarium observations on the rate of growth and enemies of the common starfish *Asterias rubens*. Rep. Dove Mar. Lab. Ser. 3, No. 2: 60-65.

Carey, A. G., Jr. 1965. Preliminary studies of animal-sediment interrelationships off the central Oregon coast. In Ocean Science and Ocean Engineering 1965. 1:100-110.

Carey, A. G., Jr. 1968. Zinc-65 in echinoderms and sediments in the marine environment off Oregon. Proc. Second Nat. Radioecology Symp. USAEC Conf. 6705-03:380-388.

Carey, A. G., Jr. ^{65}Zn in benthic invertebrates off the Oregon coast. In: A. T. Pruter (ed.) Bioenvironmental Studies of the Columbia River Estuary and Adjacent Ocean Region. U.S. Atomic Energy Comm. Publ. (in press).

Carey, A. G., Jr. Benthic infaunal abundance on two abyssal plains in the Northeast Pacific Ocean with comments on deep-sea food sources. (unpublished manuscript).

Christensen, A. M. 1970. Feeding biology of the sea-star *Astropecten irregularis* Pennant. Ophelia, 8:1-134.

Ekman, S. 1953. Zoogeography of the Sea. Sidgwick and Jackson. 417 pp.

Feder, H. and A. M. Christensen. 1966. Aspects of asteroid biology. In R. A. Boolootian (ed.), Physiology of the Echinodermata. Interscience. 822 pp.

Fenchel, T. 1965. Feeding biology of the sea star Luidia sarsi Døben and Koren. Ophelia. 2:223-236.

Fisher, W. K. 1911. Asteroidea of the North Pacific and adjacent waters. Part I. Bull. U.S. Nat. Mus. 76:419 pp.

Fisher, W. K. 1911. Asteroidea of the North Pacific and adjacent waters. Part II. Bull. U.S. Nat. Mus. 76:245 pp.

Gislén, T. 1924. Echinoderm Studies. Zool. Bidr. Uppsala. 9:1-316.

Grieg, J. A. 1913 Bidrag til Kundskapen om Hardangerfjordens fauna. Bergens Mus. Aarb. No. 1: 147 pp.

Hyman, L. H. 1955. The Intevertebrata: Echinodermata. The Coelomate Bilateria. Vol. IV. McGraw-Hill. 763 pp.

Madsen, F. J. 1956. Echinoidea, Asteroidea, and Ophiuroidea from depths exceeding 6000 meters. Galathea Report, 2: 23-32.

Madsen, F. J. 1961. On the zoogeography and origin of the abyssal fauna in view of the knowledge of the Porcellanasteridae. Galathea Report 4:117-218.

Marshall, N. B. 1954. Aspects of Deep Sea Biology. Hutchinson. 380 pp.

Mauzey, K. P., C. Birkeland, and P. K. Dayton. 1968. Feeding behavior of asteroids and escape responses of their prey in the Puget Sound region. Ecology. 49:603-619.

McCauley, J. E. 1971. A preliminary checklist of selected groups of invertebrates from otter trawl and dredge collections off Oregon. In A. T. Pruter (ed.), Bioenvironmental Studies of the Columbia River Estuary and Adjacent Ocean Region. USAEC Publ. (in press).

Mortensen, Th. 1927. Handbook of the echinoderms of the British Isles. Oxford Univ. Press. I-VIII:471 pp.

Pearse, J. S. 1965. Reproductive periodicities in several contrasting populations of Odonaster validus Kohler, a common Antarctic asteroid. Biology of Antarctic Seas. II. Antarctic Res. Ser. 5:39-85.

Sanders, H. L. and R. R. Hessler. 1969. Ecology of the deep-sea benthos. Science. 163:1419-1424.

Sokolova, M. N. 1957. The feeding of some carnivorous deep-sea benthic invertebrates of the far eastern seas and the northwest Pacific Ocean. Trans. Inst. Oceanol. 20:279-301. (Cited from Transl. published 1959 by Amer. Inst. Biol. Sci.:227-244).

Sokolova, M. N. 1958. The nutrition of some detritus-feeding invertebrates of the deep-water benthos of the Far Eastern Seas. (In Russian). Trudy Inst. Okeanol. Akad. Nauk, SSSR. 27:

Sokolova, N. N. 1959. On the distribution of deep-water bottom animals in relation to their feeding habits and the character of sedimentation. Deep-Sea Res. : 1-4.

Sokolova, M.N. 1966. La structure trophique du benthos de l'abyssal. Second Internat. Oceanog. Congress, Moscow, Abstracts of Proceed.: 345-356.

Thorson, G. 1957. Bottom communities. In J. W. Hedgpeth (ed.), Treatise on Marine Ecology and Paleoecology. Vol. I. Ecology. Mem. 67. Geol. Soc. Amer. :461-534.

Turpaeva, Ye. P. 1953. Feeding and food groups of marine benthic invertebrates. (In Russian) Trudy Inst. Okeanol. Akad., Nauk SSSR. 7: .

RECENT OPHIUROIDEA OCCURRING OFF OREGON, U.S.A.

by Michael A. Kyte

ABSTRACT

Thirty-nine species of ophiuroids have been collected off the Oregon coast since 1889. These species are listed with synonomies and geographical and bathymetrical distributions. A new species, [redacted], is described from abyssal depths. It is proposed that [redacted] be transferred to [redacted] and [redacted] be transferred to [redacted]. The distributions of Amphiophiura ponderosa, Ophiura bathybia, Ophiophthalmus eurypoma, Ophiacanthella acontophora, Ophiacantha bathybia, Amphilepis platytata, Pandelia carchara, Unioplus macraspis and Amphiacantha gastracantha are extended bathymetrically, geographically or both. The key to the Ophiuroidea of Washington and Southern British Columbia by Kyte (Journal of Fish. Res. Bd. Canada 26:1727-1741, 1969) has been expanded to include species found off Oregon.

INTRODUCTION

Through an extensive benthic faunal sampling program started in 1962 by Dr. A. G. Carey, Jr. of O.S.U. the knowledge of Ophiuroidea off Oregon has been greatly expanded. Ophiuroids have been sampled at all depths of the sublittoral, bathyal, and abyssal regions in this program. Previously only two sources of information on the species of ophiuroids occurring off Oregon were available: Clark's (1911) paper and Astrahantseff and Alton's (1965) paper (hereafter referred to as A. & A., 1965).

Clark (1911) listed and described the ophiuroids taken by the U.S. Bureau of Fisheries vessel ALBATROSS between the years 1889 and 1906 in the North Pacific. This work treated the entire North Pacific and was confined to the ophiuroids taken by the ALBATROSS. Several new species were described; many of which are now synonomous with other species.

The second source of information (A. & A., 1965) listed only those species taken on a series of cruises off northern Oregon and extending only to 1929 meters, the lower bathyal zone. Despite the restricted sampling area, the range of several species was extended to northern Oregon and valuable ecological data were obtained.

Only one other recent paper on Ophiuroidea of the North American west coast (Kyte, 1969) is applicable to the Oregon ophiuroid species. This paper keyed and listed the species reported by several sources in Southern

---

This paper will be submitted to the Journal of the Fisheries Research Board of Canada. Because of possible nomenclatural problems, names of new taxa and new name combinations have been deleted.

British Columbia and Washington. Most of these species have also been collected off Oregon. Unfortunately, no collections from abyssal depths off Washington were available to Kyte so that the species he listed are primarily from bathyal, sublittoral, and littoral zones.

To the south of Oregon the nearest collections are from southern California (Hartman and Barnard, 1958, 1960; Barnard and Ziesenhenne, 1961), but these contain few species that are found off Oregon and the collections are generally from shallower waters and different faunal regions.

Thirty-nine ophiuroid species known to occur off Oregon are listed and keyed in the present paper. Twenty species previously included by Kyte (1969) are listed only with their Oregon distributions. Nineteen other species are listed with complete synonomies and geographical and bathymetrical distributions. Nine of these have been extended either in depth or in geographical distribution by O.S.U. collections (O.S.U., 1962-70). One new species of Ophiacantha from abyssal depths is described. Two species are transferred to new genera. Kyte's (1969) key is expanded and revised to include those species collected off Oregon. A list of the included species (see Table 1) and a list of bathymetric distributions (see Table 2) are included to summarize the species and their distributions.

When available, ecological or behavioral data on faunal and substrate associations are included. A more extensive treatment of the ecology, being prepared, will correlate ophiuroid distributions with physical parameters such as water mass and sediment characteristics.

Systematics

Phylum:	Echinodermata
Subphylum:	Asterozoa
Class:	Stelleroidea
Subclass:	Ophiuroidea
Order:	Phrynophiurida
Suborder:	Ophiomyxina

Family Ophiomyxidae

Ophioscolex corynetes (Clark) Th. Mortensen, 1933. Vidensk. Medd. Naturhv.
Nomenclature and geographical distribution (Kyte, 1969).
Oregon distribution: Northern Oregon continental slope, 500-1000 m. (A. & A., 1965; Clark, 1911).

Family Asteronychidae

Asteronyx excavata? [sic] Lütken and Mortensen, 1899. Mem. Mus. Comp. Zool. 23(2):97-208.
Geographic distribution: Northern Oregon upper continental slope, 500 m. (A. & A., 1965).

Table 1

Species List:
Compiled from Clark, 1911; Astrahantseff and Alton, 1965; O.S.U. Collections, 1962-70.

Phylum Echinodermata
Subphylum Asterozoa
Class Stelleroidea
Subclass Ophiuroidea
Order Phyrnophiurida
Suborder Ophiomyxina
Family Ophiomyxidae
Ophioscolex corynetes

Family Asteronychidae
Asteronyx excavata?
Asteronyx loveni

Family Astereroschematidae
Astroschema sp.

Family Gorgonocephalidae
Gorgonocephalies caryi

Order Ophiurida
Suborder Chilophiurina
Family Ophiuridae
Amphiophiura superba
Amphiophiura ponderosa
Ophiocten pacificum
Ophiomusium lymani
Ophiomusium multispinum
Ophiomusium jolliensis
Ophiura lütkeni
Ophiura sarsii
Ophiura leptoctenia
Ophiura irrorata
Ophiura bathybia

Suborder Laemophiurina
Family Ophiacanthidae
Ophiolimna bairdii
Ophiophthalmus normani
Ophiophthalmus cataleimmoidus
[redacted]
Ophiophthalmus eurypoma
Ophiacanthella acontophora
Ophiacantha bathybia
Ophiacantha trachybactra
[redacted]

Suborder Gnathophiurina
Family Ophiactidae
Ophiopholis aculeata
Ophiopholis bakeri
Ophiopholis longispina

Family Amphilepidae
Amphilepis platytata

Family Amphiuridae
Pandelia carchara
Amphiura koreae
[redacted])
Unioplus strongyloplax
Unioplus macraspis
Axiognathus pugetana
Axiognathus squamata
Diamphiodia occidentalis
Amphiodia urtica
Amphiacantha gastracantha

Table 2

BATHYMETRICAL DISTRIBUTION IN OREGON

species	littoral inner sublittoral 0-50 meters	outer sublittoral 50-200 m	upper bathyal 200-800 m	lower bathyal 800-2000m	abyssal 2000-5000m
Diamphiodia occidentalis	x				
Axiognathus pugetana	x	x			
Ophiopholis aculeata	x	x			
Ophiura lütkeni	x	x			
Ophiopholis bakeri	x	x	x		
Axiognathus squamata	x		x		
[redacted]		x			
Unioplus macraspis		x			
Amphiodia urtica		x			
[redacted]		x	x		
Unioplus strongyloplax		x			
Gorgonocephalus caryi		x			
Ophiura sarsi		x	x		
Asteronyx loveni		x	x	x	x
Asteronyx excavata			x		
Ophioscolex corynetes			x		
Ophiophthalmus cataleimmoidus			x		
Ophiopholis longispina			x		
Amphiophiura ponderosa			x	x	
Ophiomusium jolliensis			x	x	
Amphiura koreae			x	x	x
Ophiophthalmus normani			x	x	x
Astroschema sp.				x	
Ophiura irrorata				x	
Ophiacatha trachybactra				x	
Ophiophthalmus eurypoma				x	
Amphiacantha gastracantha				x	
Amphiophiura superba				x	
Ophiacanthella acontophora				x	
Ophiomusium lymani				x	x
Ophiomusium multispinum				x	x
Ophicantha bathybia				x	x
Ophiura leptoctenia				x	x
Ophiocten pacificum				x	x
Ophiolimna bairdii				x	x
Pandelia carchara				x	x
[redacted] abyssus					x
Ophiura bathybia					x
Amphilepis platytata					x

Asteronyx loveni Müller and Troeschel, 1842. Syst. Ast. p. 119,
Behavior and geographic distribution (Kyte, 1969).
Oregon distribution: Outer sublittoral to abyssal, 50-3000 m. (Clark, 1911; A. & A., 1965; O.S.U., 1962-70).
Note: Often occurs entwined about Alcyonarians. This behavior is mentioned by Hyman (1955), A. & A. (1965), and Nichols (1966, page 64) and will be discussed in a future paper.

Family Asteroschematidae

Astroschema sp.
Oregon distribution: Northern Oregon, confined to abyssal, 1100 and 1500 m. (A. & A., 1965).

Family Gorgonocephalidae

Gorgonocephalus caryi (Lyman) Lyman, 1881. Challenger Oph. p. 264.
Nomenclature, geographical distribution and behavior (Kyte, 1969).
Oregon distribution: outer sublittoral to mid-bathyal, 90-1372 m. (Clarke, 1911; A. & A., 1965; O.S.U., 1962-70).
Note: This species occurs primarily on rocky areas but has been taken from softer sediments. Deep-sea photography and trawl catches have recorded it entwined about Alcyonarians on soft bottoms.

Order Ophiurida
Suborder Chilophiurina
Family Ophiuridae

Amphiophiura superba (Lütken and Mortensen) Matsumoto, 1915. Proc. Acad. Nat. Sci. Phila. 67:77.
Nomenclature and geographical distribution (Kyte, 1969).
Oregon distribution: Lower bathyal to abyssal, 800-2000 m. (Clark, 1911; A. & A., 1965; O.S.U., 1962-70).

Amphiophiura ponderosa (Lyman) Matsumoto, 1917. J. Col. Sci., Tokyo. 38:264.
Ophioglypha ponderosa Lyman, 1878. Bull. Mus. Comp. Zool. 5:93.
Ophiura ponderosa Meissner, 1901. Bronn's Theirreichs. 2(3):925.
Geographical distribution: Japan, Alaska, Oregon, California, outer sublittoral to lower bathyal, 137-1600 m. (Clark, 1911; D'yakonov, 1967; O.S.U., 1962-70).
Oregon distribution: Upper and lower bathyal, 400-1600 m (A. & A., 1965; O.S.U., 1962-70). Clarke (1911) does not include Oregon in the range of this species and lists the bathymetric distribution as 475-505 fathoms. The geographic distribution of the species is extended to Oregon and the bathymetric distribution to 1600 m.

Ophiocten pacificum Lütken and Mortensen, 1899. Mem. Museum Comp. Zool. 23:131.
Geographic distribution (Kyte, 1969).

Oregon distribution: Lower bathyal and abyssal, 800-3000 m (A. & A., 1965; Clark, 1911; O.S.U., 1962-70).

Ophiomusium lymani Thomsen, 1873. The depths of the sea. p. 172.
Geographical distribution and behavior (Kyte, 1969).
Oregon distribution: Upper abyssal, 800-2200 m (A. & A., 1965; O.S.U., 1962-70).

Ophiomusium multispinum Clark, 1911. Bull. U.S.N.M. 75:113.
Geographical distribution (Kyte, 1969).
Oregon distribution: Bathyal to abyssal, 800-3100 m (A. & A., 1965; O.S.U., 1962-70).

Ophiomusium jolliensis McClendon, 1909. Univ. of Calif. Publ. Zool. 6(3):36.
Geographical distribution: Japan, Oregon, California; bathyal regions only, 150-2000 m. (McClendon, 1909; Clark, 1911; A. & A., 1965; O.S.U., 1962-70).
Oregon distribution: Outer sublittoral to lower bathyal, 60-2000 m (O.S.U., 1962-70; A. & A., 1965; Clark, 1911).

Ophiura lütkeni (Lyman) Meissner, 1901. Bronn's Theirreichs. 2:925.
Nomenclature, geographical distribution, and behavior (Kyte, 1969).
Oregon distribution: sublittoral only, 40-200 m (O.S.U., 1962-70).

Ophiura sarsii Lütken, 1854. Vid. Medd. 1854:101.
Geographical distribution and behavior (Kyte, 1969).
Oregon distribution: Outer sublittoral to upper bathyal, 50-800 m (Clark, 1911; A. & A., 1965; O.S.U., 1962-70).

Ophiura leptoctenia (Clark, 1911). Bull. U.S.N.M. 75:51.
Geographical distribution and behavior (Kyte, 1969).
Oregon distribution: Upper bathyal and abyssal, 400-3000 m (A. & A., 1965; O.S.U., 1962-70).

Ophiura irrorata (Lyman) Meissner, 1901. Bronn's Theirreichs 2(3):925.
Ophioglypha irrorata Lyman, 1878. Bull. Mus. Comp. Zool. 5:73.
Ophioglypha orbiculata Lyman, 1878. Bull. Mus. Comp. Zool. 5:73.
Ophioglypha grandis Verril, 1894. Proc. U.S.N.M. 17:293.
Ophioglypha tumulosa Lütken and Mortensen, 1897. Mem. Mus. Comp. Zool. 23:120
Ophioglypha involuta Koehler, 1897. Ann. Sci. Nat. Zool. (8), Vol. 4:295.
Geographical distribution: widespread in both the Atlantic and Pacific, bathyal to abyssal, 503-4315 m (Clark, 1911; D'yakonov, 1967).
Oregon distribution: lower bathyal only, 1600-2100 m (A. & A., 1965; O.S.U., 1962-70).

Ophiura bathybia Clark, 1911. Bull. U.S.N.M. 75:58.
Geographical distribution: Bering Sea, Alaska, Oregon; abyssal only, 2100-5000 m (Clark, 1911; D'yakonov, 1967; O.S.U., 1962-70).

Oregon distribution: abyssal only 2146-4194 (O.S.U., 1962-70). This species has not been reported from Oregon before and has not been reported from below 3608 m. The records of O.S.U. have extended the distribution of this species to Oregon and to 4194 m.

Suborder Laemophiurina
Family Ophiacanthidae

Ophiolimna bairdi (Lyman) Matsumoto, 1917, J. Coll. Sci. Tokyo 38:102.
Nomenclature and geographical distribution (Kyte, 1969).
Oregon distribution: Lower bathyal to abyssal, 1260-2800 m (A. & A., 1965; O.S.U., 1962-70).

Ophiophthalmus normani (Lyman) Matsumoto, 1917. J. Coll. Sci. Tokyo 38:106.
Nomenclature and geographical distribution (Kyte, 1969).
Oregon distribution: Upper bathyal to abyssal, 180-2800 m (A. & A., 1965; O.S.U., 1962-70).

Ophiophthalmus cataleimmoidus (Clark) Matsumoto, 1917. J. Coll. Sci., Tokyo 38:108.
Ophiacantha cataleimmoida Clark, 1911. Bull. U.S.N.M. 75:217.
Geographical distribution: North Pacific, Japan, Sea of Okhotsk, Alaska, Oregon; bathyal only, 400-2000 m (Clark, 1911; D'yakonov, 1967; O.S.U., 1962-70).
Oregon distribution: Upper bathyal to abyssal, 400-2000 m (A. & A., 1965; O.S.U., 1962-70).

[redacted] (Clark) comb. nov.
[redacted] Clark, 1911. Bull. U.S.N.M. 75:209.
This species has been placed in [redacted] after examining the type and collected specimens. It possesses short and rounded radial shields rather than the long bar-like shields of [redacted]. The disc is covered with definite scales bearing sparse coarse granules instead of skin bearing thorny stumps as in [redacted] The large, flat tentacle scales and long, glassy arm spines are also characteristic of [redacted] rather than of [redacted]. For these reasons [redacted] should be transferred to [redacted]
Geographical distribution: Oregon, California; outer sublittoral to mid-bathyal, 80-1000 m (Clark, 1911; A. & A., 1965; O.S.U., 1962-70).
Oregon distribution: Outer sublittoral to mid-bathyal, 80-1000 m (Clark, 1911; A. & A., 1965; O.S.U., 1962-70).
Substrate: Clark (1911), O.S.U. collections, and benthic photography (Kulm, per. comm.) indicate that this species occurs almost solely on rock outcroppings and ledges.

Ophiophthalmus eurypoma (Clark) Matsumoto, 1917. J. Coll. Sci., Tokyo, 38:106.
Ophiacantha eurypoma Clark, 1911. Bull. U.S.N.M. 75:223.
Geographical distribution: Alaska, Oregon; lower bathyal to abyssal, 2000-2900 m (Clark, 1911; O.S.U., 1962-70).

Oregon distribution: Lower bathyal only, 2100 m (O.S.U., 1962-70). As Clark (1911) lists this species from Alaska and 1569 fathoms only, the collections by O.S.U. constitute a geographical and depth distribution extension.

Ophiacanthella acontophora (Clark) Matsumoto, 1917. J. Coll. Sci., Tokyo 38:123.
Ophiomitra acontophora Clark, 1911. Bull. U.S.N.M. 75:190.
Geographical distribution: Bering Sea, Aleutian Islands, Alaska, Oregon; upper bathyal to abyssal, 400-2400 m (Clark, 1911; D'yakonov, 1967; O.S.U., 1962-70).
Oregon distribution: One collection only by O.S.U. in 1966 from 1260 m off central Oregon. This collection however, does expand the geographical distribution of the species to Oregon.

Ophiacantha bathybia Clark, 1911. Bull. U.S.N.M. 75:233.
Geographical distribution: Bering Sea, British Columbia, Alaska, Oregon, lower bathyal to abyssal, 1600-5000 m (Clark, 1911, 1915; D'yakonov, 1967; O.S.U., 1962-70).
Oregon distribution: Lower bathyal to abyssal, 1600-5000 m (O.S.U., 1962-70). Reported by Clark (1911) and D'yakonov (1967) from Japan and as far south in the N.E. Pacific as British Columbia and only as deep as 3606 m. The collections by O.S.U. constitute a geographic extension to Oregon and depth extension to 5000 m.

Ophiacantha trachybactra Clark, 1911. Bull. U.S.N.M. 75:206-207.
Ophiolebes trachybactrus (Clark, 1911) Clark, 1915. Mem. M.C.Z. Harvard. 25(4):195.
Geographical distribution: Sea of Okhotsk, Bering Sea, Alaska, Oregon, mid-bathyal, 800-2100 m (Clark, 1911; D'yakonov, 1967; O.S.U., 1962-70).
Oregon distribution: Bathyal regions-off central Oregon, 1244 to 2100 m. In one collection, 1244 m, occurred in close association with a branching calcareous sponge (O.S.U., 1962-70).

[redacted] sp. nov. Figures 1 and 2.
Philology: [redacted], referring to the solely abyssal distribution of the species.
Description:

Disc diameter 18 mm; arm length approximately 80 mm.

Disc rounded, covered with skin bearing thorny stumps. Radial shields completely covered with thorny stumps, conspicuous as raised areas. Aboral arm plates obtusely triangular, distal edges rounded; significantly broader than long, basal plates well separated. First three or more plates bear thorny stumps on distal edges. Oral interbrachial spaces covered to or nearly to oral shield with thorny stumps as on disc. Genital slits large, conspicuous. Oral shield pentagonal, wider than long, center concave, distal edge bearing a varying number of thorny stumps or short spines as on disc. Adoral shields medium, curved, inconspicuous, bearing a varying number of papillae. Oral papilla highly variable, in one to several rows on each side of jaw.

All under arm plates with small tubercles or swelling in center. First under arm plates modified sectors of a circle with rounded distal edge and truncated proximal side, wider than long. Side arm plates large, meeting above and below, separating aboral and oral arm plates. Each side arm plate bearing eight smooth, or slightly serrated stout spines. Tentacle scales single, basal scales broad at base with pointed tip, distal scales spiniform. Color (in life) rust-red with black-appearing oral papillae. Type: Cat. No. U.S.N.M. xxxxx from Tuft's Abyssal Plain off Oregon.

[redacted] is distinguished from most other members of the genus by the proliferation of oral papillae, the aboral arm plates, and oral shields bearing spines on their distal edges. Ophiacantha spectablis Sars and O. anomala Sars resemble [redacted] in possessing some of these features. However, their distribution is restricted to the Eastern Atlantic above 2000 m (D'yakonov, 1967; Mortensen, 1933). Distribution: Abyssal areas only off Oregon and northern California, 3354-4260 m.

Suborder Gnathophiurina
Family Ophiactidae

Ophiopholis aculeata (Linnaeus) Gray, 1848. Rad. Animal Brit. Museum. p. 25.
Nomenclature, geographic distribution, and behavior (Kyte, 1969).
Oregon distribution: littoral to upper bathyal, intertidal to 700 m (Clark, 1911; A. & A., 1965; O.S.U., 1962-70).

Ophiopholis bakeri McClendon, 1909. Univ. Calif. Publ. Zool. 6:41.
Geographical distribution (Kyte, 1969).
Oregon distribution: Outer sublittoral to upper bathyal, 55-700 m (Clark, 1911; A. & A., 1965; O.S.U., 1962-70).

Ophiopholis longispina Clark, 1911. Bull. U.S.N.M. 75:119.
Geographical distribution (Kyte, 1969).
Oregon distribution: Upper bathyal only, 500-975 m (Clark, 1911; A. & A., 1965; O.S.U., 1962-70).

Family Amphilepidae

Amphilepis platytata Clark, 1911. Bull. U.S.N.M. 75:171.
Geographical distribution: Japan, Alaska, Oregon; abyssal only, 2100 - 5000 m (Clark, 1911; O.S.U., 1962-70).
Oregon distribution: abyssal only, 2100-5000 m. Clark (1911) reports this species only from Alaska and Japan. O.S.U. collections have extended the distribution to Oregon.

Family Amphiuridae

Pandelia carchara (Clark) Fell, 1962. Trans. Roy. Soc. New Zealand (Zool.)

2:9.
Nomenclature and geographical distribution (Kyte, 1969).
Oregon distribution: Mid-bathyal to abyssal, 1000 - 5000 m (O.S.U., 1962-70). Since Clark (1911) reported this species from the Bering Sea and as far south as Washington, these collections have extended the geographical range of the species.

Amphiura koreae Duncan, 1879. J. Linn. Soc. London. 14:466.
Amphiura diomedaeae Lütken and Mortensen, 1899. Mem. Mus. Comp. Zool. 23: 151.
Geographical distribution: Philippine Islands, Korea, Japan, Oregon, California, Central America; outer sublittoral to abyssal, 70-2900 m (D'yakonov, 1967; O.S.U., 1962-70).
Oregon distribution: Upper bathyal to abyssal, 450-2865 m (A. & A., 1965; O.S.U., 1962-70).

Unioplus macraspis (Clark) Fell, 1962. Trans. Roy. Soc. New Zealand (Zool.) 2:16.
Nomenclature and geographical distribution (Kyte, 1969).
Oregon distribution: Outer sublittoral, 100-400 m (O.S.U., 1962-70). This species has not been reported previously from Oregon. It occurs commonly in the N.W. Pacific but has been reported in the N.E. Pacific only as far south as Washington. O.S.U. collections have extended the distribution of this species to Oregon.

[redacted] (Clark) comb. nov.
[redacted] Clark, 1911. Bull. U.S.N.M. 75:158.
This species has been placed in [redacted] after comparing the type and collected specimens with Fell's (1962) description of the new genus, [redacted]. [redacted] is very similar to U. macraspis placed in [redacted] by Fell (1962), and there is some doubt as to whether the species are distinct. This similarity was noted by Clark(1911).
Geographical distribution: Japan, Bering Sea, Oregon, California; outer sublittoral to upper bathyal, 100-600 m (A. & A., 1965; D'yakonov, 1967; O.S.U., 1962-70).
Oregon distribution: Two collections only, northern and central Oregon, 584 and 102 m, respectively (A. & A., 1965; O.S.U., 1962-70).

Unioplus strongyloplax (Clark) Fell, 1962. Trans. Roy. Soc. New Zealand (Zool.) 2:16.
Nomenclature and distribution (Kyte, 1969).
Oregon distribution: Outer sublittoral to mid-bathyal, 100-550 m (A. & A., 1965: O.S.U., 1962-70).

Axiognathus pugetana (Lyman) Kyte, 1969. J. Fish. Res. Bd. Canada 26:1727-1741.*
Amphipholis pugetana (Lyman) Verrill, 1899. Trans. Conn. Acad. 10:322.

---

* The detailed treatment of this species by Kyte (1969) was inadvertantly omitted during publication. Therefore, nomenclature and distribution of this species in Washington and Southern British Columbia must be given here.

Amphiura pugetana Lyman, 1870. Proc. Boston Soc. nat. hist. 7:193.
Geographical distribution: North American coast, California, Peru, Northern Japan; littoral to bathyal, intertidal to 500 m (D'yakonov, 1967; Clark, 1911, 1915).
Washington and Sourthern British Columbia distribution: Reported tentatively from the outer coast (Lie, per. comm.), Straits of Juan de Fuca (Clark, 1911), Georgia Straits (Nielsen, 1932), San Juan Islands (Kyte, unpub.), Puget Sound (Ting, unpub. 1965); littoral and sublittoral, intertidal to 180 m.
Oregon distribution: Littoral to outer sublittoral, intertidal to 90 m (Ricketts, Calvin, Hedgpeth, 1968; Clark, 1911).
Substrate: muddy sand, gravel, under rocks and shell on muddy sand (D'yakonov, 1967; Lie, 1968; Kyte, unpub.).

Axiognathus squamata (Delle Chiaje) Thomas, 1966. Bull. Mar. Sci. Gulf & Carribean 16:831.
Nomenclature, distribution, and behavior (Kyte, 1969).
Oregon distribution: Littoral to upper bathyal, intertidal to 800 m (O.S.U., 1962-70).

Diamphiodia occidentalis (Lyman) Fell, 1962. Trans. Roy. Soc. New Zealand (Zool.) 2:16.
Nomenclature, distribution, and behavior (Kyte, 1969).
Oregon distribution: Intertidal only in central protected outer coast areas.

Amphiodia urtica (Lyman) Verrill, 1899. Trans. Conn. Acad. 10:313.
Nomenclature, distribution, and behavior (Kyte, 1969).
Oregon distribution: Outer sublittoral only, 100-200 m (O.S.U., 1962-70).

Amphiacantha gastracantha (Lütken and Mortensen) Matsumoto, 1917. J. Coll. Sci., Tokyo. 38:178.
Amphioplus gastracanthus (Lütken and Mortensen) Verril, 1899. Bull. Univ. Iowa, N. ser. 1:25.
Amphiura gastracantha Lütken and Mortensen, 1899. Mem. M.C.Z. Harvard. 23:156.
Geographical distribution: Mexico, Oregon; mid-bathyal, 1207-1600 m. There are only two reported collections of this species. Lütken and Mortensen (1899) collected it off Acapulco, Mexico from 1207 m and Oregon State University collected it off central Oregon from 1600 m.

KEY TO THE OPHIUROIDEA OF SOUTHERN BRITISH COLUMBIA, WASHINGTON AND OREGON

The following key has been expanded from one prepared for the species from Washington and southern British Columbia (Kyte, 1969). It includes species from Oregon, Washington, and southern British Columbia have been collected off Oregon. One species, *Diamphiodia periercta*, requires ecological conditions not found in Oregon, but has been left in the key for comparative purposes. The specimens collected by O.S.U. include all of those species collected by the ALBATROSS (Clark, 1911) and all but two collected by A. & A. (1965). These two are Astroschema sp. and Asteronyx excavata. Astroschema sp. is not included in the key because of the lack of a specific designation. Asteronyx excavata is omitted because of its doubtful identification by Mr. Fred C. Ziesenhenne as noted by A. & A. (1965).

Fell (1960) gives an excellent explanation and diagrams of the terms used in this key.

KEY TO THE OPHIUROIDEA OF SOUTHERN BRITISH COLUMBIA, WASHINGTON & OREGON

1(6). Disc and arms covered with thick skin, granules may or may not be present; a layer of plates or scales may or may not be present; arm joint vertebrae articulating by broad, hourglass-shaped surfaces enabling arms to roll into vertical coils .... Order Phrynophiurida

2(5). Arms slender and unbranched; thick soft skin without granules covering disc and arms.

3(4). Thick, soft skin covering scales and plates becoming visible after drying; arm spines erect; ventral arm plates present; oral angles bearing spiniform oral papillae resembling teeth and tooth papillae.
Family Ophiomyxidae: .... Ophiscolex corynetes

4(3). Disc and arms cover with thick skin; no plates or scales, only radial shields extending to center of disc show through; arms long and whip-like; eight or nine hook-shaped arm spines per joint.
Family Asteronychidae: .... Asteronyx loveni

5(2). Arms branching; disc and arms covered by skin imbedded with granules; rib-like radial shields; arm spines beginning from base of arm.
Family Gorgoncephalidae: .... Gorgoncephalus caryi

6(1). Disc and arms not covered by skin; plates or scales always present on arms and disc; arm joint vertebrae articulate by ball and socket joints or with interlocking processes; arm spines placed laterally on arms which are simple and move in horizontal positions: .... Order Ophiurida

7(27). A pair of infradental papillae at apex of jaws; arms long and slender.. Family Amphiuridae

8(12). Two oral papillae not forming a continuous row along the jaws, a gap occurs between infradental papilla and outer papilla arising from the adoral plate; an additional papilla occurs dorsal and distal to infradental papilla. .... Amphiura group

9(10). Disc scales bearing spines..............Amphiacantha gastracantha

10(11). Disc scales not bearing spines; disc scaled above but partially or wholly naked below; one tentacle scale.............. Pandelia carchara

11(10). Disc scaled completely above and below; two tentacle scales. .... Amphiura koreae

12(8). Continuous row of three or more oral papillae along each jaw; tentacle scales various.

13(18). Four or five oral papillae; one tentacle scale, sometimes a second rudimentary scale on the basal pores; 4-6 arm spines.... Genus Unioplus

14(17). Radial shields short; disc scaled with irregular scales with no definite arrangement.

15(16). Interbrachial spaces finely scaled; upper arm plates more or less triangular with truncated angles, in contact with each other, at least at base of arm, rather wider than long; oral shields pentagonal or hexagonal .... [redacted] ([redacted]).

16(15). Interbrachial spaces practially naked with no scales; upper arm plates more or less rounded, little wider than long, scarcely in contact even at base of arm; oral shields large and pointed within, rounded laterally, truncate distally, about as long as wide .... Unioplus strongyloplax (= Amphioplus).

17(14). Radial shields long and crescentic; disc scales larger near radial shields; all other features similar to U. euryaspis .... Unioplus macraspis (= Amphioplus).

18(13). Three oral papillae.

19(22). Basal oral papillae at least twice as long as the second.

20(21). Oral shields more elongate transversely than longitudinally; arm-disc ratio 4-5:1; arm spines equal in length to one arm segment .... Axiognathus squamata

21(20). Oral shields more elongate longitudinally than transversely; arm-disc ratio 7-8:1; arm spines one and one-half times length of arm segment. .... Axiognathus pugetana

22(19). Three sub-equal oral papillae.

23(26). Three sub-equal oral papillae on each side of each jaw; two tentacle scales; disc bordered with definite, flat marginal scales, not bearing minute spines; no conspicuous primary scales; ventral arm plates not notched on distal side.

24(25). Specimens collected in Washington are very large with arms up to 20 cm. long or more; disc is large and often swollen with orange gonads and is easily lost; radial shields small and closely joined for most of their length; three terete arm spines.............................. Diamphoidia periercta

25(24). Smaller than D. periercta with flat rounded arm spines; radial shields relatively round, slightly divergent with single row of scales between them.................................. Diamphiodia occidentalis

26(23). Disc sometimes bordered with marginal scales bearing minute spines; one or two tentacle scales; small, conspicuous primary scales; three terete arm spines; radial shields elongated oval, tapering within and closely joined for most of their length; under arm plates notched on the distal side.
.... Amphiodia urtica

27(7). No pair of infradental papillae at the jaw apex; arms shorter and more stout.

28(53). Disc overhangs arm base and arms appear to emerge from oral side.

29(48). A continuous row of oral papillae along edge of jaw.

30(31). Disc covered with flat naked scales; arms smooth and slender; second podial pore outside mouth slit; a single infradental papillae with two wide truncate papillae on each side of jaw; no tentacle scales; an abyssal species. Family Amphilepidae: .... Amphilepis platytata

31(30). Disc covered with tubercules, short spines, or scales or both; arms knotty with swelling on each joint; second podial pore located inside mouth slit. .... Family Ophiacanthidae

32(41). Radial shields short and rounded or triangular.

33(34). Radial shields usually concealed by tubercules or granules; disc with dense granules or very low tubercules; mouth angle and outer edge of oral shield set with granules; most distal oral papillae large and opercular.
.... Ophiolimna bairdi

34(33). Radial shields usually naked; disc sparsely covered with granules; mouth angle and oral shield without granules........... Genus Ophiophthalmus

35(40). Distal edges of proximal aboral arm shields with granules or tubercules; arm spines smooth or slightly serrated.

36(39). Three or four oral papillae on each side of jaw.

37(38). Three long, thin oral papillae on each side of jaw; one small pointed tentacle scale; four smooth arm spines per arm joint.... Ophiophthalmus normani

38(37). Three or four large, flat oral papillae; tentacle scale large, flat, curved; six or seven smooth arm spines......... Ophiophthalmus cataleimmoidus

39(36). Five to seven or more flat, narrow, blunt oral papillae on each side of jaw; two or three flat, narrow tentacle scales; seven or eight smooth arm spines .... [redacted]

40(35). Arm spines thorny or serrated; distal edges of proximal aboral arm shields without granules or tubercules; outer oral papillae wide and blunt; one large flat tentacle scale .... Ophiophthalmus eurypoma

41(32). Radial shields long and narrow.

42(43). Radial shields joined in pairs and more or less naked; disc covered with scales carrying long, thin spines; single tentacle scale of moderate size; small species.............................. Ophicanthella acontophora

43(42). Radial shields divergent and rod-like, usually concealed; disc usually completely covered with skin bearing tubercules or fine spinelets concealing scales...................................... Genus Ophiacantha

44(47). Single row of oral papillae on each side of jaw.

45(46). Outer oral papillae flat, wide, and pointed; tentacle scale thorny or smooth; lower arm spines thorny; oral papillae smooth .... Ophiacantha bathybia

46(45). Oral papillae subequal, narrow, bluntly pointed; tentacle scale thorny; oral papillae slightly serrate .... Ophiacantha trachybactra

47(44). Oral papillae disposed in two or more rows on oral plate; seven to nine smooth or serrate arm spines per arm joint; one small pointed tentacle scale; a large species; confined to abyssal depths. .... [redacted]

48(29). Oral papillae separated from the infradental papillae and not forming a continuous row; disc bearing variable spines; dorsal arm plates surrounded by supplementary pieces.
Family Ophiactidae .... Genus Ophiopholis

49(52). Supplementary pieces very small and granule-like or pointed; disc spines complex with several points and few and long.

50(51). Radial shields large and bare; disc spines few and long; upper arm spines equal to about three arm joints in length .... Ophiopholis longispina

51(50). Radial shields and disc completely covered by slender, more or less thorny spines; upper arm spines equal to about two arm joints or less in length.. Ophiopholis bakeri

52(49). Supplementary pieces large and angular; disc spines simple and coarse; arm spines several, short and thick; color highly variable... .... Ophiopholis aculeata

53(28). Arms emerge directly from disc, disc does not appear to overhang the arm bases; usually more than ten oral papillae per jaw.. Family Ophiuridae

54(61). Disc not notched at base of arms.

55(56). Arm comb present; tentacle pores present entire length of arm; basal dorsal arm plates carrying a transverse row of spinules; three sharp slender arm spines.. Ophiocten pacificum

56(55). No arm comb; only two to four pair of tentacle pores; arm spines short and numerous; no spinules on basal dorsal arm plates .... Genus Ophiomusium

57(58). Two pair of tentacle pores; six to eight rudimentary arm spines; disc covered with small but distinct irregular scales; disc rounded and slightly swollen.. Ophiomusium lymani

58(57). More than two pair of tentacle pores.

59(60). Three pair of tentacle pores; three small, blunt arm spines; disc covered with numerous scales, interradial marginal plate and radial shields prominent; disc thin and flat......................... Ophiomusium jolliensis

60(59). Four pairs of tentacle pores; twelve to sixteen short, slender, pointed arm spines; disc covered with numerous, irregular, rounded, small plates more or less embedded in skin; disc flat, thin and pentagonal with large radial shields...............................Ophiomusium multispinum

61(54). Disc notched at the base of arms.

62(65). Disc high, thick with stout, often swollen plates........ .... Genus Amphiophiura

63(64). Disc very high and thick, set with high protuberances formed by swollen plates; two series of arm spines .... Amphiophiura ponderosa

64(63). Disc stout, flat or slightly arched, no high protuberances; single series of five small, thick, blunt, well-spaced arm spines .... Amphiophiura superba

65(62). Disc low and flat .... Genus Ophiura

66(67). Thick granular skin completely covering disc; disc notches not distinct; arm combs well-developed; seven to nine short arm spines ... . Ophiura cryptolepis

67(66). Disc not covered with granular skin; disc notches distinct; arm combs various; fewer arm spines.

68(71). Arm comb papillae blunt, flat and forming a continuous row.

69(70). Arm comb papillae short, broad, and flat; disc scales large and distinct; proximal oral papillae long and pointed, distal oral papillae broader, truncate; disc high and thick................. Ophiura lütkeni

70(69). Arm comb papillae longer, broad, blunt; disc scales small and even; all oral papillae except those at jaw apex, small and truncate...... .... Ophiura irrorata

71(68). Arm comb papillae not flat or forming continuous row.

72(75). Arm comb papillae fine and acicular.

73(74). Radial shields three times as long as wide, crescentic, widest at distal ends, entirely separated; disc scales small and numerous with minute spinelets which leave pit when rubbed off .... Ophiura bathybia

74(73). Radial shields two times longer than wide, diverging but not crescentic, sometimes touching at distal end; disc scales flat and larger with centro-dorsal scale conspicuous, sometimes minute spinelets present on scales .... Ophiura leptoctenia

75(72). Arm comb papillae short, coarse, conical, and well separated; disc scales large and conspicuous; radial shields roughly triangular and separated only by single row of scales........................... Ophiura sarsii

DISCUSSION

The study of Oregon State University collections since 1962 has greatly expanded the knowledge of ophiuroid systematics and ecology in the N.E. Pacific. The distribution of nine species is extended, the nomenclature of two species, [redacted] and [redacted] is revised, and a new species of [redacted] from Tuft's Abyssal Plain in the Northeast Pacific is described. Further evidence of the importance of this collection is that all of the fifteen species added to those from Washington and British Columbia (Kyte, 1969) are from below 200 meters. From this depth distribution and the wide distribution of other deep-sea species it can be hypothesized that many of those fifteen species range into Washington waters and perhaps futher northward. However, no collection data are available from off-shelf areas of Washington and British Columbia later than the ALBATROSS collections of 1889 to 1906.

The taxonomy of the Ophiuroidea is highly artificial. Without precise knowledge of the functional morphology and reproductive behavior a taxonomic character cannot be related to its biological and genetic importance. For example, spines or thorny stumps on the proximal aboral arm plates probably serves no obvious function and often vary between individuals of the same species. However, this character is used to distinguish certain species and genera. On the other hand, the number and shape of the oral papillae are probably quite important in feeding processes and these characters may have a biological basis. The reproductive habits of ophiuroids are seldom used taxonomically because little is known of this aspect of their behavior. Research presently in progress on the reproductive habits and ecology of several species will hopefully benefit the systematics of the group.

ACKNOWLEDGMENTS

The collections used in this study have been made under a series of grants from the National Science Foundation, grants GB-531 and GB-4629, and ship operations grant GD-27257, from the Atomic Energy Commission, AT(45-1)-2227, task order 12. This manuscript has been assigned publication number RLO-2227-T12-12. The assistance of ship support personnel and technicians is gratefully acknowledged.

In writing this paper I am particularly indebted to Dr. Dave Pawson of the Smithsonian Institution for his continuing advice and help with type specimens. I am also indebted to Drs. James McCauley and Andrew G. Carey, Jr., for their extensive advice and encouragement and for critically reading the manuscript at several stages.

REFERENCES

Astrahantseff, S. and M.S. Alton. 1965. Bathymetric distribution of brittle stars (Ophiuroidea) collected off the Northern Oregon Coast. J. Fish. Res. Bd. Canada 22:1407-1424.

Barnard, J.L. and F. C. Ziesenhenne. 1961. Ophiuroid communities of southern Californian coastal bottoms. Pac. Naturalist, 2:131-152.

Clark, H. L. 1911. North Pacific Ophiurans in the collection of the United States National Museum. Bull. U.S. Natl. Museum 75:1-295.

Clark, H. L. 1915. Catalog of Recent Ophiurans. Mem. Museum Comp. Zool. Harvard 25:180-340.

D'yakonov, A. M. 1967. Ophiuroids of the U.S.S.R. seas. Zool. Inst. Acad. Sci. U.S.S.R. 55:1-123.

Fell, H. B. 1960. Synoptic key to the genera of Ophiuraidea. Zool. Pub. Victoria University at Wellington. Number 26:1-44.

Hartman, O., and J. L. Barnard. 1958. The benthic fauna of the deep basins off southern California. Allan Hancock Pacific Expeditions, 22(1):67.

Hartman, O. and J. L. Barnard. 1960. The benthic fauna of the deep basins off southern California. Allan Hancock Pacific Expeditions, 22(2):297.

Hyman, L. H. 1955. The Invertebrates: Echinodermata. Vol. 4 McGraw-Hill Book Company, Inc. New York. 763 pp.

Kyte, Michael A. 1969. A synopsis and key to the recent Ophiuroidea of Washington state and southern British Columbia. J. Fish. Res. Bd. Canada 26:1727-1741.

Lie U. 1968. A quantitative study of benthic infauna in Puget Sound, Wn. U.S.A. in 1963-1964. Fiskerdirektorat. Skrifter Sec. Havunders 14:229-556.

Lütken, C. F. and Th. Mortensen. 1899. Reports on an exploration off the west coasts of Mexico, Central and South America, and off the Galapagos Islands, in charge of Alexander Agassiz, by the U.S. Fish Commission Steamer ALBATROSS, during 1891, Lt. Commander Z. L. Tanner, U.S.N. Commanding XXV. The Ophiuroidea. 116 p. 23 pl.

McClendon, J. F. 1909. The Ophiurans of the San Diego region. Univ. Calif. Publ. Zool. 6:33-64.

Mortensen, Th. 1933. Ophiuroidea. The Danish Ingolf Expedition 4(8):1-121.

Nichols, David. 1966. Echinoderms. Hutchinson University Library, London, 200 p.

Nielsen, E. 1932. Papers from Dr. Th. Mortensen's Pacific Expedition, 1914-16. LIX. Ophiurans from the Gulf of Panama, California, and the Straits of Georgia. Vidensk. Medd. Dansk Naturv. Forh. 91:241-346.

O.S.U. 1962-70. Unpublished collection research. Department of Oceanography. Oregon State University.

Ricketts, E. F., J. Calvin, and J. Hedgpeth. 1968. Between Pacific Tides. 4th ed. Stanford University Press, Stanford, Calif. 516 pp.

Ting, R. Y-M. M.S. 1965. Ecology of demersal animals: problems in sampling. Ph.D. Thesis College of Fisheries, University of Washington, Seattle, Wash.

A REDESCRIPTION OF OPHICANTHA RHACHOPHORA CLARK AND A DESCRIPTION OF [redacted] SP. N.* (ECHINODERMATA: OPHIUROIDEA).

by Michael Allen Kyte

ABSTRACT

Ophiacantha rhachophora Clark, 1911, from Japan is redescribed. Bering Sea specimens of O. rhachophora are separated as a distinct species, [redacted] sp. nov. Complete descriptions with photomicrographs and discussions of the taxonomic status of both species are included.

INTRODUCTION

Recently, the type specimen of Ophiacantha rhachophora Clark, 1911, was obtained from the United States National Museum for comparison with material collected off Oregon. A routine examination of the specimen revealed definite discrepancies between it and Clark's original description and figures. Clark gave a very brief description including a complete drawing of O. rhachophora referring to the descriptions of O. levispina Lyman, 1878, and O. adiaphora Clark, 1911. Further specimens of O. rhachophora were obtained in an effort to match Clark's specimens to his published description. However, the specimens that were received had been collected from the Bering Sea and, although similar to O. rhachophora were significantly different. Because of these differences and the geographical separation of the two groups of specimens, the Bering Sea specimens are described as a new species. More specimens from near the type locality were then requested and received from the Museum. Most of these specimens closely resembled the type of O. rhachophora. However, specimens labeled O. rhachophora, USNM 26985, from Albatross Station 4809 (1906) not resembling the type were reidentified as O. adiaphora. Other specimens obtained at a later date were also identified as O. adiaphora. There were USNM 27060, O. rhachophora; four specimens of O. adiaphora; and USNM 26605, O. rhachophora, two specimens, one identified as O. rhachophora, one identified as O. adiaphora.

Matsumoto (1917) published a brief description and figure of specimens that he had identified as O. rhachophora. His figures resembled Clark's type specimen quite closely except for some minor differences.

---

* This manuscript will be submitted to the Journal of the Fisheries Research Board of Canada. To prevent nomenclature problems, new names and new combinations have been deleted.

RLO 2227-T12-11.

<u>Ophiacantha</u> <u>rhachophora</u> H. L. Clark, 1911. Bulletin USNM 75: 201-202.

(Figures 1 and 2)

Description: <u>Ophiacantha</u>. Disc diameter 5.0 mm; arm length approximately 20 - 30 mm (no intact arms).

Disc aboral surface thickly covered with minute thorny stumps. Radial shields exposed, bare at distal tips. Upper arm plates triangular, widely separated, without spines. Oral interbrachial spaces covered with thorny stumps like on disc except immediately distal to oral shield where scales are visible. Genital slits large, conspicuous. Oral shield triangular, longer than wide with distal obtuse lobe joining disc oral interbrachial space. Adoral shields relatively massive, wider without than within, sometimes bearing one thorny papilla. Oral shield and first lateral arm segment separated by adoral shields. Each jaw bearing six oral papillae and one infradental papilla; distal oral papillae markedly thorny; more proximal papillae flatter and broader, sometimes bifid at tips. First oral arm plate small, pentagonal, slightly wider than long; succeeding plates larger, triangular, wider than long, well separated. Lateral arm plates broad, meeting both orally and aborally, separating oral and aboral arm plates. Lateral plate bearing six to eight arm spines. Spines extending completely over top of arm on most proximal arm segment. Lower arm spines very thorny with definite thorns extending to tip of spines. Serration becoming less extensive on upper spines and occurring only at bases on uppermost. Second spine from tip longest, about two to three joints long. Tentacle scale single, slender, pointed, markedly thorny.

Distribution: Japanese outer sublittoral and upper bathyal, 63-505 fm. Clark, 1911; Matsumoto, (1917).
Type: Because of the variability of this species and the confusion surrounding it the above description applies to both Clarks's original holotype and designated paratypes. Clark's holotype of <u>O.</u> <u>rhachophora</u> is USNM 25630 (Clark's, 1911, type). USNM 26704 (from Albatross Station 5091), and USNM 26048 (from Albatross Station 4893) are designated as paratypes.

DISCUSSION

The above description differs from Clark's (1911) original description and figures in several points: the arm spines on the most proximal arm segment meet on the aboral side of the arm; the uppermost arm spines are thorny at the base; the genital slits are large and conspicuous; the oral shields are definitely triangular, longer than wide with a lobe distally joining with the oral interbrachial space, separated from the first lateral arm plates by the aboral shields.

Matsumoto's (1917) description <u>O.</u> <u>rhachophora</u> differed from the type specimen in stating that the outermost oral papillae arise from the adoral shields and one scale-papilla occurs on the first oral arm plate, projecting inwards and vertically. However, he does not figure this papilla and it is not clear as to its placement. The uppermost arm spines are not thorny at their bases as shown in his figures. These variations are not important enough to separate further specimens of this species. One of the designated paratypes, USNM 26704, possesses the papilla arising from the adoral plate but is still obviously O. rhachophora.

However, specimens labeled O. rhachophora from three Albatross stations in the Bering Sea differ significantly from the type of O. rhachophora. These differences are both geographic and morphological and form the basis of a new species, [redacted]

[redacted] sp. nov. (figures 3 and 4).
Philology: [redacted]; referring to the shape of the aboral arm plates.
Description: Ophiacantha. Disc diameter 4 - 6 mm; arm length approximately 25 - 30 mm. Aboral surface of disc completely covered with thorny stumps; radial shields and all scales completely hidden. Upper arm plates variable from triangular, distal edge rounded, to shield-shaped, widely separated; first two basal upper arm plates bearing thorny stumps like those covering disc. Oral interbrachial spaces more sparsely covered with stumps, scales partially visible especially near oral shields. Genital slits small, inconspicuous. Oral shields quadrangular, slightly wider than long. Adoral shields relatively massive, rectangular. Oral shield and first lateral arm plates not separated by adoral shields. Each jaw bearing six to ten blunt oral papillae and one infradental papilla. All oral papillae slightly serrate, distal papillae slightly more so. First oral arm plate variable, small to medium size, triangular to pentagonal. Succeeding plates larger, pentagonal, corners rounded, shallow notch sometimes in distal side. Lateral arm plates broad, meeting both orally and aborally, separating oral and aboral arm plates; each lateral plate bearing six arm spines. Lower arm spines very thorny. Serration decreases on ascending spines, top spine entirely smooth, longest, 2-1/2 to 3 arm joints. Tentacle scale single, spiniform, slightly thorny at tip. Color, dried and in alcohol, brownish white.

Distribution: Bering Sea, Albatross stations 4771, 4772, and 4775; upper bathyal, 344-584 fm. (Clark, 1911).

Type: Holotype: Cat. No. USNM 26241. Paratype: USNM 26698. From Albatross Stations 4771 and 4772.

DISCUSSION

[redacted] sp. nov. is similar in appearance to Clark's (1911) O. rhachophora, but differs in being distributed in the Bering Sea whereas O. rhachophora has been collected entirely to date in Japanese waters and the Eastern Sea (Clark, 1911; Matsumoto, 1917). Although the depth ranges of the two species overlap, O. rhachophora is found in somewhat shallower water than [redacted].

[redacted] although close to O. rhachophora differs in several morphological characters. The distal tips of the radial shields are hidden, the basal upper arm plates bear thorny stumps, the genital slits are small and inconspicuous, the oral shields are quadrangular and wider than long, first lateral arm shields and oral shields are not separated by the adoral plates, the arm spines on the first basal segment do not meet on the aboral side of the arm segment, and the uppermost arm spine is entirely smooth. [redacted] has six to ten oral papillae that are only slightly serrate whereas those of O. rhachophora are markedly thorny. A papillae does not arise from the adoral shield in [redacted]. The above differences indicate clearly that Clark's (1911) Bering Sea specimens of O. rhachophora should be separated as a distinct species.

ACKNOWLEDGMENTS

I wish to acknowledge especially Dr. David Pawson and Dr. James McCauley for their advice and encouragement in the preparation of this paper. Financial support was provided by the U. S. Atomic Energy Commission Contract AT(45-1)-2227 Task Agreement No. 12. RLO 2227-T12-11.

REFERENCES

Clark, Hubert Lyman. 1911. North Pacific Ophiurans in the Collection of the United States National Museum. Bulletin United States National Museum 75: 1-295.

Matsumoto, H. 1917. A monograph of Japanese Ophiuroidea arranged according to a new classification. Journal of the College of Science, Tokyo 28(2): 1-408.

BIOLOGICAL FOULING ON TOTEM-1, A DEEP-SEA SPAR BUOY

by James E. McCauley, Michael A. Kyte
David L. Stein and Andrew G. Carey, Jr.

ABSTRACT

After 14 months at sea 55 km. from the Oregon coast where the bottom depth was 560 m., the surface of the spar buoy sustained biological fouling that showed vertical zonation with maximum growth about 15 m. beneath the surface. Lepas anatifera, Caprella verrucosa, Corophium sp., and Scruparia ambigua occurred in great numbers. Thirty-five other species were recognized. The absence of anemones, sponges, and tunicates is attributed to the distance from reservoir populations.

Only rarely is there an opportunity to observe the flora and fauna on a stationary floating object at sea when the history of the object is well known. Navigational buoys and lightships are the most common objects and these have usually been located near to the shore or have been moored in shallow waters of the continental shelf. A series of observations on deep-sea fouling were made by staff members of the Woods Hole Oceanographic Institution but remain unpublished (Turner, 1963) except for a species list (WHOI, 1952). More recently Dolgopoliskaya (1959) reported on the development of fouling far off the coast of Crimea in the Black Sea. She found, in a quantitative study, that fouling increased with depth of submergence to a maximum at about 10 m. from the surface, then decreased. Gunter and Geyer (1955) studied biological fouling in the northwest Gulf of Mexico on oil-drilling platforms and a moored vessel with a vertical series of collecting plates. Their observations were from near-shore stations in less than 20 m. of water. There are scattered reports from lightships and navigational buoys but these, in general, emphasized prevention and control of fouling and have not provided much data on the fauna or on depth distribution (WHOI, 1952).

Recently TOTEM-I of the Oregon State University Department of Oceanography was removed from an offshore mooring site after fourteen months in the water. TOTEM-I, a 55-meter spar buoy designed for unmanned monitoring of sea and weather conditions, was placed in position on 13 September 1969 at a site 55 kilometers west of Cascade Head, Oregon (lat. 45°2.6'N; long. 124°44'W) in 560 meters of water. About 46 m. of the buoy was submerged, but this fluctuated somewhat in the early months (until April 1970) because of a leak and periodic trimming. After April 1970, however the waterline was maintained at 46 m. with an automatic trimming device. The buoy was removed from the site on 12 November 1970 and towed to Yaquina Bay at Newport, Oregon.

Submitted to the Fisheries Research Board of Canada for publication.

The data reported here are based on observations taken on routine SCUBA inspections of the buoy while it was in place; quantitative scrapings at depths of 3, 10, 20, and 45 meters collected at sea when the buoy was returned to the horizontal position for towing to port (4 replicates, from 10 x 20 cm. areas at dach depth); and a detailed inspection of the buoy three days after it was returned to the harbor. The organisms were identified in our laboratory. Except for the annelids which were identified by Mr. D. R. Hancock, the identifications must be considered tentative.

Many of the species encountered on TOTEM-1 occur in the intertidal and subtidal biota of the nearby coast, but one species, Lepas anatifera (Linnaeus) does not generally occur intertidally and is a characteristic fouling organism of free-floating objects from the open sea.

Vertical zonation below the water line was quite apparent. The macroscopic algae were obvious only on the upper meter except for a few scattered individuals down to 20 m. depth. The largest number of animals was near the depth of 15 m. by qualitative visual inspection, and diminished gradually towards the ends of the buoy. The spar buoy had very little vertical motion (Neshyba, personal communication) and waves tended to expose and cover a rather wide zone. Notwithstanding, the biological boundary at the air-sea interface was surprisingly narrow, grading from a heavy coating of organisms to almost-clean painted metal in about 10 cm. The relationship of this narrow boundary to actual sea surface level could not be determined, nor could its relationship to the range of exposure by waves because wave data were not recorded from the buoy. Table 1 lists the organisms and their observed depth ranges.

Table 1. Numbers of caprellid and gammarid amphipods collected from 10 x 20 cm. scrapings on TOTEM-1 at 3, 10, 20, and 45 m. depths.

	Gammarids				Caprellids			
Depth:	3	10	20	45	3	10	20	45
	195	35	19	19	0	274	118	50
	410	457	51	3	2	186	200	16
	601	103	44	3	4	42	310	20
	940	396	3	2	69	166	12	13
No./m^2:	26,825	12,388	1,438	338	938	8,350	8,000	1,238

In the quantitative samples only two groups were useful, the caprellid and gammarid amphipods. Other species in the quantitative samples were either colonial forms that could not be accurately counted, or they occurred infrequently.

The Woods Hole Report (WHOI, 1952) stated that gammarid and caprellid amphipods of the genera Corophium and Caprella are more common on buoys than on other structures. On TOTEM-1 these genera were dominant forms. Their distribution was patchy but trends were apparent. The Gammarids were primarily tubicolus species that constructed a mat of tubes over the surface of the buoy providing a place of attachment for bryozoans, algae and other forms. These amphipods were probably one or more species of Corophium, but were not identified specifically. They were most abundant near the water surface and diminished with depth. The caprellids appeared to be all of the species Caprella verrucosa (Boeck), although the many sizes present made definite identification difficult. This species was most abundant at the 10 to 20 meter depths (Table 2). Corophium was not present at the surface on offshore oil well drilling structures in the Gulf of Mexico, but these amphipods were found at all other depths (Gunter and Geyer, 1955).

General non-quantitative observations showed that Lepas anatifera was abundant near the surface and decreased with depth. It was so distributed that the small quantitive samples missed it completely except at the 3-meter level. The dominant arborescent species was a bryozoan, Scruparia ambigua (d'Orbigny), covering the amphipod mat more or less uniformly from depths of 10 meters downward. Colonies of Bugula californica (Robinson) and of several species of hydroids were widely scattered. In shallow waters on the Gulf of Mexico, bryozoans (Acanthodesia) were found from the surface to 15.2 m. but were widely scattered (Gunter and Geyer, 1955).

Three species of fish were found on the buoy, the cabezon Scorpaenichthys marmoratus (Ayres); the kelp greenling Hexagrammus decagrammus (Pallas); and a rockfish tentatively identified as Sebastodes melanops (Girard). All were small. These three species are benthic species and could only have been transported to the buoy as pelagic larvae. A small school of jack mackrel, Trachurus symmetrica (Ayres) of about 107 mm. standard length remained at a depth of about 9 m. within sight of the buoy at all times unless disturbed.

Most of the solitary specimens were small for the species suggesting immaturity. No Mytilus edulis (Linnaeus) present was more than 3 cm long. Small specimens of two other pelecypods were numerous. Hinnites multirugosus (Gale) was quite abundant on the horizontal surfaces and had generally not yet become cemented to the surface as adults. Saxicava arctica (Linnaeus) tended to be located on horizontal and other irregular surfaces where they would not fall. Although Mytilus californianus (Conrad) is more common on the outer coast of the region, and could be expected to occur on TOTEM-1, none of the mussels appeared to be this species. Separation of the juveniles of M. californianus and M. edulis is difficult, but those from TOTEM-1 were shorter and broader, smoother, and had a bluish color that is not characteristic of M. californianus.

Table 2. Species with depth distributions collected from TOTEM-1 after 14 months in the open ocean. Collections from 4-15, 23, and 37 m. were non-quantitative and may not represent as complete a species list as at depths where quantitative samples were included.

Depth (meters):	0-3	9-11	14-15	18-20	23	37	43-46
Codium setchelli	x						
Enteromorpha sp	x						
E. tubulosa	x						
Ectocarpus sp.	x						
Scytosiphon lomentaria	x						
Ulva angusta	x						
Sebastodes melanops	x						
Balanus sp.	x						
Hexagrammus, *decagrammus*	x	x					
Ulva sp	x			x			
Scorpaenichthys marmoratus	x	x	x	x	x		
Halosydna brevisetosa	x	x	x	x			
Cladophora sp.	x	x		x			x
Cheilonereis cyclurus	x	x		x			x
Corophium sp.	x	x		x			x
Lepas anatifera	x	x	x	x			x
Caprella verrucosa	x	x	x	x			x
Nephthys sp.		x					
Antithamnion sp.		x	x				
Obelia longissima		x	x	x			
Pododesmus macroschisma		x	x	x			
Strongylocentrotus purpuratus		x	x		x		
Saxicava arctica		x	x	x	x		
Hinnites multrugosus		x	x	x		x	
Pecten caurinus		x				x	
Mytilus edulis		x	x	x			x
Foraminiferans		x					x
Scruparia ambigua		x	x	x			x
Syncorone mirabilis			x				
Modiolus modiolus			x	x	x		
Hermissenda opalescens			x		x		
Laminaria sp.			x				x
Platynereis bicaniculata				x			
Aphrodite parva				x			
Spriorbis sp.				x			
Isopod				x			
Amphissa columbiana					x		
Spirorbis moerchi							x
Campanularia speciosa							x
mite							x
Bugula californica							x

There were no anemones, sponges, or tunicates. There was only one balanoid barnacle. These are often dominant fouling organisms in coastal and estuarine zones (WHOI, 1952). The absence is difficult to explain. Perhaps the period of exposure (14 months) was not great enough, but this does not seem likely because barnacles have been shown to set within four weeks (WHOI, 1952). It seems unlikely that spawning seasons for these species could have been missed during the fourteen month period that the buoy was in place. Perhaps more important is the distance from a reservoir population. The movement of water in the region is primarily parallel to the coast and no extensive rocky outcrops are known from the upper continental slope near the mooring site.

ACKNOWLEDGMENTS

TOTEM-1 was part of the THEMIS project directed by Dr. Steve Neshyba and supported by a contract with the Office of Naval Research (Contract NR-083-230). This research was supported in part by the Atomic Energy Commission, contract no. AT(45-1)2227, Task Agreement 12 (Publication Number RLO-2227-T12-8).

REFERENCES

Dogopolskaya, M. A. 1959 The development of fouling in connection with the depth of submergence far off the Crimean coast in the Black Sea (in Russian). Trudy Sevastopolskoy Biologii Stantsii 12:192-208.

Gunter, G. and R. A. Geyer. 1955 Studies on fouling organisms in the northwest Gulf of Mexico. Publ. Inst. Marine Sci. University of Texas 4(1):37-67.

Turner, H. J. 1963 Deep ocean marine fouling. Oceanus 10(2):2-7.

Woods Hole Oceanographic Institution. 1952 Marine fouling and its prevention. Annapolis, Maryland, United States Naval Institute, 388 pp.

A NOTACANTHID <u>MACDONALDIA CHALLENGERI</u> COLLECTED OFF THE OREGON COAST

by David Stein and John Butler

ABSTRACT

A fifth specimen of a rare deep-sea spiny eel *Macdonaldia challengeri* is reported, extending the known range in the North Pacific Ocean to the Oregon Coast.

A female notacanth, *Macdonaldia challengeri* Vaillant (1888) of 490 mm standard length (OSU collection number 1891) was captured in a three-meter beam trawl at a depth of 2,450 meters, 120 km west of Cape Falcon, Oregon (45°39.4'N, 125°57.3'W) by R/V YAQUINA on 19 March 1970. The bottom temperature at this station was 2.03°C, salinity was 33.755%, and oxygen was 0.829 ml/l. The bottom sediment was mud.

Four specimens of *M. challengeri* have been previously reported; the holotype off Japan in 3,429 meters (Vaillant, 1888); one in the Bering Sea in 2,971 meters (Gilbert, 1896); and two off Vancouver Island in 2,103-2,196 meters (Peden, 1968).

Marshall (1962) divided the Notacanthidae into three genera according to the structure of the dorsal fin: *Notacanthus* (6-12 spines plus 1-2 rays, medium to long based); *Polyacanthonotus* (29-37 spines plus 1 ray, long based); and *Macdonaldia* (27-34 spines, long based). *Macdonaldia* is considered a synonym of *Polyacanthonotus* by McDowell (unpublished manuscript).

Although morphometric characters of our specimen are close to those previously reported, several meristic characters are not within the range of *M. challengeri* previously reported by Peden (1968), who summarized the previous morphometric and meristic data in a lengthy table. Our specimen has 37 dorsal spines (previous range 32-35), 15 pectoral fin rays (previous range 11-13), and 10 pelvic fin rays (previous range 8-9). There are 17 gill rakers on the first gill arch (previous report, 14). Fin spine and ray counts are quite variable in this family, however, even between individuals captured in the same trawl (McDowell, personal communication).

The description of the specimen generally follows that of Peden (1968), with the following elaboration: two nostrils immediately adjacent, unseparated by scales, maxillary extending behind the posterior nostril. One row each of maxillary, palatine, and mandibular teeth. Articulation of jaw horizontally level with ventral end of first gill cleft. Second dorsal spine on vertical through pectoral base. Tips of short pelvic fins almost reach anus. Intestine yellow; ovaries paired, long, thin, dorso-laterally in posterior 2/3 of body cavity. Body cavity extends short distance behind anus. Peritoneum dark brown.

Accepted for publication by Journal of the Fisheries Research Board of Canada RLO 2227-T12-3

Color in alcohol: gray with brown around scales; pectoral and pelvic fins brown; operculum blue, shading into black at posterior edges; interior of mouth and gill cavity black.

The stomach contained about 2 ml. of materials, mostly unidentifiable. All identifiable material consisted of crustacean fragments, including the anterior part of a small shrimp and the abdomen of a tenaid-like isopod. The intestine contained about 3 ml. of unidentifiable material, a few crustacean fragments, one parasitic nematode, and 15 digenetic trematodes.

The authors would like to thank Dr. Samuel McDowell of Rutgers University for his advice and for the use of his unpublished manuscript, and Dr. William G. Pearcy for his assistance and advice. This work was supported by contract No. AT(45-1)2227 Task Agreement No. 12 and has been assigned publication number RLO-2227-T12-3.

REFERENCES

Gilbert, C. H. 1896. The ichthyological collections of the steamer Albatross during the years 1890 and 1891; Report on the fishes collected in the Bering Sea and the North Pacific Ocean during the summer of 1890. Rept. U. S. Comm. Fish. 1893:393-476.

Marshall, N. B. 1962. Observations on the Heteromi, an order of Teleost fishes. Bull. Brit. Museum Zool., 9:249-270.

Peden, A. 1968. Two new specimens of the Notacanthid fish Macdonaldia challengeri in the Eastern North Pacific Ocean. J. Fish. Res. Bd. Canada, 25 (1): 181-188.

Vaillant, L. 1888. Expeditions scientifiques du "Travailleur" et du "Talisman" pendant les annees 1880, 1881, 1882, 1883. Poissons, Paris. 406 pp.

RADIOACTIVITY IN JUVENILE COLUMBIA RIVER SALMON: A MODEL TO INTERPRET MOVEMENT AND FEEDING HABITS

Gerald P. Romberg* and William C. Renfro

ABSTRACT

Juvenile salmon in the lower Columbia River took up characteristic amounts of radioactive phosphorus and zinc originating from the plutonium production reactors at Hanford, Washington. The ^{32}P specific activities (n Ci ^{32}P/g P) and ^{65}Zn activities (p Ci ^{65}Zn/g ash) of individuals provided clues regarding their movements and feeding behavior.

INTRODUCTION

In recent years hatchery rearing of salmon has become an important factor in the sport and commercial fisheries of the Pacific Northwest. Great numbers of yearling salmon are released from hatcheries to supplement the native stocks. An important factor bearing on the survival of a given batch of hatchery-reared salmon is the time and size at which they are released (Wallis, 1968). The subsequent history and behavior of the young fish in their downstream migration to the ocean may determine the success of the hatchery program.

In the Columbia River Basin a number of hatcheries supplement native chinook (Oncorhynchus tshawytscha) and coho (O. kisutch) salmon runs which have been adversely affected by hydroelectric dams. The utility of the hatchery program must be measured by the numbers of adult fish caught by sport and commercial fishermen plus those which complete their life cycle by returning to their natal stream. To improve the operation of the hatchery program, it is important to understand all parts of the life cycle of the artificially reared fish. This report suggests a means to learn more about one important phase of the salmon life cycle: the movement and feeding behavior of yearlings as they migrate to sea.

Radioisotopes of several elements are introduced in small concentrations into the Columbia River during the operation of plutonium production reactors at Hanford, Washington. The majority of these radionuclides are produced by neutron activation of impurities in the coolant water and consist of both gamma and beta emitting radionuclides. Phosphorus-32 with a half life of 14.2 days and zinc-65 with a half life of 245 days are the radionuclides of most biological importance. Phosphorus-32 decays by beta emission with no gamma emission while zinc-65 decays by electron capture and positron emission with a 48% yield of 1.12 million electron volt gamma rays. Both

* Present address: Argonne National Laboratory
Argonne, Illinois 60439

Submitted to Transactions of the American Fisheries Society, RLO 1750-84.

nuclides are concentrated by most Columbia River organisms (Foster and McConnon, 1962).

An unusual opportunity to observe the uptake of ^{32}P and ^{65}Zn by juvenile chinook salmon in the natural environment occurred when 200,000 marked yearlings were released to the Columbia River from a hatchery at Ringold, Washington. Samples of these fish were subsequently collected downstream over a period of three weeks and the ^{65}Zn concentration (^{65}Zn activity/g dry wt.) and ^{32}P specific activity (^{32}P activity/g total phosphorus) of each fish determined. The results of this uptake study permitted construction of a graphical set of boundaries (or model) which was used to interpret the recent movement and feeding habits of other unmarked juvenile chinook salmon.

METHODS

Juvenile chinook salmon marked with cold brands were released from the Ringold hatchery at 2100 hours 12 May 1969. The actual release point was approximately 300 m up the hatchery stream from the Columbia River (Fig. 1). A sample of these hatchery-reared yearlings was taken at the time of release and in the ensuing three weeks other samples of these marked fish were collected at two downstream dams by biologists of the U.S. National Marine Fisheries Service. The fish, ranging from 6.8 - 10.3 cm standard length, were dipnetted from the gate wells of the dams and immediately preserved in 10% formalin solution. They were prepared for radioanalysis (following removal and disposal of the alimentary tract contents) by vacuum drying at 60C for 24 hours. For purposes of radioactivity decay corrections, the fish were assumed to have entered the Columbia River at 2400 hours, 12 May 1969 and to have been captured at 1200 hours on the date of collection.

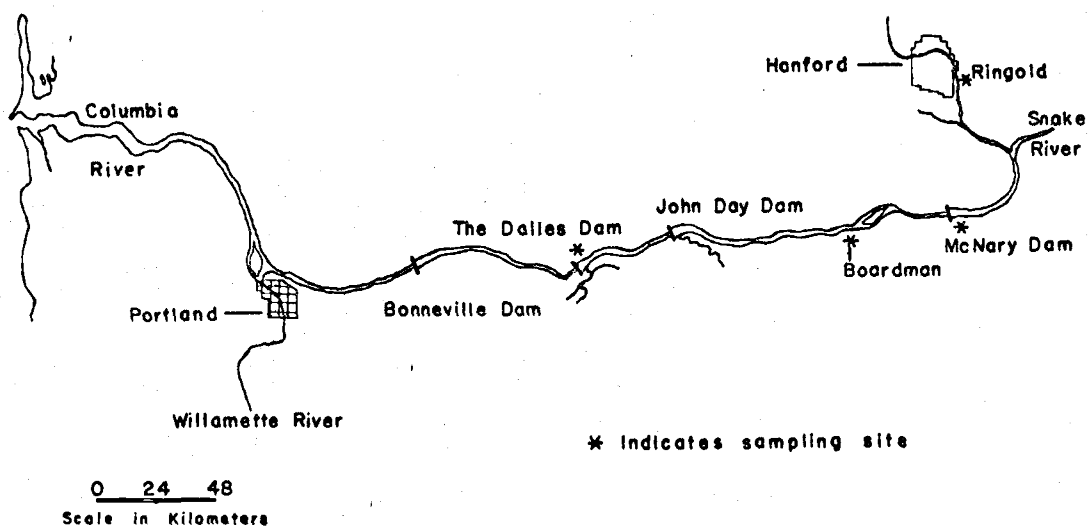


Figure 1. Map of lower Columbia River showing the locations of dams and fish sampling sites.

On 23 March 1969, a collection of 24 unmarked salmon ranging from 8.3 to 13.4 cm (standard length) was taken with a small seine from the Columbia River near Boardman, Oregon. They were packed in ice and returned to the laboratory, where muscle-bone samples were dried and radioanalyzed.

We radioanalyzed all fish for ^{65}Zn individually by placing the dried specimen anterior end first into a 12 cc plastic tube and counting for 100 minutes in a 12.7 x 12.7 cm NaI(Tl) well crystal coupled to a 512 channel analyzer. Each fish was then removed from the counting tube and dissolved in nitric acid for chemical extraction and concentration of phosphorus. Preliminary precipitation as ammonium phosphomolydate was followed by purification precipitation as ammonium phosphate. Final precipitates were collected by filtration, transferred to 2.5 x 0.8 cm stainless steel planchets, dried, weighed, and counted for ^{32}P with a low background beta counter in conjunction with a time interval printer. Percent phosphorus in the precipitate was determined by dissolving a portion of the dried precipitate and analyzing for total phosphorus using the common molybdenum blue colorimetric technique. Both ^{65}Zn and ^{32}P activities were corrected for decay to the time of collection.

RESULTS

Uptake Study

Hatchery fish contained little ^{32}P or ^{65}Zn before release. Increase in ^{32}P specific activity, as shown in Figure 2, was rapid and tended to approach a constant value around 17 nanocuries per gram phosphorus (n Ci/g P). The increase in ^{65}Zn concentration in picocuries per gram dry weight (p Ci/g dry wt.), shown in Figure 2, was also rapid but failed to approach a constant value during the sample period. In both cases interpretation of initial rate of increase depends on whether McNary and The Dalles Dam samples are considered together. The second set of McNary Dam samples have anomalously low activities, as will be shown later, and are therefore not considered here.

The solid uptake curves in Figure 2 reflect the integrated increase in radioactivity between the time fish entered the Columbia River and the time they reached The Dalles Dam. If the fish accumulated ^{32}P and ^{65}Zn at a regular rate, then the activity levels at some point before reaching The Dalles Dam should be approximated by a value on the solid curve. The first samples taken at McNary Dam and The Dalles Dam were taken the first day a large number of marked fish appeared at the dams. It is probable then that the first marked fish collected at The Dalles Dam must have passed through McNary Dam near the time that the first McNary samples were taken. Levels of radioactivity in these first McNary samples, however, are lower in relation to The Dalles samples than predicted by the solid curves in Figure 2.

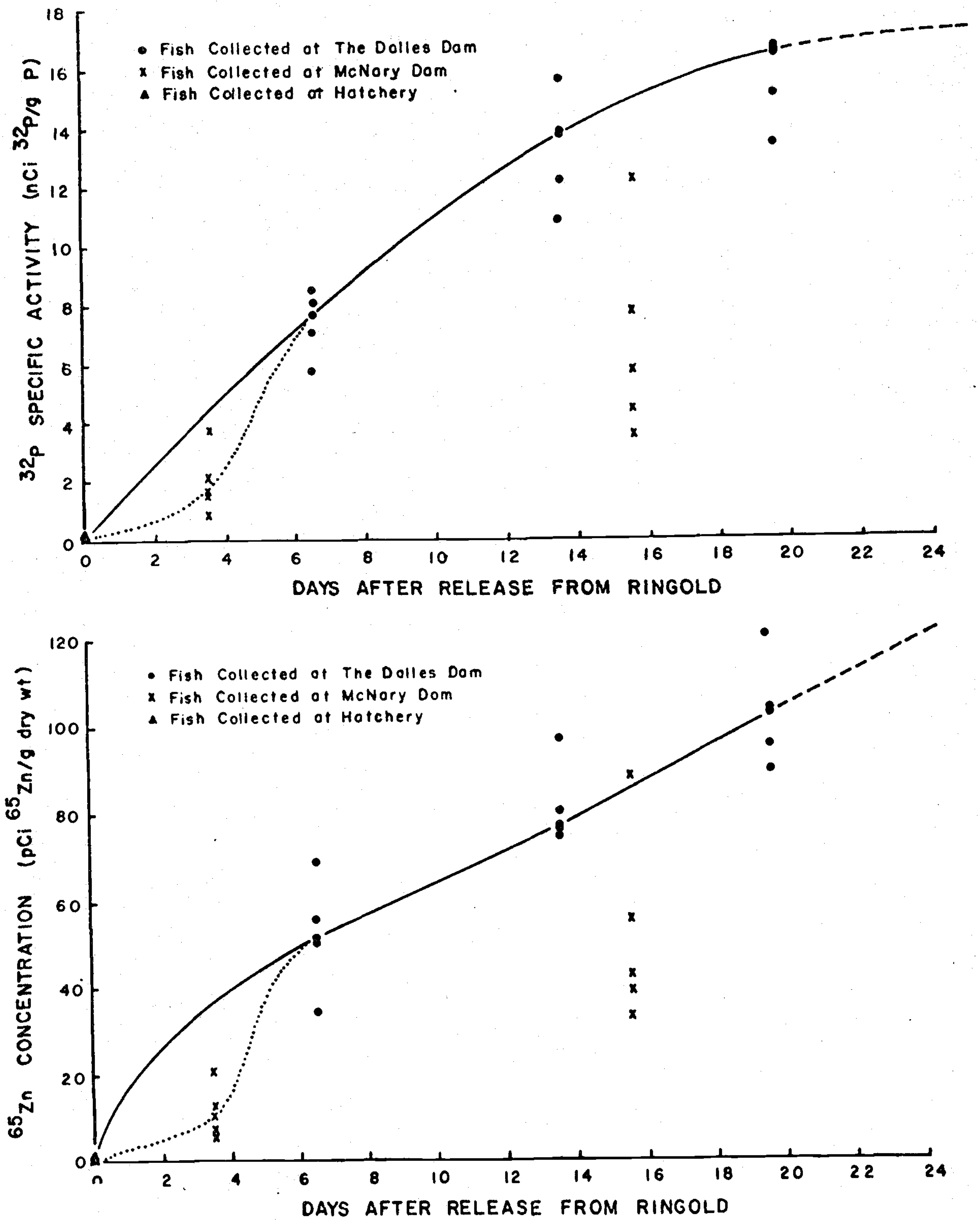


Figure 2. Radioactivity of marked juvenile salmon vs. days spent in the Columbia River. Solid curve shows uptake trends for fish taken at The Dalles Dam. The dotted curve includes the first McNary Dam fish.

Radioactivity levels generally decrease with distances from Hanford, therefore, the most rapid uptake of ^{32}P and ^{65}Zn would be expected to occur when the fish entered the river. The data, however, show there is a lag in time before the radioactivity increased greatly in these young chinook salmon. This lag may reflect the time required for a hatchery fish to acclimate to the Columbia River environment and to begin feeding. Efficiency of a hatchery fish in obtaining natural food would undoubtedly increase with time, as would its degree of activity and food requirements. The quantity and type of food available in different portions of the river could also affect the rate of ^{32}P and ^{65}Zn uptake.

Graphic Model

When the ^{32}P specific activities and ^{65}Zn concentrations of individual fish are plotted as in Figure 3, a characteristic pattern is apparent. Juvenile hatchery fish new to the radioactive Columbia River contain little ^{32}P or ^{65}Zn. As they begin to feed, the fish accumulate ^{32}P and ^{65}Zn in a definite pattern and eventually approach equilibrium concentrations. Phosphorus-32 specific activity reaches a steady state sooner than ^{65}Zn concentration as is shown in the uptake study. Levels of radioactivity accumulated by individual fish with similar past histories have a certain range. In the model this range is given boundaries which we call the "limits of normal variability." These limits are set arbitrarily by considering the plotted values for a population. Radioactivity values which fall outside these limits are attributed to atypical behavior.

The factor which would most likely cause the largest variations in radioactivity levels between individual fish is a difference in consumption of radioactive food. Such differences could arise from atypical feeding behavior or insufficient time for a fish migrating into the area to consume enough food to approach equilibrium.

Application of the Graphic Model

In Figure 3 values of ^{32}P specific activity and ^{65}Zn concentration in young chinook salmon from the uptake study are graphed. Stomach content examinations indicated these fish were actively feeding and they are assumed to exhibit normal behavior for juvenile salmon in the river. Increase in radioactivity follows the expected patterns with the values for each set of samples also being grouped together chronologically. Fish from the second McNary sample (numbered one through five) are an exception to this trend. If these young chinook salmon had remained in the Columbia River above McNary Dam for 15.5 days and behaved as the others, their concentrations of radionuclides should have been greater than that found in similar fish collected earlier at The Dalles Dam. Boundaries for normal variability were therefore set by considering all values except for the second McNary sample.

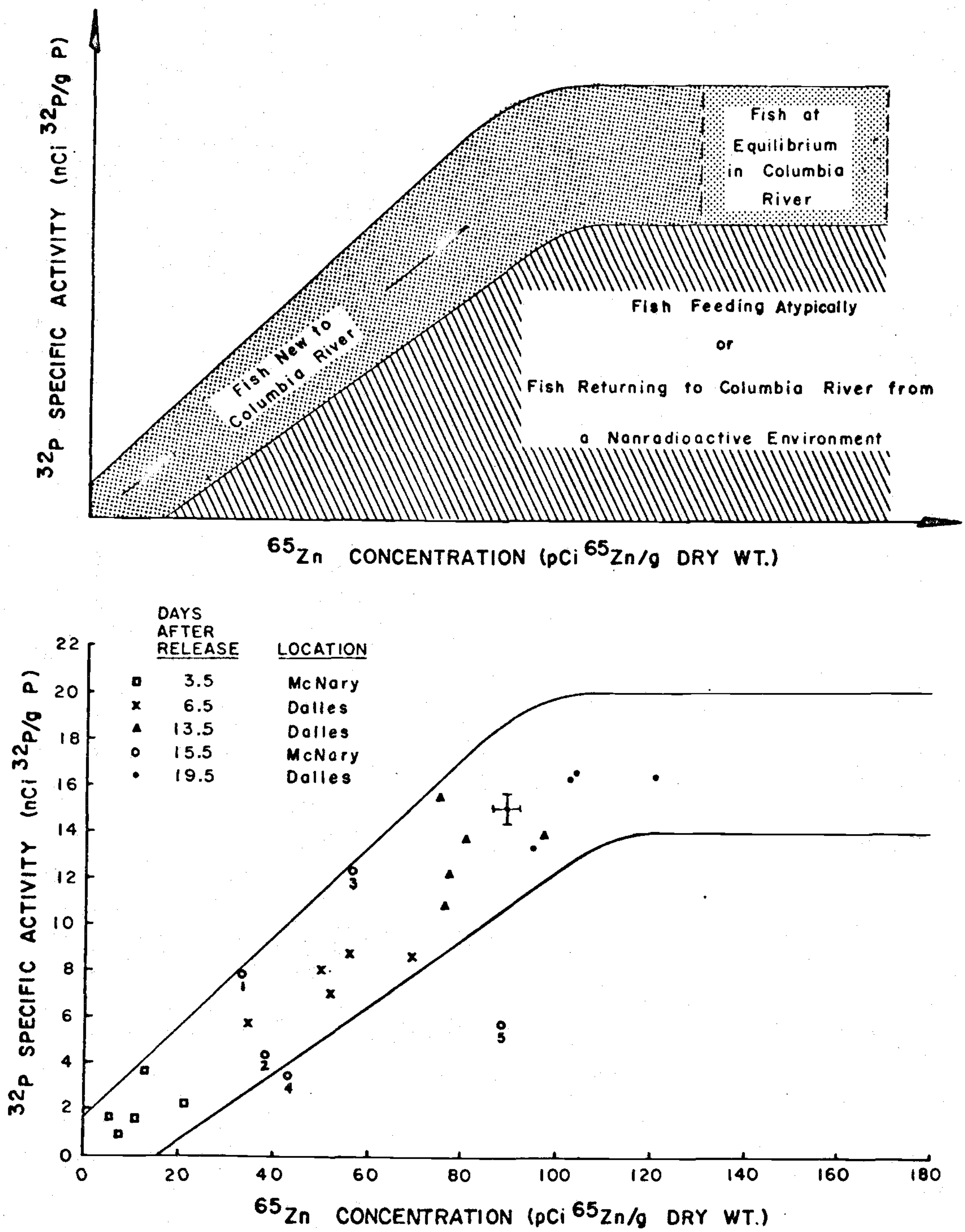


Figure 3. (Above) General model for the radioactivity of juvenile salmon released to the Columbia River. (Below) Application of the general model to the marked hatchery fish.

Although values for McNary fish numbers one through three fall within the boundaries, their location in the model relative to the location of the first The Dalles samples (designated by X's) indicate that time spent in the river was only about six to ten days. It appears that these fish either remained in the hatchery creek for several days before entering the Columbia River or entered another tributary and remained there several days before returning to the river. If the fish in the second McNary sample remained in the Columbia River the full time, then they must not have eaten during the first week. Values for fish number five and possibly four, suggest either their feeding habits were unlike the other fish or that they returned to the river from a nonradioactive environment.

There appears to be no definite method for establishing whether a point outside the set limits of normal variability has resulted from abnormal feeding or, alternately, from migration. If a fish stopped feeding or was restricted in its food consumption, its ^{32}P specific activity would decrease more rapidly than its ^{65}Zn concentration (due to the shorter physical half-life of ^{32}P). The same result might occur if a fish moved from the Columbia River into nonradioactive waters and then returned to the river. A point on the model corresponding to concentrations of radioactivity resulting from such behavior would fall outside the limits of normal variability, with a ^{32}P specific activity low in relation to the ^{65}Zn concentration. A decision as to whether values result from abnormal feeding or migrations must consider river conditions, season, location of collection, and life stage of the fish in relation to its position in the model.

The most likely tributary to influence Ringold hatchery fish above McNary Dam is the Snake River. The Snake River contributes about one-third as much water to the upper end of McNary reservoir as does the Columbia. Furthermore, the Snake River plume, extending along the eastern bank of upper McNary reservoir, constitutes an environment in which fish would be exposed to lower levels of radionuclides than in undiluted Columbia River water (U.S. Geological Survey, 1968).

Radioactivity levels present in muscle-bone samples of twenty-four juvenile salmon collected near Boardman are shown in their relation to the graphical model in Figure 4. Ten individuals were relatively new to the Columbia River having both low ^{32}P specific activities and low ^{65}Zn concentrations. Of the other fourteen fish, only five had ^{32}P specific activities larger than 1.05 nCi ^{32}P/g P, the highest being 5.5 nCi ^{32}P/g P.

There are at least two possible reasons why the boundaries of Boardman fish should differ from those established for recaptured hatchery fish. First, the Boardman sample was collected in March when the levels of radioactivity in fish are usually low due to decreased food consumption and reduced radioactivity in the food (Davis and Foster, 1958; Foster and McConnon, 1962). Secondly, the values are for muscle and bone only and not the entire fish. Both factors would serve to lower the equilibrium levels and change the range of variability.

The best application of the model may be to distinguish obviously different groups of fish. There is the group of Boardman fish new to the

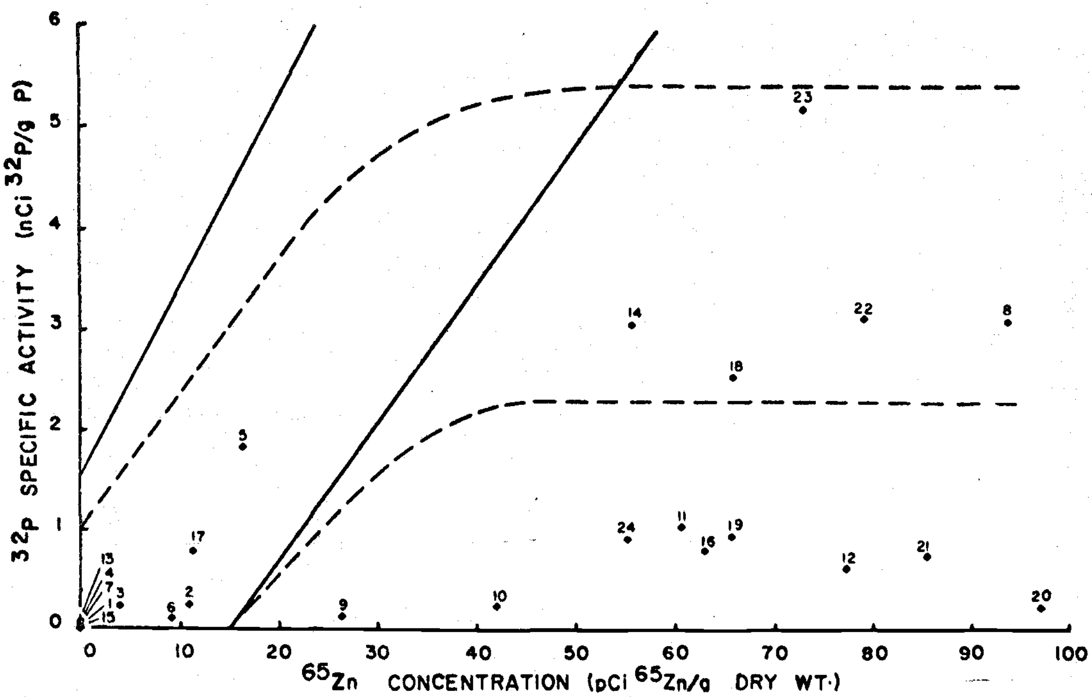


Figure 4. Application of the model to distinguish several different groups of juvenile salmon collected near Boardman, Oregon. Solid lines represent boundaries of variability for hatchery fish. Dashed curves are boundaries which appear to apply to Boardman fish.

Columbia River including fish numbers 5 and 17, which have radioactivity levels sufficient to indicate that some feeding is taking place. A second group of fish with high ^{32}P specific activities and ^{65}Zn concentrations may be at equilibrium for the season or perhaps have migrated from further upriver. Another group of fish are those with relatively high ^{65}Zn concentrations and low ^{32}P specific activities. These fish had probably reached relatively high values during the previous summer and remained in the Columbia River through the winter.

Position of the lines for limits of normal variability and equilibrium conditions are variable, being highly dependent on time of the year, reactor operations, species of fish, and location along the river. Opportunity for an environmental uptake study is also not always available. The behavior model will therefore probably be of greatest value when analysis of a single large sample population shows general trends making it possible to establish boundaries.

SUMMARY

1. The ^{32}P specific activity and ^{65}Zn concentrations were measured in juvenile chinook salmon collected from the Columbia River during winter and spring of 1969.

2. An environmental uptake study involving marked juvenile chinook salmon indicated that ^{32}P specific activity reaches a steady state sooner than ^{65}Zn concentration.

3. The uptake study also suggested a short lag period before hatchery fish released to the Columbia River began rapid uptake of ^{32}P and ^{65}Zn.

4. A model based on their ^{32}P specific activities and ^{65}Zn concentrations was constructed which allows fish to be classified and differentiated with regard to this feeding and movement behavior.

5. Use of the behavior model indicated that some hatchery fish released to the river either had feeding behavior unlike the others or were not in the Columbia the entire time from release until collection.

6. In a sample population of unmarked juvenile salmon collected from the Columbia River, the behavior model revealed what appeared to be several obviously different groups of fish.

ACKNOWLEDGEMENTS

This study is part of a thesis submitted by the senior author to Oregon State University in partial fulfillment of a Master of Science Degree. The work was supported by a Federal Water Pollution Control Administration traineeship and the U.S. Atomic Energy Commission contract number AT(45-1) 1750, (RLO-1750-84). We are grateful to Drs. William O. Forster, Norman H. Cutshall, and Mr. Lauren Larsen for advice and analytical assistance. We also thank the biologists of the U.S. National Marine Fisheries Service for collecting samples.

BIBLIOGRAPHY

Davis, J. J. and R. F. Foster. 1958. Bioaccumulation of radioisotopes through aquatic food chains. Ecology 39(3):530-535.

Foster, R. F. and Dan McConnon. 1962. Relationship between the concentration of radionuclides in Columbia River water and fish. *In:* Biological problems in water pollution, ed. by Clarence M. Tarzwell. Cincinnati, Ohio, U.S. Robert A. Taft Sanitary Engineering Center. p. 216-224.

U.S. Geological Survey. Water Resources Division. 1968. Average monthly discharge for the 15-year base period, water years 1953-67[1] inclusive, at selected gaging stations and change of storage in certain lakes and reservoirs in the Pacific Northwest. Data for stations in British Columbia furnished by Water Survey of Canada. Washington, D.C. 1 sheet (Table nl. 1, sup.).

Wallis, Joe. 1968. Recommended time, size, and age for release of hatchery reared salmon and steelhead trout. Oregon Fish Commission. Research Briefs.

SPECIFIC ACTIVITY OF IRON-55 IN PACIFIC SALMON

C. David Jennings[1] and Charles L. Osterberg[2]

ABSTRACT

Fallout iron-55 from the nuclear tests of 1961-62 was measured in Pacific salmon during 1964-67, and from these measurements the half time for the loss of iron-55 from the mixed layer of the North Pacific Ocean was estimated to be 11.5 months. On the assumption that salmon accumulate iron-55 and stable iron in a ratio corresponding to the specific activity of iron-55 in the sea water in which they feed, estimates are made of total iron-55 in the North Pacific Ocean. Circumstantial evidence suggests that iron-55 from fallout is in a form which is more readily available to marine organisms than the stable particulate iron in the ocean; thus fallout iron-55 may not be an adequate tracer for stable particulate iron in the ocean.

ACKNOWLEDGMENTS

We wish to thank H. E. Palmer and R. M. Bernard for their assistance in counting the samples and Norman Kujala and W. C. Hanson for help in obtaining samples. This research was supported by USAEC Contract AT(45-1)1750 and PHS Training Grant 5T1-WP-111-01. (RLO-1750-86)

INTRODUCTION

Iron-55 from fallout, formed predominantly by (n,γ) reactions on stable iron-54 in bomb hardware, constituted a significant portion of the total radioactivity in the mixed layer of the North Pacific Ocean after the nuclear weapons testing of 1961-62. Little is known, however, about the oceanic distribution of iron-55 despite its relative importance as a fallout radionuclide.

---

[1] Present address: Department of Natural Sciences and Mathematics, Oregon College of Education, Monmouth, Oregon 97361

[2] Present address: Division of Biology and Medicine, U. S. Atomic Energy Commission, Washington, D. C. 20545

Paper presented at Third Symposium on Radioecology, Oak Ridge, Tennessee 10-12 May 1971. RLO 1750-86.

Iron-55 in the sea can be more easily studied by measuring it in marine organisms than by direct measurement in sea water because concentrations are usually much higher in organisms than in water. Furthermore, collections of marine organisms available from past years preserve the record of iron-55 in the sea during those years. The 2.7 year half-life of iron-55 allows a reasonable time for analysis of these older samples before the iron-55 decays below the limits of detectability. For these reasons our assessment of iron-55 in the mixed layer of the North Pacific Ocean has been from analyses of Pacific salmon which contained the highest concentrations of iron-55 reported for any organism examined (Palmer, Beasley, and Folsom 1966).

SOURCE OF IRON-55 IN THE NORTH PACIFIC OCEAN

The iron-55 that we measured in this study appears to have been introduced into the North Pacific Ocean by the Russian nuclear tests of 1961-62. The Russian test sites were in the Arctic (75°N, 55°E) and in Central Asia (52°N, 78°E) and the American test sites of 1961-62 were at Johnston Island (17°N, 169°W) and Christmas Island (2°N, 157°W) (Peirson and Cambray 1965). At the latitude of the Russian tests, debris would be carried in an easterly direction by the prevailing westerlies whereas debris from the American tests in the Pacific would be transported to the west by the trade winds and the North Equatorial Current. Thus, fallout from the Russian tests was carried into our study area, the Eastern North Pacific Ocean, whereas fallout from the American tests was carried away from our study area.

In our study, the specific activity[3] of iron-55 in ocean organisms was 250 times higher in 1964 than just prior to resumption of testing in 1961 (Rama, Koide, and Goldberg 1961). So, there did not appear to be a reservoir of iron-55 in the ocean remaining from earlier nuclear tests even though iron-55 has a 2.7 year half-life. A large increase in iron-55 from tropospheric fallout appeared in the North Pacific in a short time after the tests, and stratospheric fallout contributed an ever decreasing amount. We conclude, therefore, that fallout from the Russian nuclear tests of 1961-62 gave rise to relatively high concentrations of iron-55 in the North Pacific Ocean and that the contribution in rainfall occurring after this initial large input in 1962 was significantly less.

---

[3] Specific activity of iron-55 is defined as the ratio activity iron-55/weight total iron.

TREATMENT OF SAMPLES

In this study we measured iron-55 in viscera from three species of salmon provided by commercial fishermen who fish the Eastern North Pacific Ocean. Our samples were caught at eight stations between Bristol Bay, Alaska, and Eureka, California. Samples were preserved in formalin and shipped to the laboratory where they were dried at 100°C and ashed at 600°C for 24 hours in a muffle furnace. The ashed samples were dissolved in 6 M hydrochloric acid; an aliquot was removed for spectrophotometric determination of stable iron, and the remainder of the sample was used to measure iron-55.

Iron-55 was measured by first extracting iron from the dissolved sample with 10% Alamine-336[4] in xylene, electroplating the iron by the method of Maletskos and Irvine (1956) and counting the K-x-rays of the manganese-55 daughter of iron-55 in a gas flow proportional counter, anti-coincidence shielded by two 24 x 10 cm NaI (Tl) crystals. The method has been described in detail elsewhere (Palmer and Beasley 1967).

SPECIFIC ACTIVITY IN IRON-55 IN SALMON

The specific activities of iron-55 in salmon in 1964, 1965, and 1967 (Table I) represent averages of more than 150 separate analyses of samples from eight stations in the Northeast Pacific Ocean. The most complete set of samples was from Bristol Bay, Alaska, so averages of measurements in years after 1964 were normalized to the specific activity of iron-55 in Bristol Bay salmon.

A 250-fold increase in specific activity of iron-55 occurred between 1961 and 1964 which reflects the large input into the ocean of iron-55 from the 1961-62 nuclear tests. The decrease in specific activity of iron-55 in each succeeding year after 1964 will be discussed later.

[4] Available from General Mills, Chemical Division, Kankakee, Illinois. Trade names referred to in this paper do not imply endorsement of commercial products.

Table I. Specific activity of iron-55 in Pacific salmon

Year of Collection	Average specific activity (μCi/g Fe)
1961	.037*
1964	9.1
1965	3.4
1967	0.5

* From tuna data of Rama, Koide, and Goldberg (1961).

ESTIMATE OF IRON-55 IN THE OCEAN FROM THE SPECIFIC ACTIVITY OF IRON-55 IN SALMON

Oceanic organisms concentrate iron-55 from their environment and thus facilitate measurement of iron-55 in the ocean. If we assume that organisms accumulate iron-55 and other isotopes of iron in the same ratio as they occur in sea water, we would expect the specific activity of iron-55 in the organisms to be less than the specific activity of sea water by an amount determined by the decay of iron-55 as it moves up the food chain. Because iron-55 has a 2.7 year half-life, it is reasonable to expect that little radioactive decay occurs and that the specific activity of iron-55 in oceanic organisms gives a good estimate of the specific activity of the sea water in which they live. Assuming marine organisms concentrate iron-55 at the same specific activity as occurs in sea water, the product of the specific activity of oceanic organisms and the average concentration of iron in the ocean (10 μg/l, Goldberg 1965) approximates the average concentration of iron-55 in sea water at the time the organisms accumulated the isotope.

Iron-55 in the ocean was first estimated in this way in 1961 on the basis of the specific activity of iron-55 in tuna (Rama, Koide, and Goldberg 1961) and we estimated iron-55 in the North Pacific Ocean similarly for 1964, 1965, and 1967 on the basis of our analyses of salmon (Table II).

Table 11. Estimate of iron-55 in the North Pacific Ocean from specific activity of iron-55 in salmon.

Year	Iron-55 at collection time (mCi/km^2)	Iron-55 corrected to 1962 (mCi/km^2)
1961	0.037×10^3*	
1964	9×10^3	15×10^3
1965	3×10^3	7×10^3
1967	0.5×10^3	2×10^3

* Calculated from tuna data of Rama, Koide, and Goldberg (1961).

Calculations of the iron-55 inventory of the North Pacific Ocean were made on the assumption that salmon obtain their iron from the mixed layer of the ocean where they feed. We assumed a mixed layer 100 m thick and an average iron concentration in the ocean of 10 μg/l and corrected all iron-55 measurements for radioactive decay back to 1962 when the original large input of iron-55 in the ocean took place.

The assumption that radioisotopes deposited as fallout on the ocean behave in a manner similar to their stable counterparts is not new. It forms the basis for marine geochemical tracer studies, biological uptake studies, and the specific activity concept for prediction of maximum permissible concentrations of radioactivity in sea water (NAS-NRC 1962). If the chemical or physical forms of the stable and radioactive isotopes of an element differ, however, it is doubtful that knowledge of the role of the radioisotope can be extended to the stable isotope.

Some studies have suggested that certain radioisotopes can behave differently from their stable isotopic counterparts in sea water. Schelske et al. (1966) found the specific activity of manganese-54 to be higher in estuarine scallops than in the surrounding water. Slowey et al. (1965) suggested the possibility that the chemical form in which manganese-54 reaches the sea is different from that for stable manganese and, thus, that manganese-54 is not in equilibrium with stable manganese. Robertson et al. (1968) showed that the specific activities of cobalt-60 and zinc-65 were generally several orders of magnitude higher in marine organisms than in sea water, but that the specific activities of cesium-137 in marine organisms and sea water were essentially the same. Also, the specific activity of iron-55 in salmon caught between 1964 and 1967 was 1,000 to 10,000 times higher than the specific activity of iron-55 in the particulate fraction of sea water off the northern California coast (Palmer et al. 1968) and off the Oregon coast (Robertson et al. 1968) in 1968.

A lower specific activity for a radioisotope in water than in a marine organism suggests preferential uptake of the radioisotope over its stable counterpart. Caution should be exercised, however, in drawing such a conclusion. Because of local variations in fallout and stable element concentrations, the specific activity of a sample of sea water collected in one location should not be expected to equal the specific activity of a marine organism from another location. Furthermore, samples of sea water and marine organisms collected simultaneously may have specific activities at variance with one another because the organism obtained its radioactivity at another time or in a different body of water. It has been suggested that salmon retain most of the iron they take up (Palmer and Beasley 1967). Thus, rather than compare specific activities of salmon and water collected simultaneously, it would be more reasonable to compare the specific activity of iron-55 in salmon with the specific activity of iron-55 in sea water collected during the time of the salmon's period of most rapid growth (from one to six years before maturity, depending on the species). Unfortunately, such measurements are not available for sea water, but considering that the input of fallout iron-55 to the oceans has been decreasing from 1963 to the present, it should not be surprising to find mature salmon with a specific activity higher than the waters from which they were caught.

Although higher specific activities of a radioisotope in marine organisms than in their sea water environment must not be taken as conclusive evidence for selective uptake of the radioisotope, it does provide circumstantial evidence. A growing body of this type of evidence suggests that iron-55 from fallout is in a form which is more readily available to marine organisms than the stable particulate iron in the ocean. Some comparisons in Table III support this hypothesis. Calculation of the iron-55 reservoir in the ocean on the assumption that the specific activity of iron-55 in salmon equals the specific activity of iron-55 in sea water produces estimates of iron-55 in the North Pacific Ocean which are over 100 times higher than the contribution of iron-55 in rainfall at Westwood, New Jersey. Part of the discrepancy probably represents real differences in fallout between the two locations. The North Pacific Ocean is much closer to the Russian test sites than is Westwood. Alaskan lichen, also closer to the test sites than is Westwood, fit into this scheme with intermediate values of fallout iron-55. Likewise, iron-55 in the North Atlantic Ocean in 1965, calculated from our analyses of false albacore in the same way as the North Pacific Ocean data, was about one-tenth of the iron-55 in the North Pacific Ocean in 1965. Finally, still less iron-55 was measured in rainfall in France, with a greater distance of travel from the Russian test sites, than in rainfall in Westwood.

The discrepancy between iron-55 in the ocean calculated from measurement of iron-55 in fish and iron-55 measured in rainfall at Westwood and in France appears to be too great to be explained solely on the basis of proximity to the test site, and thus provides circumstantial evidence that fallout iron-55 and stable iron in the ocean do not behave in the same way.

Table III. Comparisons of iron-55 in the North Pacific Ocean calculated from iron-55 in salmon, iron-55 in the North Atlantic Ocean calculated from iron-55 in false albacore, iron-55 in lichen, and iron-55 in rainfall.

Year	Iron-55 in the North Pacific Ocean from specific activity of salmon viscera, decay corrected to 1962 (mCi/km^2)	Iron-55 in the North Atlantic Ocean from specific activity of false albacore viscera, decay corrected to 1962 (mCi/km^2)	Iron-55 in Alaskan lichen, decay corrected to 1962 (mCi/km^2)	Iron-55 in rainfall at Westwood, N.J.,* decay corrected to 1962 (mCi/km^2)	Iron-55 in rainfall in France,** decay corrected to 1962 (mCi/km^2)
1963	--	--	--	249	54
1964	15000	--	--	108	30
1965	7000	700	--	48	16
1966	--	--	231	18	--
1967	2000	--	187	--	--

* From Hardy and Rivera (1968).
**From Hoang et al. (1968).

The discrepancy can be noted particularly in the 15-fold difference between iron-55 in the North Atlantic Ocean and in rainfall at Westwood in 1965 and the 11-fold difference between iron-55 in the North Pacific Ocean and in Alaskan lichen in 1967.

LOSS OF IRON-55 FROM THE OCEANIC MIXED LAYER

When the estimates of iron-55 in the North Pacific Ocean for 1964, 1965, and 1967 are all decay-corrected to 1962, an annual decrease occurs which indicates reduced availability of iron-55 to salmon due to some process other than radioactive decay. To calculate how long iron-55 remains available to organisms in the surface layer of the ocean, we assumed that all the iron-55 in the North Pacific Ocean from 1964 to 1967 was deposited in a short time following the nuclear tests. Of course, this assumption is not strictly correct because of the fallout contribution each year, but in the North Pacific Ocean the relatively large increment of fallout immediately after testing makes this a workable assumption.

A semilog plot of iron-55 in the ocean versus time results in a straight line which suggests a first order reaction as the mechanism for removal of iron-55 (Fig. 1). The equation for the plot of Fig. 2 is derived from

$$\frac{-dA}{dt} = k_1 A \qquad (1)$$

giving

$$\log A = \frac{-k_1}{2.303} t + \log A_o \qquad (2)$$

where

A = radioactivity of iron-55 per unit area in the ocean at t

A_o = radioactivity of iron-55 per unit area in the ocean at $t = 0$

k_1 = rate constant for removal of iron-55 from the mixed layer of ocean

From the slope of the line described above by eq. (2), k_1 was calculated to be 0.0603 month^{-1} and the half-time for the removal of iron-55 from the surface layer of the ocean to be 11.5 months.

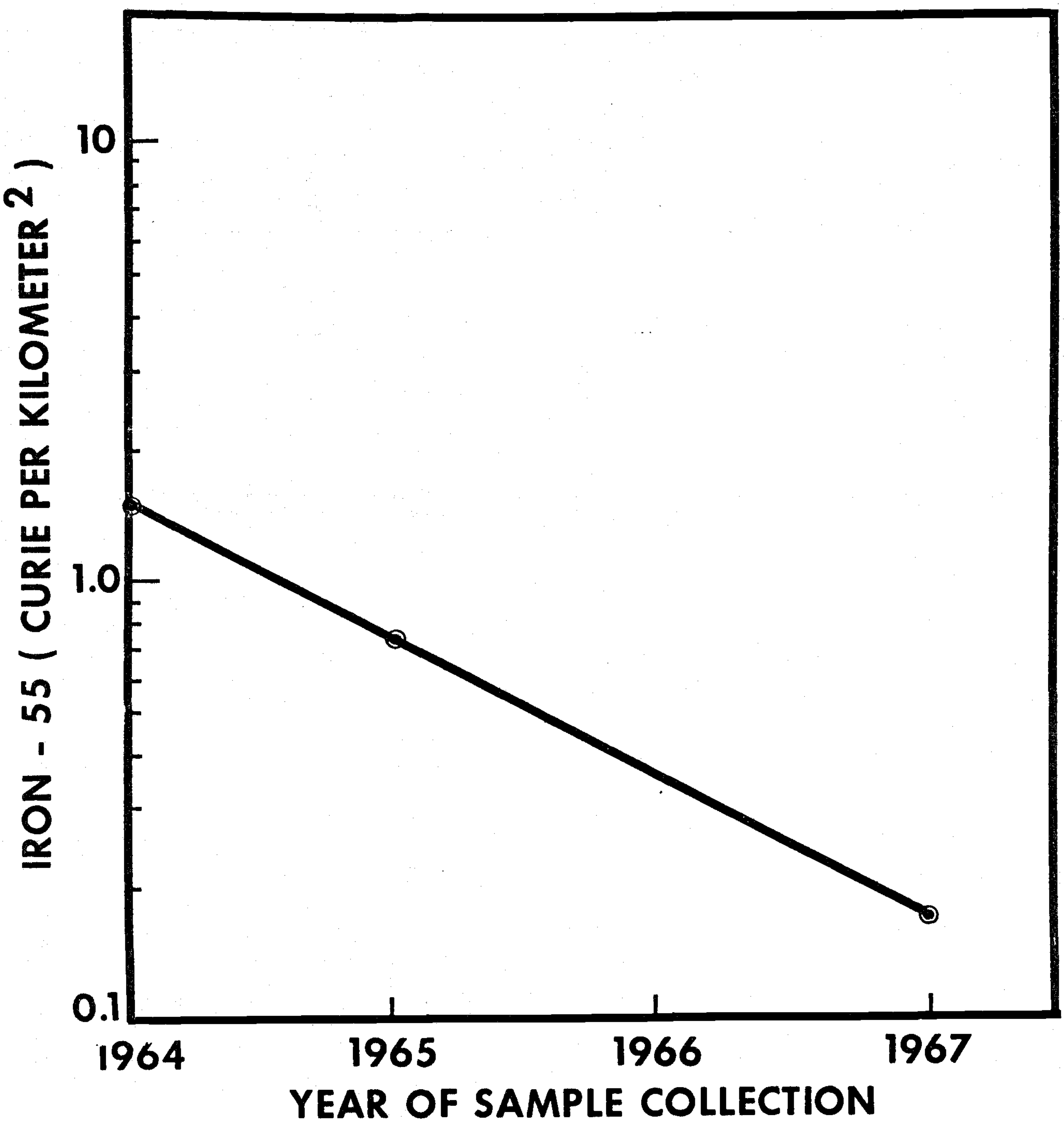


Figure 1. Decrease of iron-55 in the mixed layer of the North Pacific Ocean from 1964 to 1967 based on measurements of the specific activity of iron-55 in salmon.

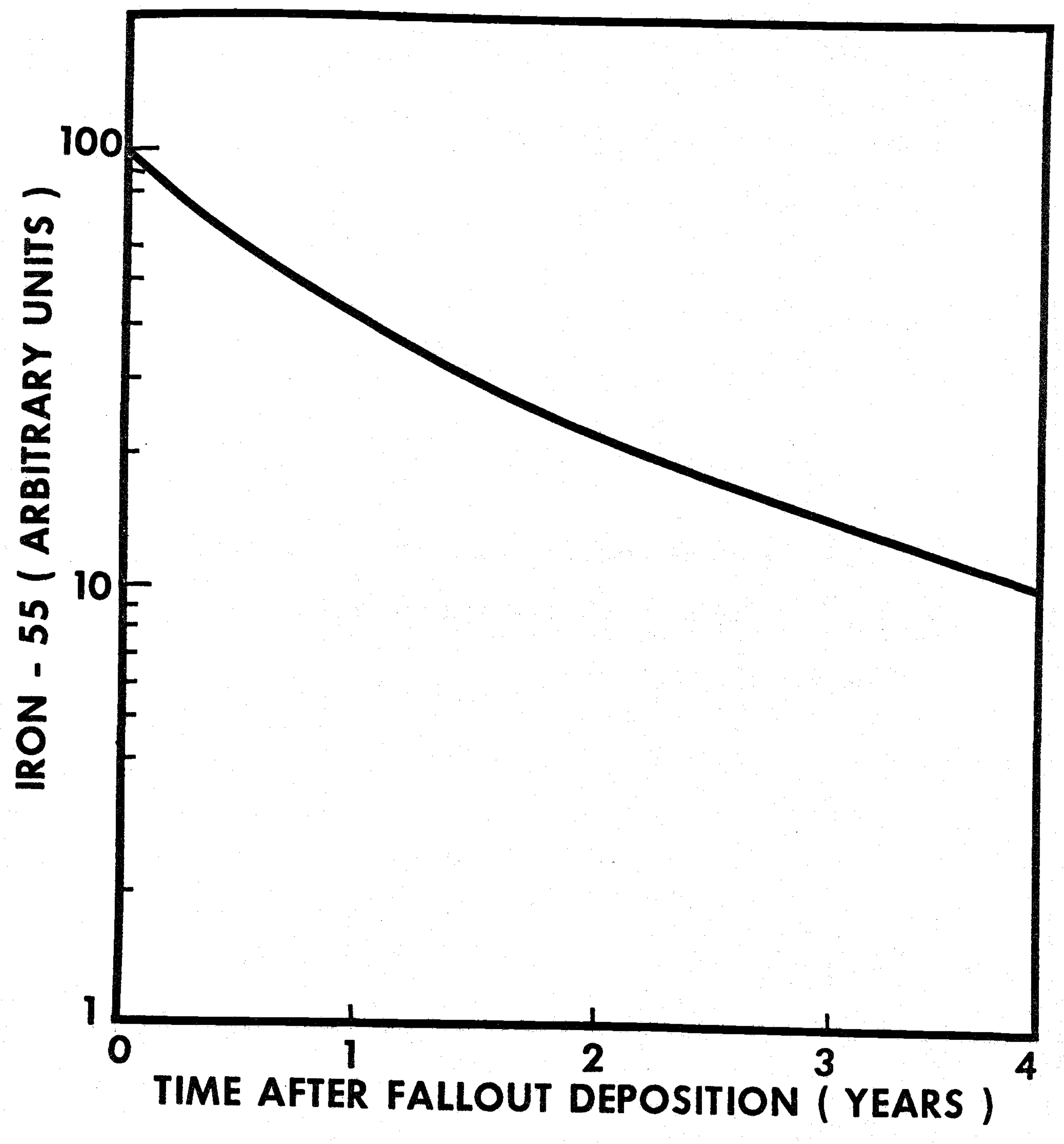


Figure 2. Decrease of iron-55 in the ocean calculated on the assumption that Stokes Law accounts for all the loss of iron-55 from the mixed layer.

POSSIBLE LOSS MECHANISMS

The settling of fallout particles by gravitational forces as described by Stokes Law is one way in which iron-55 might be lost from the mixed layer of the ocean. To calculate the loss of fallout from the mixed layer as predicted by Stokes Law, one must know or assume the fraction of the total radioactivity present in each particle size fraction. It would be most suitable to assign a size distribution to fallout particles on the basis of actual sampling of the nuclear tests in question, but since these data were not available, we assumed the particle size distribution found by Sisefsky (1961) to be applicable. We chose the six size ranges shown in Table IV and calculated settling velocities for each mean particle size.

Table IV. Percent of total radioactivity in each of six mean sizes of fallout particles and their associated velocity of settling in the ocean predicted by Stokes Law.

Size range* (μ)	Mean particle size* (μ)	Settling velocity (m/day)	Initial total radioactivity* in size range (%)
0.1-0.5	0.30	0.0081	1.0
0.5-1.0	0.75	0.051	8.7
1.0-1.5	1.25	0.141	30.6
1.5-2.0	1.75	0.276	29.2
2.0-3.0	2.30	0.477	14.8
3.0-4.0	3.50	1.11	15.7

* Adapted from Sisefsky (1961).

Calculations of settling for each particle size were made on the basis of complete mixing of the upper 100 m every 24 hours (Wooster and Ketchum 1957) from the Stokes Law equation for the limiting velocity of spherical particles in a fluid,

$$v_{lim} = \frac{2}{9\eta} g(p-p_o)r^2$$

where η = viscosity of sea water = 1.39×10^{-2}

$g = 980\ cm/sec^2$

p = density of particles = 3.70 (Benson et al. 1967)

p_o = density of sea water = 1.03

A semilog plot of iron-55 remaining in the mixed layer after Stokes Law settling has been accounted for versus time is shown in Fig. 2. The half time for the removal of iron-55 varies from 8.2 to 19.0 months so that the mean half time of 13.6 months is near the half time of 11.5 months observed in the salmon data.

A second possible explanation for the decrease of iron-55 measured in salmon may be found in the decrease of iron-55 in rainfall. If fallout iron-55 becomes unavailable to salmon in a short time after its introduction to the ocean, the amount of iron-55 in salmon would be regulated by the amount of iron-55 in rainfall and the decrease of iron-55 in salmon should correspond to the decrease of iron-55 in rainfall. Any residual iron-55 in the ocean should have the effect of lowering the apparent rate of decrease of iron-55 in salmon relative to rainfall. Comparisons by Palmer et al. (1968), however, show a higher rate of decrease of iron-55 in salmon than in rainfall. This discrepancy can be explained if, as suggested earlier, the fallout iron-55 in the North Pacific Ocean from 1964-67 resulted largely from tropospheric fallout with stratospheric fallout making a relatively minor contribution.

Other loss mechanisms which may be operating to reduce the concentration of iron-55 in the mixed layer of the North Pacific Ocean include horizontal or vertical diffusion and dilution by horizontal or vertical mixing. It is likely that these and other processes all are operating simultaneously to produce the observed result.

CONCLUSIONS

Pacific salmon are concentrators of iron-55 in the ocean, and, thus, contain high specific activities of iron-55. Whether they achieve the same specific activity as the sea water in which they feed, so that they preserve the record of the iron-55 reservoir in the sea, has not been firmly established. It is possible that fallout iron-55 is in a form different from the form of stable particulate iron in sea water and that salmon or organisms on which salmon feed selectively filter fallout iron-55 from sea water. However, evidence for isotopic discrimination or selective uptake by salmon of iron-55 from sea water is circumstantial only and much of the observed difference could be caused by geographical variations in fallout deposition and by real differences between the specific activities of the sea water when the salmon obtained their iron-55 and the specific activity of sea water when it was sampled. In the event of renewed nuclear testing in the atmosphere, simultaneous programs of sampling sea water and marine organisms should be undertaken to resolve the present dilemma.

REFERENCES

Benson, P. A., M. W. Nathans, A. Amos, and L. Leventhal. 1967. The density of fallout particles from airbursts. Health Phys. 13: 1331-1335.

Goldberg, E. D. 1965. Minor elements in sea water, p. 163-196. In: J. P. Riley and G. Skirrow (eds.), Chemical oceanography, vol. 1. Academic Press, New York.

Hardy, E. P., Jr., and J. Rivera. 1968. Fission product and activation product radionuclides in monthly deposition at selected sites, p. B-1-B-22. In: Appendix to Health and Safety Laboratory, Fallout program quarterly summary report, January 1, 1968. HASL-184. New York.

Hoang, C. T., J. Servant, and J. Labeyrie. 1968. Evaluation de la retombee mondiale du ^{55}Fe a la suite des essais nucleaires dans l'atmosphere des annees 1961 et 1962. Health Phys. 15: 323-332.

Maletskos, C. J., and J. W. Irvine, Jr. 1956. Quantitative electro-deposition of radiocobalt, zinc, and iron. Nucleonics 14(4): 84-93.

National Academy of Sciences--National Research Council. 1962. Disposal of low-level radioactive waste into Pacific coastal waters. NAS-NRC Publ. No. 985, Washington, D. C. 87 p.

Palmer, H. E., and T. M. Beasley. 1967. Iron-55 in man and the biosphere. Health Phys. 13: 889-895.

Palmer, H. E., T. M. Beasley, and T. R. Folsom. 1966. Iron-55 in marine environment and in people who eat ocean fish. Nature 211: 1253-1254.

Palmer, H. E., J. C. Langford, C. E. Jenkins, T. M. Beasley, and J. M. Aase. 1968. Levels of iron-55 in humans, animals, and food, 1964-1967. Radiol. Health Data Rep. 9: 387-390.

Peirson, D. H., and R. S. Cambray. 1965. Fission product fall-out from the nuclear explosions of 1961 and 1962. Nature 205: 433-440.

Rama, Minoru Koide, and E. D. Goldberg. 1961. Iron-55 from nuclear detonations. Nature 191: 162.

Robertson, D. E., W. O. Forster, H. G. Rieck, and J. C. Langford. 1968. A study of the trace element and radionuclide behavior in a northeast Pacific Ocean ecosystem 350 miles off Newport, Oregon, p. 92-108. In: Pacific Northwest Laboratory annual report for 1967 to the USAEC Division of Biology and Medicine, Vol. II: Physical Sciences, Pt. 2: Radiological Sciences. BNWL-715.

Schelske, C. L., W. D. C. Smith, and Jo-Ann Lewis. 1966. Radio-assay, p. 12-14. In: Annual report of the Bureau of Commercial Fisheries Radiobiological Laboratory, Beaufort, N. C., for the fiscal year ending June 30, 1965. Circ. U. S. Fish. Wildl. Serv., 244.

Sisefsky, Jan. 1961. Debris from tests of nuclear weapons. Science 133: 735-740.

Slowey, J. F., David Hayes, Bryan Dixon, and D. W. Hood. 1965. Distribution of gamma emitting radionuclides in the Gulf of Mexico, p. 109-129. In: D. R. Schink and J. T. Corless (eds), Marine geochemistry. Occ. Publ., Narragansett Marine Laboratory, Graduate School of Oceanography, Univ. Rhode Island, No. 3.

Wooster, W. S., and B. H. Ketchum. 1957. Transport and dispersal of radioactive elements in the sea, p. 43-51. In: The effects of atomic radiation on oceanography and fisheries. NAS-NRC Publ. No. 551, Washington, D. C.

ZINC-65 SPECIFIC ACTIVITY IN *MYTILUS CALIFORNIANUS* TISSUES

by I. L. Larsen, W. C. Renfro and N. H. Cutshall

ABSTRACT

Zinc-65 specific activity (nCi ^{65}Zn/g Zn) in soft parts of mussels living along the Pacific Northwest coast varies with distance from the Columbia River mouth. At any given site the specific activity in different tissues (muscle, gills, mantle, gonads, foot, and viscera) is less variable than either a measure of radioactivity or stable zinc concentrations. No significant uniform relationship between specific activities in different tissues is evident. Mussels 174 km south of the river mouth have higher ^{65}Zn specific activity than would be predicted by linear mixing of river water with seawater.

INTRODUCTION

Zinc-65, produced by neutron activation of material present in Columbia River water used to cool the plutonium production reactors at Hanford, Washington, is found in marine organisms widely distributed along the Pacific Northwest coast. The California sea mussel, *Mytilus californianus* Conrad, has previously been used as a biological indicator of ^{65}Zn levels (Watson, *et al.*, 1961; Folsom, *et al.*, 1963; Nagaya and Folsom, 1964; Seymour and Lewis, 1964; Young and Folsom, 1967; Alexander and Rowland, 1966; Toombs and Culter, 1968). Early determinations of this radionuclide were concerned primarily with its concentration in a given mass of tissue. However, as advocated by the working committee on oceanography (National Research Council, 1962) a more satisfactory index of ^{65}Zn levels in organisms is the specific activity which expresses in a ratio the amount of a radioactive isotope to the total isotopes of that element. Whereas many radioactivity measurements on mussels have been made, few determinations of the ^{65}Zn specific activities of total soft tissue or internal organs have been reported. This study was undertaken to determine ^{65}Zn specific activities in various organs of mussels along the Oregon coast to better assess the influence of Columbia River on intertidal organisms.

COLLECTION AND PREPARATION

Mussels were collected from three stations along the Oregon coast (Fig. 1) during late June and early July 1967. Twelve to sixteen mussels ranging in length from 8 to 13 cm were collected from each station. The samples were frozen and returned to the laboratory to be dissected into specific components: adductor muscle, foot, mantle, gills, reproductive organs, and viscera. The pooled organs were dried, ashed in a muffle

---

Paper presented at Third Symposium on Radioecology, Oak Ridge, Tennessee, 10-12 May 1971. RLO 2227-T12-5.

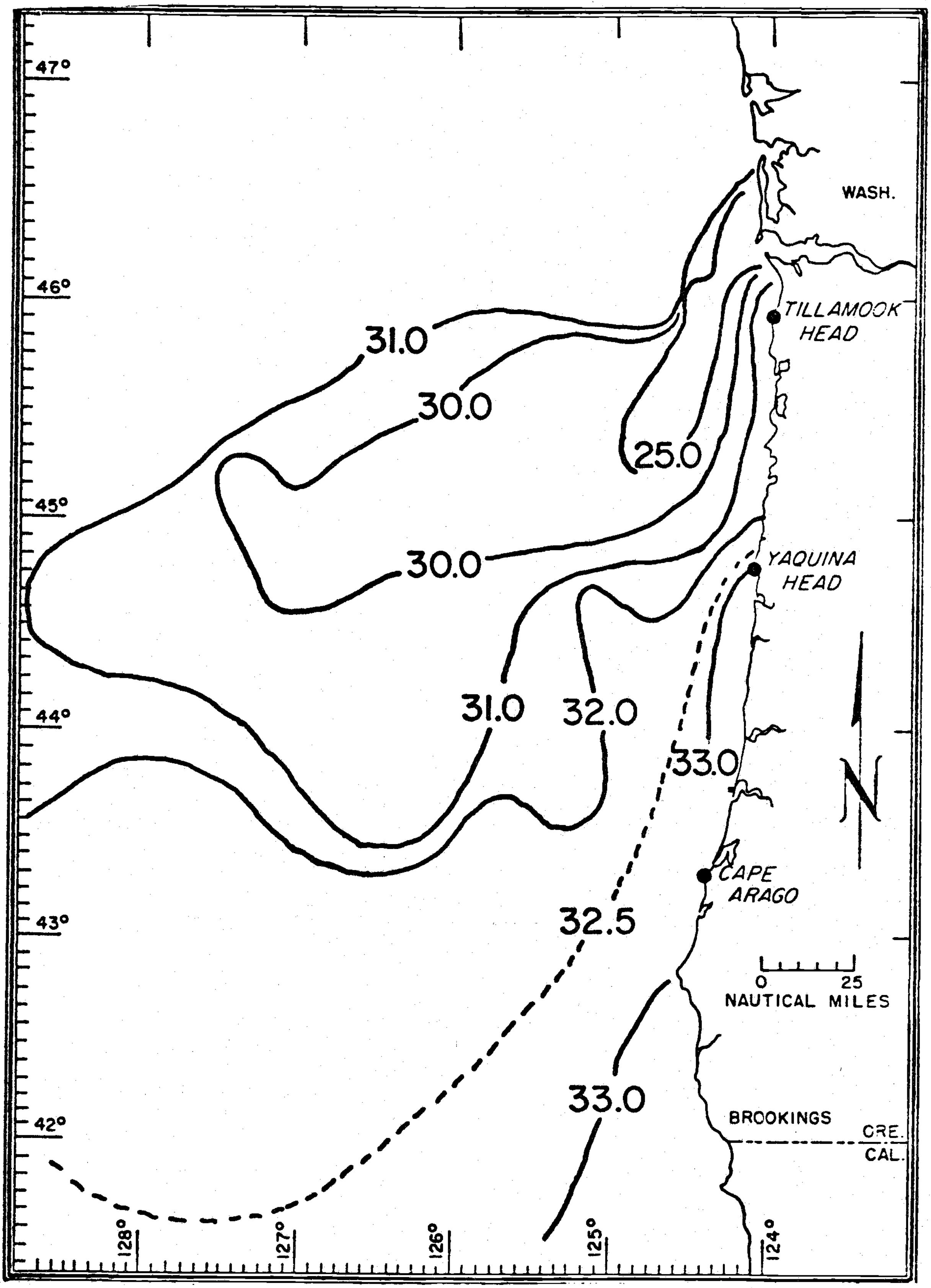


Figure 1. Collecting areas (Tillamook Head, Yaquina Head, Cape Arago) and Surface Salinity off Oregon 5-15 July 1967

furnace at 450 C and dissolved in 8 M nitric acid. Diluted aliquots of this dissolved ash were analyzed for ^{65}Zn in a 12.7 x 12.7 cm NaI (Tl) well-type detector coupled to a 512 channel analyzer. Stable zinc was measured by neutron activation. The samples were placed in a rotating rack in the TRIGA reactor at Oregon State University and activated for two hours with a thermal neutron flux of 6×10^{11} n/cm^2/sec. Samples, standards, and reagent blanks were activated simultaneously. Following activation the samples were allowed to "cool" for several months to allow short half-life radionuclides to decay. Samples were then counted and the data reduced by a nonlinear least squares program utilizing a 3300 CDC computer. Figure 2 illustrates gamma-ray spectra of a sample counted before and several months after neutron activation.

RESULTS OF ANALYSIS

Table 1 summarizes the results of the determination of ^{65}Zn and stable zinc for the samples. Specific activity of ^{65}Zn was calculated by dividing the ^{65}Zn concentration by the stable zinc concentration and multiplying by 10^3 to obtain units of nanocuries of ^{65}Zn/g Zn. The uncertainty term (given at the 95% confidence level) is expressed as a percent of the mean. This term includes uncertainties due to counting, weighing, and comparisons with the activated standards.

Samples collected near the mouth of the Columbia River have higher ^{65}Zn content and ^{65}Zn specific activity than samples more distant. Significant uniform patterns among tissues for the various stations are not evident. Values of the ^{65}Zn specific activities are less variable than with either ^{65}Zn or stable zinc concentrations. Tissues which are high in ^{65}Zn likewise have high stable zinc concentrations. Similarly, tissues low in ^{65}Zn also reflect correspondingly low stable zinc.

Table 2 presents ^{65}Zn specific activity values determined by others. Values from Table 1 corresponding to similar areas appear to be in general agreement with these values.

DISCUSSION

Figure 1 illustrates the surface salinity patterns off Oregon during 5-15 July 1967. These patterns indicate the degree of mixing of Columbia River water with seawater, with the river water depressing surface salinities below ambient seawater values and yielding an identifiable plume extending offshore southwest of the river mouth during the summer months. The 32.5‰ salinity isopleth has previously been used to distinguish between Columbia River water and ambient seawater (Budinger, Coachman, and Barnes, 1964). This plume has been traced at sea by salinity determiniations as well as by radioactivity measurements (Osterberg, Cutshall, and Cronin, 1965; Park,

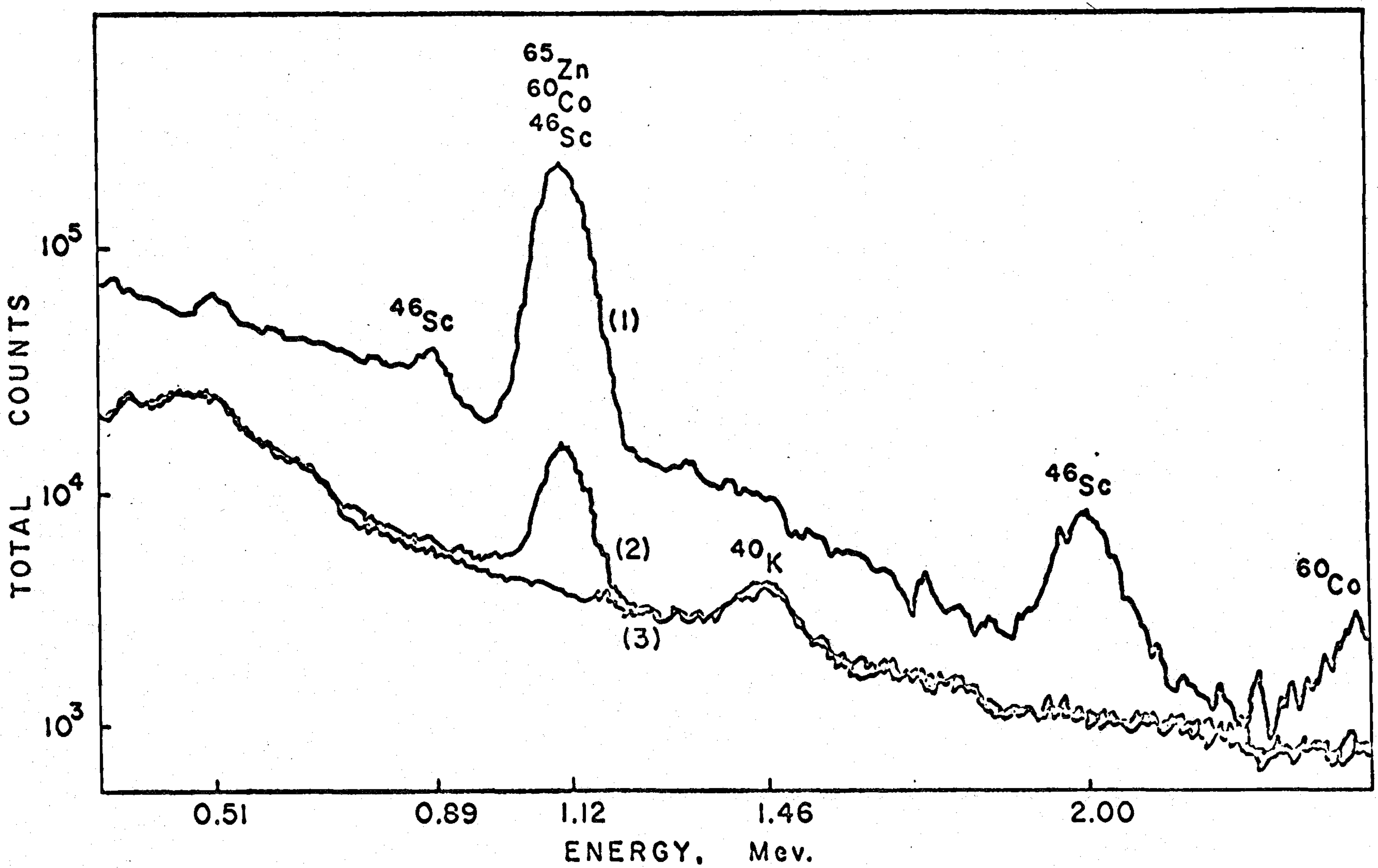


FIGURE 2. SPECTRA OF RADIOANALYSIS. (1) NEUTRON ACTIVATED SAMPLE 145 DAYS FOLLOWING EOB (NORMALIZED TO A 400 MIN. COUNT). (2) SPECTRUM OF SAMPLE PRIOR TO NEUTRON ACTIVATION (400 MIN. COUNT). (3) 400 MIN. BACKGROUND COUNT.

Table 1. Concentrations of ^{65}Zn and stable Zn in mussels collected from the Oregon Coast.

Collection Area			Muscle	Foot	Mantle	Gills	Reproductive Organs	Viscera
Tillamook	Sp. Act.	nCi ^{65}Zn/g Zn	785. ± 11.6	835. ± 10.2	759. ± 14.9	798. ± 8.45	909. ± 6.22	766. ± 10.4
Head	^{65}Zn	pCi ^{65}Zn/g ash	413. ± 8.84	465. ± 6.35	123. ± 12.9	443. ± 3.91	571. ± 1.91	441. ± 6.12
(TH)	Stable Zn	μg Zn/g ash	526. ± 7.46	557. ± 7.94	162. ± 7.34	555. ± 7.49	628. ± 5.92	576. ± 8.38
Yaquina	Sp. Act.	nCi ^{65}Zn/g Zn	140. ± 22.8	176. ± 36.4	163. ± 32.1	186. ± 15.5	231. ± 13.0	206. ± 16.3
Head	^{65}Zn	pCi ^{65}Zn/g ash	72.8 ± 21.8	42.0 ± 35.9	20.4 ± 30.0	37.1 ± 13.4	78.1 ± 9.17	84.8 ± 13.8
(YH)	Stable Zn	μg Zn/g ash	520. ± 6.65	239. ± 5.83	125. ± 11.3	200. ± 7.90	338. ± 9.20	411. ± 8.66
Cape Arago	Sp. Act.	nCi ^{65}Zn/g Zn	50.1 ± 88.6	75.0 ± 110.	77.0 ± 63.8	50.6 ± 76.9	116. ± 18.5	72.3 ± 21.9
(CA)	^{65}Zn	pCi ^{65}Zn/g ash	27.3 ± 88.4	18.9 ± 110.	12.7 ± 63.5	7.64 ± 76.4	30.6 ± 17.4	69.4 ± 20.4
	Stable Zn	μg Zn/g ash	545. ± 5.64	252. ± 8.95	165. ± 6.38	151. ± 9.02	263. ± 6.32	961. ± 8.10

± indicates the estimated percent uncertainty in the measurements at the 95% confidence level.

TABLE 2. Zinc-65 specific activities in total soft tissues of *Mytilus californianus*.

Location	Approximate Distance south from Columbia River km	mi	Sampling date	^{65}Zn specific activity (nCi ^{65}Zn/g Zn)	Reference
Mouth, Columbia River	0	0	August 1964	706	Alexander and Rowland, 1966
Tillamook Head, Oregon	31	19	March 1964	506*	Oregon State University (unpublished)
			August 1964	278	Alexander and Rowland, 1966
Cannon Beach, Oregon	40	25	July 1969	308	Toombs, 1969 (personal communication)
Nehalem River Jetty, Oregon	64	40	July 1969	466	Toombs, 1969 (personal communication)
Agate Beach, Oregon	172	107	August 1969	147	Toombs, 1969 (personal communication)
Yaquina Head, Oregon	174	108	March 1964	135*	Oregon State University (unpublished)
Cape Arago, Oregon	335	208	March 1964	67*	Oregon State University (unpublished)
La Jolla, California	1770	1100	1964 - 1965	0.39	Alexander and Rowland, 1966

* muscle tissue

et al., 1965; Gross, Barnes, and Riel, 1965; Frederick, 1967). During summer months, upwelling takes place along the coast and may form a barrier between the plume and the coastline. The association of ^{65}Zn with the plume as well as with coastal organisms suggests that the Columbia River is the prime contributor to ^{65}Zn on the Pacific coast (Alexander and Rowland, 1966).

Mussels collected from Yaquina Head (174 km south of the river mouth) have a higher specific activity than would be predicted by linear mixing of river water with seawater. Figure 3 illustrates a simple linear mixing model for Columbia River water of zero salinity with seawater of 33‰ salinity. An approximate mean specific activity (1.0 μCi $^{65}Zn/g$ Zn) for organisms in the Columbia River estuary is taken as the specific activity of the undiluted Columbia River (unpublished data). Organisms are assumed to reflect the specific activity of the water in which they are found. Mixing of ^{65}Zn in Columbia River water with seawater, if conservative (no loss of mass), should produce a ^{65}Zn specific activity in proportion to the salinity, assuming the stable zinc concentration in Columbia River water is equal to that in seawater. Buffo (1967) reports values of zinc concentrations in offshore Oregon seawater similar to those reported by Silker (1964) and Kopp and Kroner (no date), for Columbia River water. Weighted averages of the mussel tissues from each station are shown as data points in Figure 3. Note that the line on Figure 3 denotes specific activity for water and that the specific activity for organisms ought to fall on or below the line. Observed ^{65}Zn specific activities exceed the values expected from linear mixing.

This situation might occur if the stable zinc concentration in Columbia River water were higher than that of Pacific Ocean water. However, if the difference in observed specific activity at Tillamook Head from that predicted by the linear mixing of seawater and river water of equal zinc concentration is ascribed to actual inequality in zinc concentration, the Columbia River would need zinc concentration approximately two orders of magnitude higher than seawater (Cutshall, Renfro, and Larsen, in preparation). An error of two orders of magnitude in trace metal analysis is thought to be unlikely. Measurements of zinc in seawater and Columbia River water by independent investigators yield very similar concentrations (Goldberg, 1963; Rona, et al., 1962; Silker, 1964; Kopp and Kroner, no date; Buffo, 1967). It is therefore clear that deviations of observed specific activities from the linear mixing model are not entirely caused by error in the assumption that zinc concentrations in seawater are equal. Zinc-65 from another source also seems unlikely because specific activities are greater than those reported for ^{65}Zn from sources other than the Columbia River (Alexander and Rowland, 1966; Wolfe, 1970).

Another possible explanation is that the salinity isopleths reflect mean conditions and that lower salinity (i.e., higher Columbia River water content) waters occasionally do reach the coast of Oregon. Drift bottles released off the Oregon Coast in summer of 1962 indicated that variable

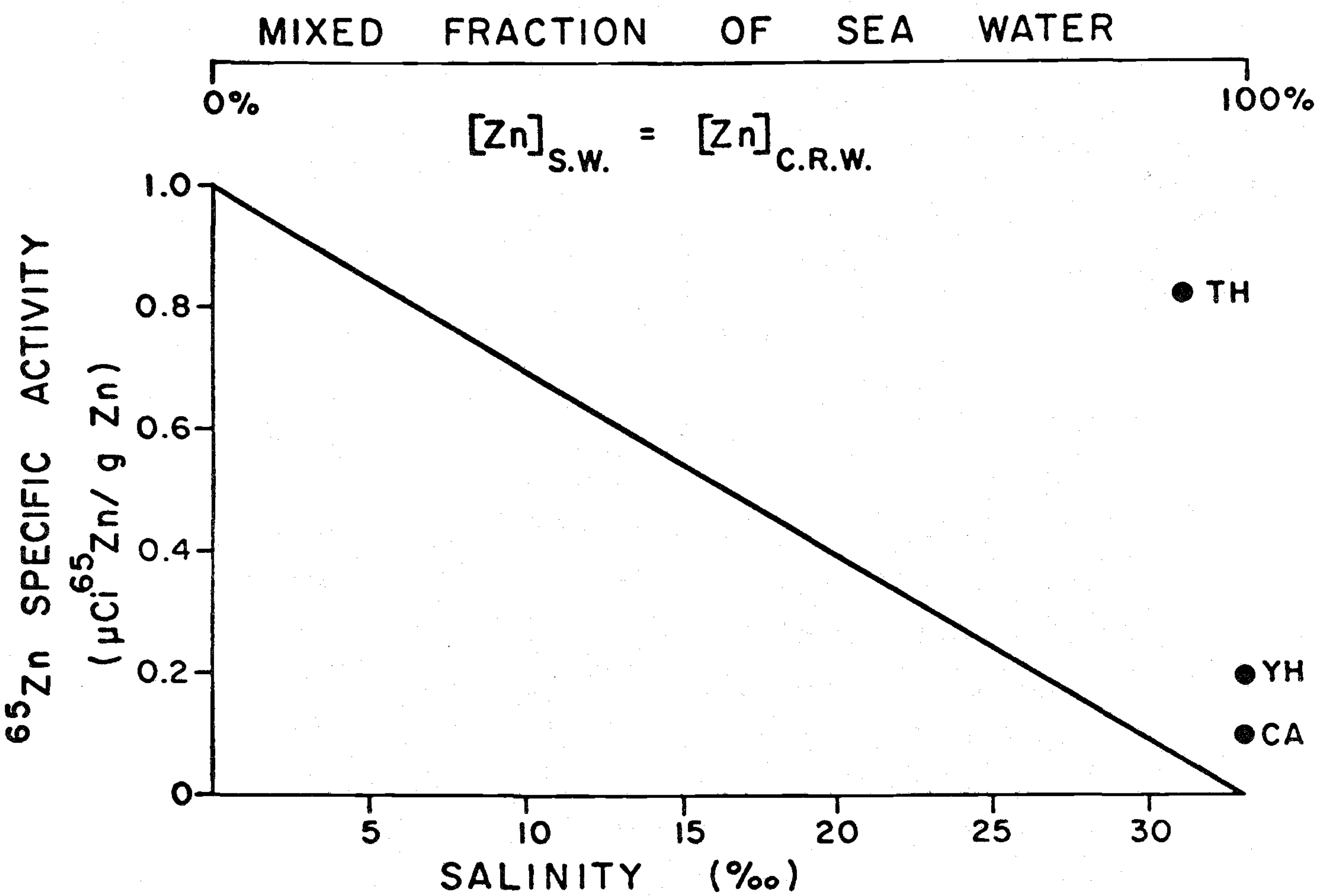


Figure 3. LINEAR MIXING MODEL

Effect of mixing Columbia River water (C.R.W.) having a ^{65}Zn specific activity of 1.0 µCi/g Zn with Pacific Ocean water of equal stable zinc concentration. If mussels had the same ^{65}Zn specific activity as their sea water environment, they should fall on the line. Note that the mussels from Tillamook Head (TH), Yaquina Head (YH), and Cape Arago (CA), have higher ^{65}Zn specific activities than predicted by the linear mixing model.

onshore surface water transport does take place (Burt and Wyatt, 1964). The plume may become highly convoluted exhibiting many eddies with the eastern edge being especially erratic and reaching the beaches along the northern Oregon Coast (Panshin, 1969). If occasional contact with water high in Columbia River water content is responsible, it is necessary that either:

1) the river water content be very much higher during these periods since the exposure time is not long, or

2) zinc assimilation rates of mussels be higher than average during these exposures.

Neither of these seems especially likely although available data do not afford a test of either hypothesis.

Two other possibilities are noted. Relatively higher specific activity ^{65}Zn from the Columbia River may be in a chemical or physical form that is more readily assimilated by mussels than the form of zinc in seawater. Alternatively, some unknown process may separate Columbia River zinc from Columbia River water and transport the zinc onshore. As an unlikely example of the latter, an organism might accumulate ^{65}Zn and zinc near the river mouth and then be transported to the beach where it is eaten by mussels.

SUMMARY

We have reported ^{65}Zn specific activities in mussels along the Oregon coastline. Measured values are provocatively higher than would be expected.

This research supported by USAEC contract number AT(45-1)2227 Task Agreement 12 Publication number RLO-2227-T12-5.

REFERENCES

Alexander, G. V. and R. H. Rowland. 1966. Estimation of zinc-65 background levels for marine coastal waters. Nature 210:155-157.

Budinger, T. F., L. K. Coachman, and C. A. Barnes. 1964. Columbia River effluent in the northeast Pacific Ocean, 1961, 1962: Selected aspects of physical oceanography. Seattle, University of Washington, Dept. of Oceanography. 78 p. (Technical Report No. 99)

Buffo, Lynn Karen. 1967. Extraction of zinc from sea water. M.S. thesis. Oregon State University, Corvallis. 49 p.

Burt, Wayne V. and Bruce Wyatt. 1964. Drift bottle observations of the Davidson current off Oregon. In Studies in Oceanography, ed. by K. Yoshida, Tokyo p. 156-165.

Folsom, T. R., D. R. Young, J. N. Johnson, and K. C. Pillai. 1963. Manganese-54 and zinc-65 in coastal organisms of California. Nature 200: 327-329.

Frederick, Lawrence Churchill. 1967. Dispersion of the Columbia River plume based on radioactivity measurements. Ph.D. thesis. Oregon State University, Corvallis. 134 p.

Goldberg, E. D. 1963. The oceans as a chemical system. In The Sea, vol. 2, The composition of sea-water. Ed. by M. N. Hill, Interscience publishers, Wiley, New York, p. 3-25.

Gross, M. G., C. A. Barnes, and G. K. Riel. 1965. Radioactivity of the Columbia River effluent. Science 149: 1088.

Kopp, John F. and Robert C. Kroner. No date (about 1968). A five year summary of trace metals in rivers and lakes of the United States (Oct. 1, 1962 - Sept. 30, 1967). In Trace metals in waters of the United States Department of the Interior. Federal Water Pollution Control Administration. Division of Pollution Surveillance. Cincinnati, Ohio. Various paging.

Nagaya, Yutaka and T. R. Folsom. 1964. Zinc-65 and other fallout nuclides in marine organisms of the California coast. Journal of Radiation Research 5: 82-89.

National Research Council. 1962. Disposal of low-level radioactive waste into Pacific coastal water, a report of the Committee on Oceanography. Washington, D. C., National Academy of Sciences - National Research Council, 1962. 87 p. (National Research Council, Publication 985).

Osterberg, Charles L., Norman Cutshall, and John Cronin. 1965. Chromium-51 as a radioactive tracer of Columbia River water at sea. Science 150: 1585-1587.

Panshin, Daniel A. 1969. Oregon State University Albacore Central Bulletin 69-2. Marine Advisory Program, Sea Grant. Oregon State University, Dept. of Oceanography, Corvallis. No paging.

Park, Kilho, Marilyn J. George, Yasuo Miyake, Katsuko Saruhashi, Yukio Katsauragi, and Teruko Kanazawa. 1965. Strontium-90 and caesium-137 in Columbia River plume, July 1964. Nature 208: 1084-1085.

Rona, Elizabeth, Donald W. Hood, Lowell Muse, and Benjamin Buglio. 1962. Activation analysis of manganese and zinc in sea water. Limnology and Oceanography 7: 201-206.

Seymour, Allyn H. and Gary B. Lewis. 1964. Radionuclides of Columbia River origin in marine organisms, sediments, and water collected from the coastal and offshore waters of Oregon and Washington, 1961-1963. University of Washington, Laboratory of Radiation Biology, Seattle. 73 p.

Silker, W. B. 1964. Variations in elemental concentrations in the Columbia River. Limnology and Oceanography 9 (4) p. 540-545.

Toombs, George L. and Peter B. Culter. 1968. Lower Columbia River environmental radiological survey in Oregon. Comprehensive Final Report 1961-1967. Division of Sanitation and Engineering. Oregon State Board of Health. 115 p.

Watson, D. G., J. J. Davis, and W. C. Hanson. 1961. Zinc-65 in marine organisms along the Oregon and Washington coasts. Science 133: 1826.

Wolfe, Douglas A. 1970. Levels of stable Zn and ^{65}Zn in Crossostrea virginica from North Carolina. J. Fish. Res. Bd. Canada 27:47-57.

Young, D. R. and T. R. Folsom. 1967. Loss of ^{65}Zn from the California sea mussel Mytilus californianus. The Biological Bulletin 133: 438-447.

ZINC-65 IN OREGON-WASHINGTON CONTINENTAL SHELF SEDIMENTS

by Norman Cutshall, William C. Renfro,
David W. Evans and Vernon G. Johnson

ABSTRACT

Approximately 520 Ci of Zn-65 are estimated to be present in sediments off the Columbia River mouth according to river discharge and measurements of Zn-65 concentrations in riverwater. Analysis of topmost 1 cm of shelf sediments for Zn-65 reveals that 45 Ci is present in this layer within an area bounded by a constant activity/area contour of 0.5 nCi/m^2 ($\sim 10^{10} m^2$). Mean regression coefficients for 6 vertical profiles yield a half-value depth of 4.5 cm in sediment. Another 270 Ci is therefore estimated to be buried below 1 cm within the same area. The remaining 205 Ci appears to have been transported beyond the 0.5 nCi/m^2 boundary. These observations are compatible with known bottom currents in the shelf.

Two principal routes of entry of Zn-65 into the Pacific Ocean are known: worldwide fallout from atmospheric nuclear detonations and input, via the Columbia River from reactors at Hanford, Washington. The latter source is considered to predominate within a few hundred kilometers of the river mouth. The clear association of Zn-65 content of marine organisms with the known position of the Columbia River plume strongly supports this view (Osterberg, Pattullo and Pearcy 1964). In addition, the Zn-65 specific activity (Zn-65/total Zn) in the Columbia River system clearly marks Columbia River zinc. Whereas Zn-65 specific activities found elsewhere are in the range 10^{-2} - 10^{1} pCi/g (Alexander and Rowland 1966, Wolfe 1970), values of 10^{3} - 10^{6} pCi/g are routinely observed near the Columbia River. The analyses reported in this paper become practically insensitive when the specific activity is below about 3 x 10^{3} pCi/g. Thus they represent only Zn-65 from the Columbia River. Zinc-65 has previously been reported in marine sediments near the river mouth (Osterberg, Kulm and Byrne 1963; Gross 1966). Indeed, the sorption and retention of Zn-65 by sediments in the river proper (Johnson 1966) suggest that the principal reservoir of Columbia River zinc in the sea would be marine sediment. The present work represents an attempt to assess the size and geographic shape of this reservoir. Observed distribution and quantity of Zn-65 in shelf sediments will be compared to a total inventory predicted from river discharge data. Alternative extreme models based on burial and on transport of Zn-65 will be considered. Finally, we will attempt to construct an accountability ledger for Zn-65.

Paper presented at Third Radioecology Symposium, Oak Ridge, Tennesee. 10-12 May, 1971.

RLO 2227-T12-4

Predicted Ocean Inventory

If a constant rate of delivery of Zn-65 into the sea had persisted for a few years, it would be a rather simple matter to calculate the resulting steady-state inventory. Transport rates downstream vary seasonally with river discharge, however, and have also declined during recent years owing to reactor shutdowns. During 1968, transport rates past Astoria, Oregon, near the river mouth, varied from 0.5 Ci/day (December) to 8.2 Ci/day (June) with an average of 2.8 Ci/day (see Appendix for discussion of calculations). The average during 1969 was 2.3 Ci/day. When monthly discharges during 1968-69 are cumulated by month and allowance is made for radioactive decay the resultant total inventory in the marine environment is 550 Ci on 1 January 1970. Transport rates prior to 1968 were greater, but their cumulative total is subject to considerably more decay. With a 245-day half life Zn-65 decays to $A/A_o = 0.127$ in two years. We estimate the pre-1968 residual contribution to be 100 Ci on 1 January 1970 for a total inventory of about 650 Ci.

Not all Zn-65 is associated with sediment. In the lower river, filtration of water through 0.45μ membrane filters typically removes 75 to 85% of Zn-65. The remainder is presumably in "solution" either as ions, complexes or perhaps on (in) colloids small enough to pass through the filter. Lowman, <u>et al</u>. (1966) found that essentially all "dissolved" Zn in river water from the west coast of Puerto Rico rapidly becomes associated with particles after entering the sea. If similar events occur off the Columbia River it is possible that virtually the entire 650 Ci ocean inventory is contained in suspended and bottom sediments. On the other hand, if no such precipitation occurs in the Columbia River system, the sediment inventory might be only 80% of the total or 520 Ci. We will use the latter value and consider it a minimum. We also assume that the inventory remained constant throughout 1970.

If substantial desorption or release of particle-bound Zn-65 occurred in seawater the portion of the total inventory contained in sediment might be lowered. Johnson, Cutshall and Osterberg (1967) reported that seawater leached only a very slight proportion (about 1%) of Zn-65 from Columbia River sediments. Their experiments provided only about two hours of contact with seawater, however. Furthermore, other authors have noted substantial desorption of metals that have a chemistry somewhat similar to zinc. For example, Murata (1939) found that appreciable manganese is released from riverborne sediments to seawater and Kharkar, Turekian and Bertine (1967) reported that sediment-sorbed cobalt is substantially desorbed by seawater. We have therefore measured Zn-65 content of Columbia River sediment exposed to seawater for relatively long times.

To approximate losses of Zn-65 from sediment deposited at sea, several kilograms of sediment (silty sand) collected from the Columbia River near McNary Dam were placed in Yaquina Bay at Newport, Oregon. Yaquina Bay is about 180 km south of the Columbia River mouth and its Zn-65 content is negligible. One portion of sediment was placed in a shallow plastic pan and covered with a plastic screen which allowed free passage of seawater but excluded large organisms. The other portion was packaged in dialysis bags which presumably allowed penetration only by ionic solutes. Periodic samples of each portion were collected at intervals over the following 11 weeks. Each of these samples was analyzed by direct counting and by the $CuSO_4$ leaching method described later. Bay water salinity at the site was determined twice during the experiment. On day 12 the salinity was 33.7% and on day 26, 31.5%. These values confirmed the expectation of essentially undiluted seawater at the site.

Zinc-65 content of the sediment (Table 1) did not perceptibly change, except for decay, during 11 weeks of exposure to seawater. Uncertainties estimated from counting statistics are about 10% (coefficient of variation) so that desorption of a few percent might not have been detected. It is clear, though, that any losses from deposited sediments are small enough to be neglected in estimating the sediment inventory of Zn-65. Therefore, at least 520 Ci of Zn-65 ought to have been present in sediments off the mouth of the Columbia River on 1 January 1970.

$CuSO_4$ Leaching Method

Johnson, et al. (1967) noted that solutions of 0.05M $CuSO_4$ leached as much as 54% of Zn-65 from Columbia River sediment. We have used $CuSO_4$ extraction for analysis of Zn-65 in sediments. Approximately 250 cc of wet sediment are suspended in 500 ml of 0.05 M $CuSO_4$ solution for 1-3 weeks. The suspension is then filtered and the filtrate is analyzed for zinc by atomic absorption spectrophotometry and for radionuclides by gamma-ray spectrometry. After filtration the volume of filtrate is measured and a sub-sample is taken for zinc determination. In most cases the zinc concentration is in a range suitable for direct measurement. Measured zinc concentrations are corrected for $CuSO_4$ blanks, the correction usually amounting to less than 1%. The remainder of the filtrate is evaporated to dryness and the residue placed in a 12 cc tube for counting in a well-type NaI(Tl) detector. The method allows extracts representing rather large samples to be placed in a high geometry thus increasing analytical sensitivity. In addition, commonly interfering gamma-emitters such as Sc-46, K-40 and Bi-214 (U-238 series) are not extracted. The principal disadvantage as compared to direct counting is the uncertainty introduced by extraction yield variations. (Specific activity determinations are probably not affected by absolute yields, however.)

Sediments from the long-term seawater exposure above were also analyzed by $CuSO_4$ leaching. Extraction yields (Table 1) ranged from 28% to 61% with a mean of 47% and a standard deviation of ± 7.2% for 10 extractions. The extraction efficiency does not appear to change with time of exposure of the sediment to seawater.

We have also examined the rate of extraction of Zn-65 to assure that one week contact time is sufficient for maximum yield. Approximately 2 kg of sediment was suspended in 16 l of 0.05 M $CuSO_4$ solution. Small aliquots (175 ml) were extracted at times up to 16 days later and analyzed for zinc

Table 1. Zinc-65 content of Columbia River sediment exposed to seawater.

Exposure Time (Days)	Total ^{65}Zn Content pCi/g ± Counting Error	$CuSO_4$ Leached, ^{65}Zn pCi/g ± Counting Error	^{65}Zn Leached with $CuSO_4$, percent ± Counting Error
0	69.2 ± 6.6		
	57.6 ± 10.2	35.7 ± 1.6	
	79.1 ± 6.8		
	66.2 ± 5.6		
5	68.1 ± 6.0	28.6 ± 6.0	41.9 ± 9.6
	72.2 ± 5.3 (D)	29.4 ± 2.2 (D)	40.7 ± 4.3
12	69.4 ± 5.7	33.9 ± 2.0	48.8 ± 4.9
	69.2 ± 6.0 (D)	32.5 ± 1.2 (D)	46.8 ± 4.2
26	66.8 ± 8.8	35.2 ± 5.3	52.6 ± 10.5
	71.3 ± 10.0 (D)	35.2 ± 5.8 (D)	49.3 ± 10.7
	71.5 ± 11.3 (D)	28.2 ± 5.3 (D)	39.4 ± 9.7
50	65.3 ± 7.1	24.7 ± 4.1	37.8 ± 7.5
	62.1 ± 7.1 (D)	32.7 ± 1.6 (D)	52.6 ± 6.5
	65.0 ± 7.2 (D)	39.6 ± 1.9 (D)	60.9 ± 7.4
77	71.7 ± 6.6 (D)		

(D) Samples marked (D) were contained in dialysis bags.

(All values have been corrected for radioactive decay.)

and for gamma-emitters. Extraction curves for Zn-65 (Figure 1) rise quite rapidly at first and become essentially flat after about 3-4 days. Final yields in the two runs were 46.4 and 46.6%, in good agreement with the earlier determinations. Zn-65 specific activity in solution did not vary during the experiment. That is, Zn-65 and zinc were extracted at the same rate.

Analysis of Shelf Sediments

During 1970, samples were collected on each of three cruises, in January, March and December, at locations shown in Figure 2. Sediments ranged from sand to silt in the area sampled. The topmost one cm was skimmed from 250 cm^2 of Smith-McIntyre grab (Smith, W. and McIntyre, A. D. 1954) samples and immediately placed in $CuSO_4$ solution. The suspension was returned to the laboratory at Corvallis where it was filtered and analyzed as above. Combined data from all three cruises have been used to construct contour maps for specific activity and activity per unit area (Figure 4). Variations in Zn-65 values at certain locations sampled on different dates have been noted so that combination of all data is not rigorously valid. The aim here is to make a first approximation to the total inventory. Variations in time will be considered when we have series of data for longer periods. Results of several replicate analyses (different grabs) indicate surprisingly good analytical precision (Table 2).

Areas between contour intervals in Figure 4 were determined graphically and multiplied by the arithmetic mean of contour boundaries to obtain estimates of total activity (Table 3). No yield correction has been made in Figure 4 and Table 3. If 47% is taken as a uniform extraction yield, the 21 Ci total in Table 3 represents 45 Ci. The topmost 1 cm of sediment within the 0.5 nCi/m^2 contour in Figure 4 then contains 8.7% of the calculated 520 total sediment inventory. This is somewhat less than the 14% calculated by Gross (in press) for 1963 although both estimates are only small fractions of the total. We have considered the extreme cases of two models which would account for the remainder by: 1) assuming that the remainder is all buried below one cm but contained within the 0.5 nCi/m^2 contour, or 2) assuming that the remainder has been entirely transported outside the 0.5 nCi/m^2 contour.

Burial as the Extreme Case

In this case we assume that the total 520 Ci is contained within the 0.5 nCi/m^2 contour and that the activity-depth profile is exponential. Such a profile might be expected if both sediment and Zn-65 deposition rates were uniform and constant over the entire area and if no post-depositional vertical mixing occurred. The 45 Ci found within the 0.5 nCi/m^2 contour is taken to represent the integral of the activity-depth curve from zero to one cm deep and the profile is calculated (Figure 5). The half-value depth for this line is 7.6 cm.

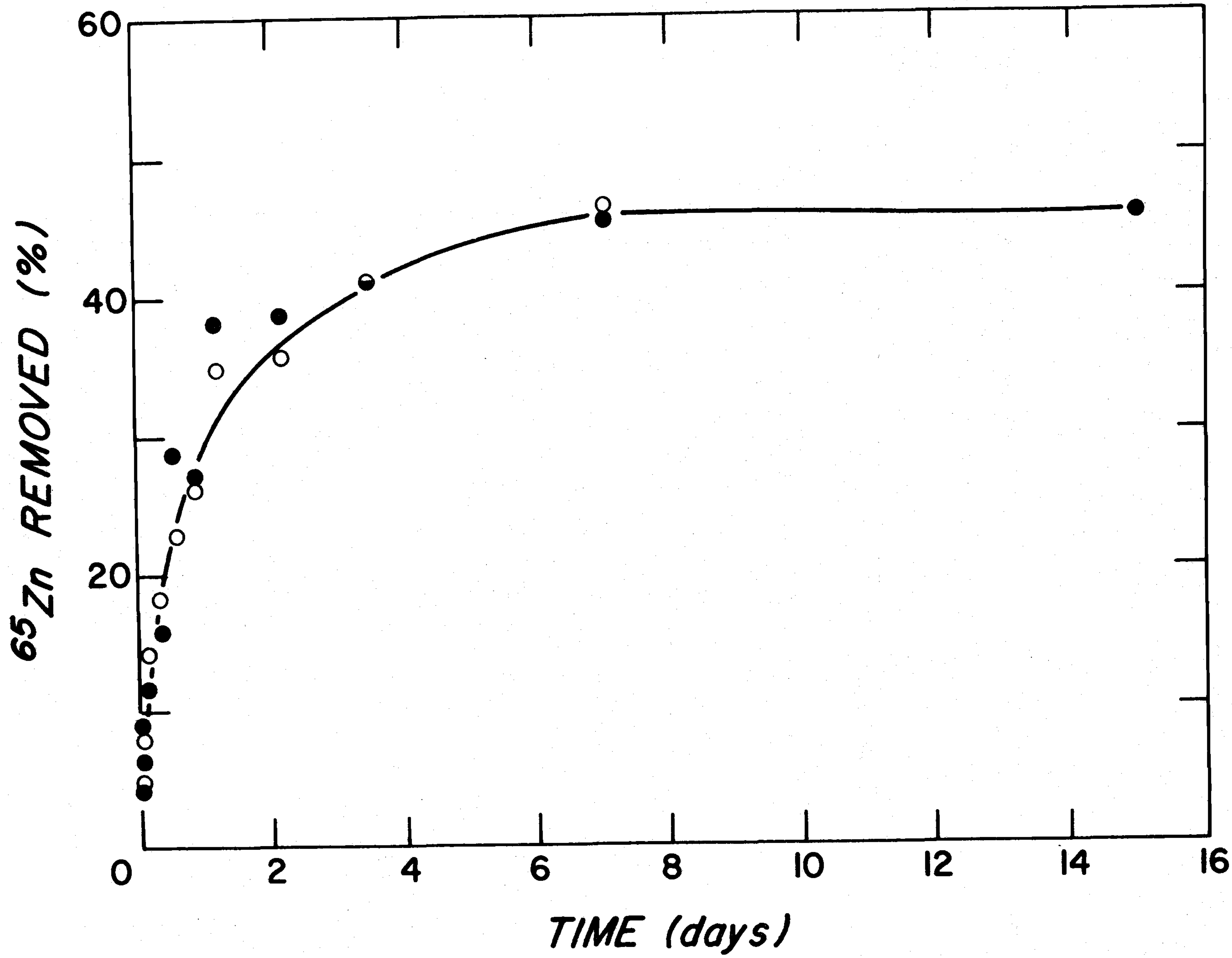


Figure 1. Percent of zinc-65 removed from sediment by 0.05 M $CuSO_4$ solution as a function of contact time.

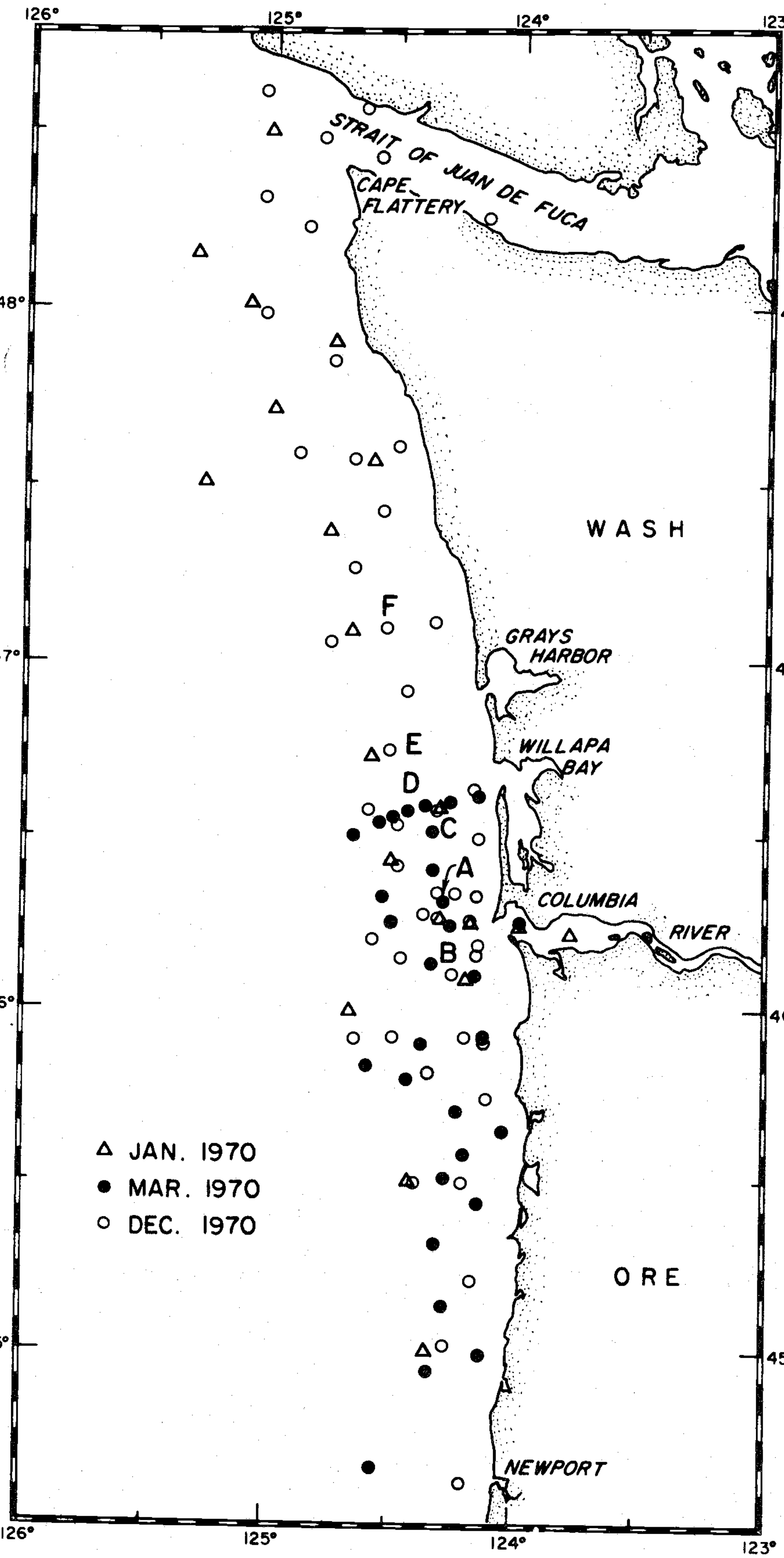


Figure 2. Chart showing sampling locations.

Table 2. Results of analyses of replicate grab samples for zinc-65 using $CuSO_4$ method

Location		Date	Zn-65 Content	
N. Latitude	W. Longitude	mo/yr	Activity/unit area, nCi/m^2	Specific Activity nCi/g Zn
46°17'	124°17'	1/70	11.8	76.5
			13.0	93.4
			12.1	63.3
			7.8	52.1
46°14'	124°15'	3/70	4.4	68.2
			3.7	63.0
			3.5	68.0
46°19'	124°17'	3/70	3.4	40.0
			3.1	31.2
			4.2	35.7
46°24'	124°19'	3/70	4.1	39.1
			4.6	63.8
			5.3	66.4
46°31'	124°20'	3/70	5.8	55.9
			5.2	66.9
			5.4	89.1
46°37'	124°10'	3/70	2.0	70.2
			2.3	17.3
			2.5	37.4
46°36'	124°16'	3/70	4.6	67.6
			4.5	65.0
			4.0	62.6

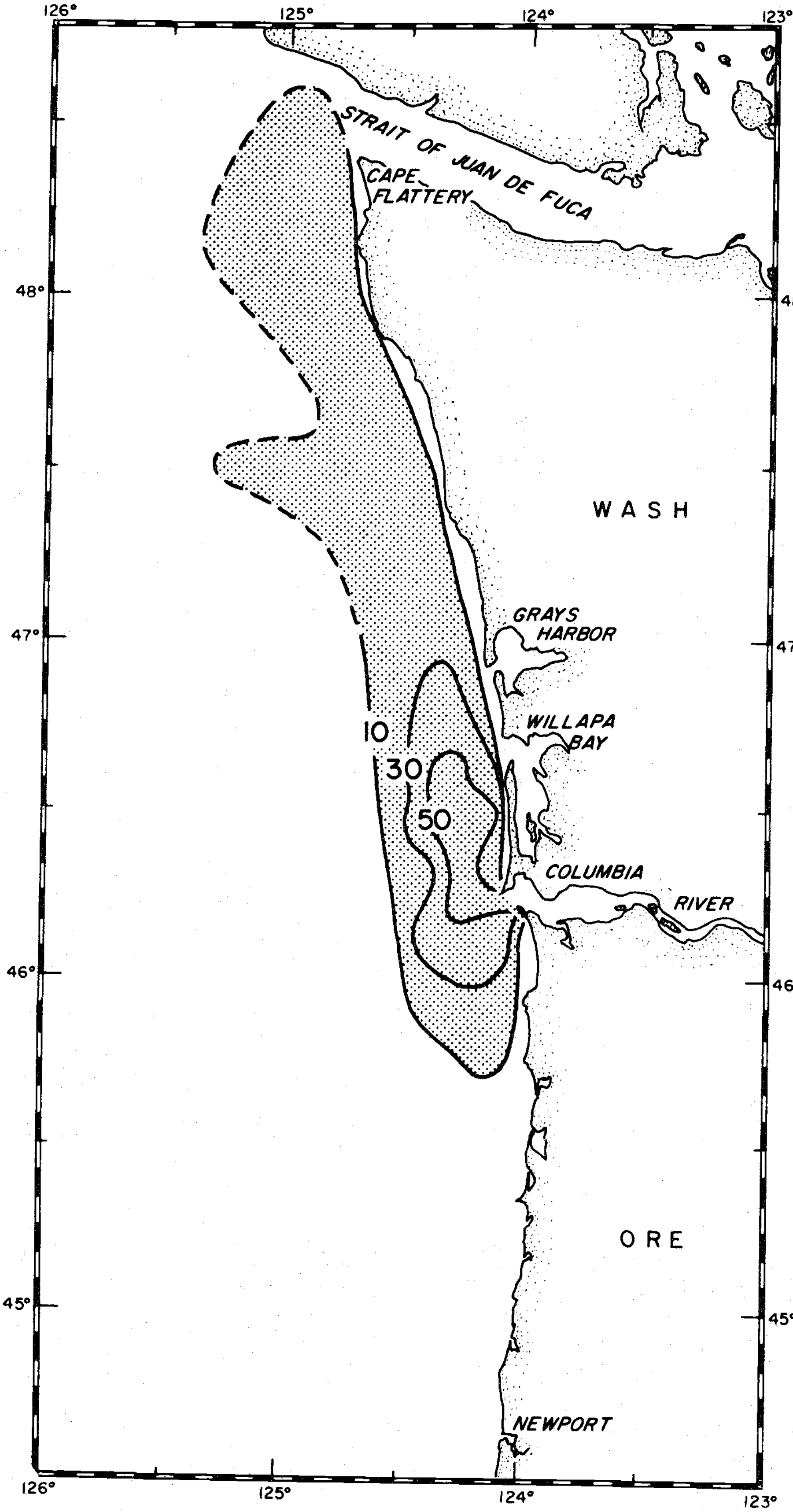


Figure 3. Isopleths of zinc-65 specific activities in topmost one cm of shelf sediments, nCi/g Zn.

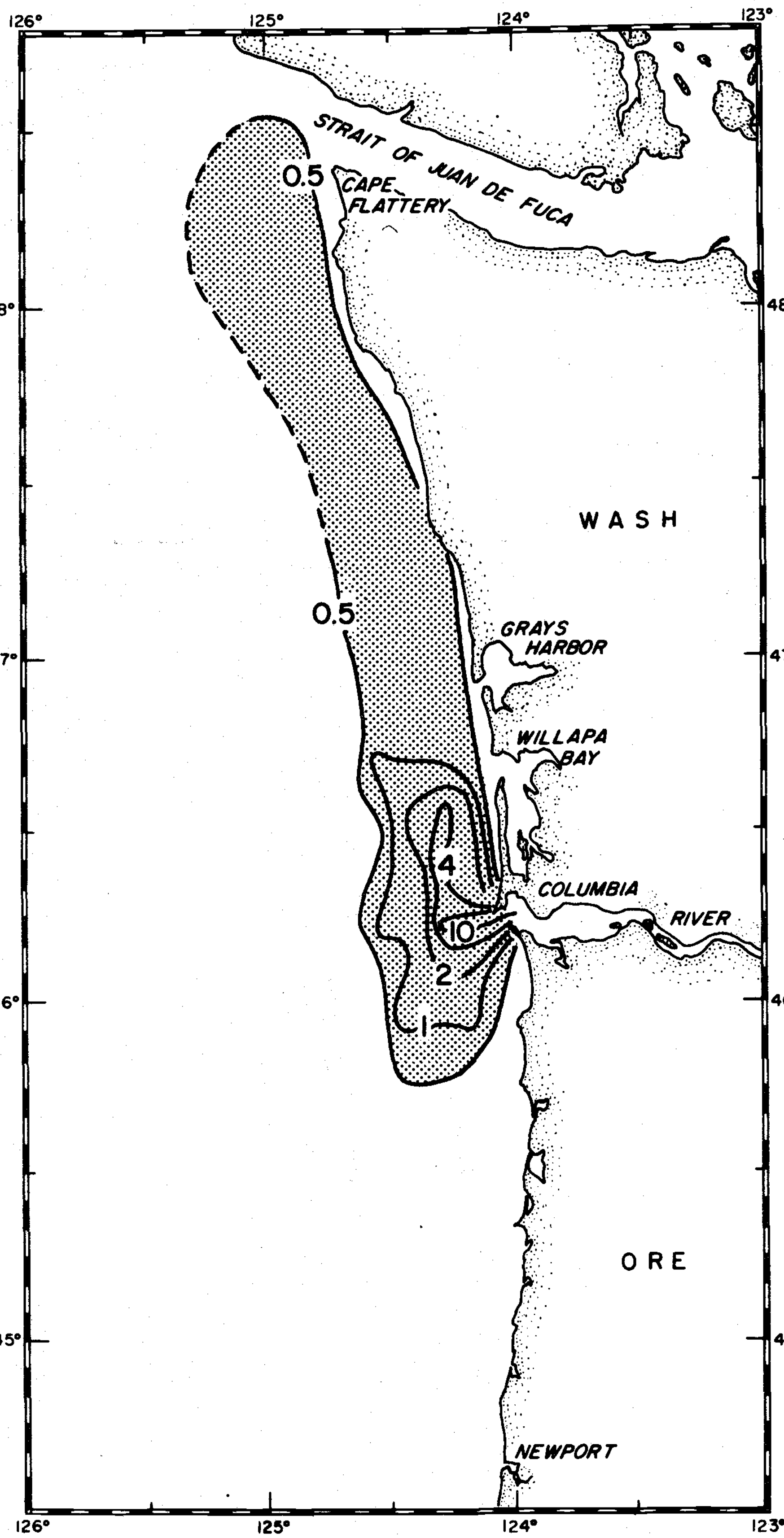


Figure 4. Isopleths of zinc-65 in topmost one cm of shelf sediments. Activity per unit area, nCi/m^2. (not corrected for extraction yield.)

Table 3. Estimation of Zn-65 contained in topmost one cm of shelf sediment

Contour Interval nCi/m^2		Mean Zn-65/unit area nCi/m^2	Area m^2	Total Zn-65 Ci
10<		11.0	3.7×10^8	4.0
4<	<10	7.0	5.5×10^8	3.8
2<	< 4	3.0	11.9×10^8	3.6
1<	< 2	1.5	18.3×10^8	2.7
0.5<	< 1	0.75	94×10^8	7.0
			TOTAL =	21.1

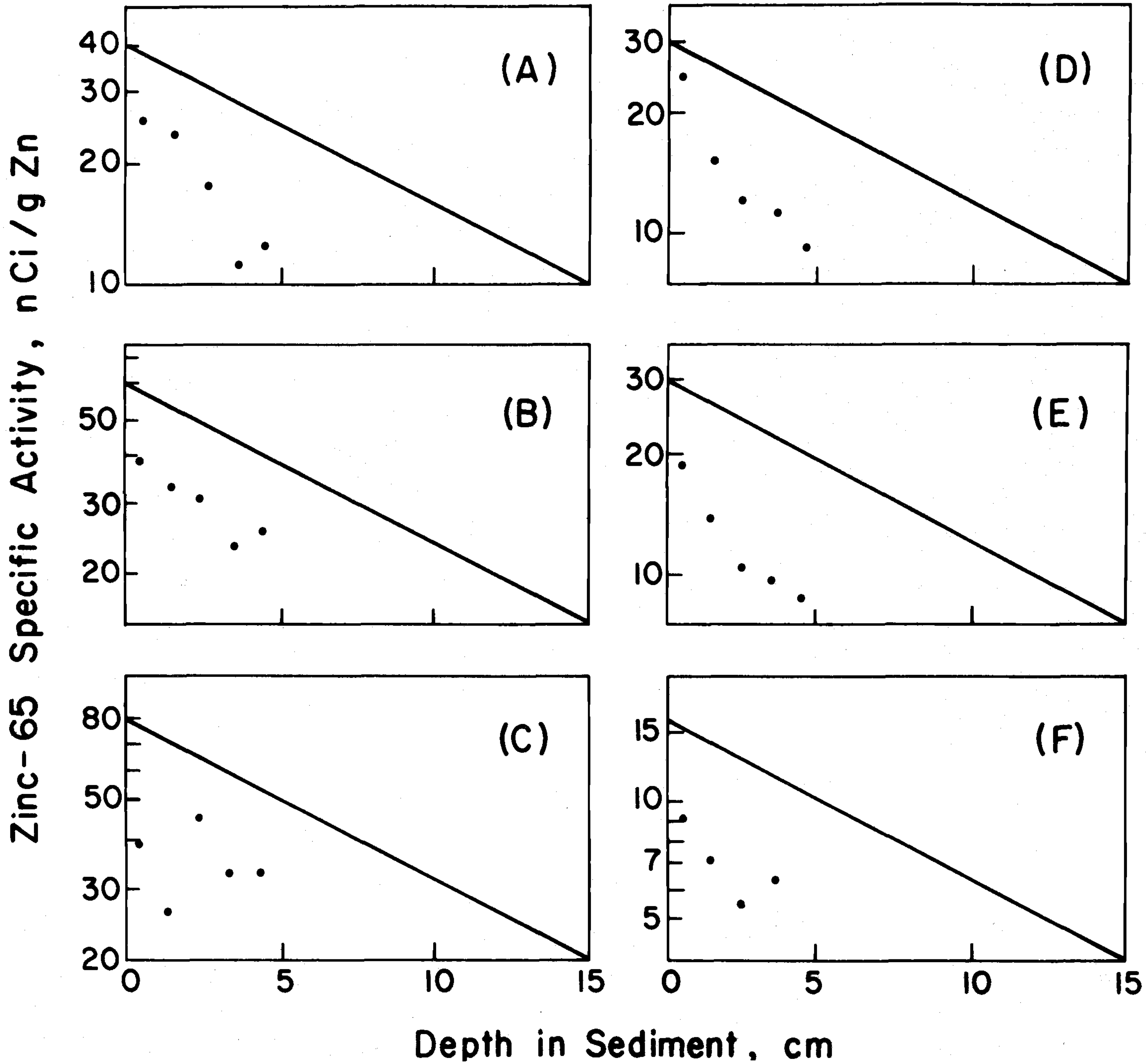


Figure 5. Vertical profiles of zinc-65 in sediment. Solid line indicates profile calculated from total-burial model.

Vertical profiles have been determined at sites designated by letters A through F in Figure 2. Successively deeper one cm layers were collected separately from grab samples and analyzed. Zinc-65 specific activity for these samples declines with depth as expected (Figure 5). However, with the exception of profile C, the slopes are all greater than predicted by the total burial model. Half-value depths based on least-squares fits to profiles A through F are 2.8, 5.0, 35, 3.2, 3.8 and 5.6 centimeters, respectively. Field notes indicate that sample C was collected from a sampler only partially filled with sand. It is possible that mixing of the sample occurred while the sampler was being raised. The mean regression coefficient for the logarithm of specific activity versus depth is 0.156 cm^{-1} (mean of 6 profiles) which corresponds to a half-depth of 4.5 cm. It is apparent from the profiles that some Zn-65 is buried below one cm but burial alone does not account for the total sediment inventory.

Transport as the Extreme Case

Alternatively, we assume that no Zn-65 is buried below one cm on the shelf but rather, is entirely transported outside the 0.5 nCi/m^2 boundary. Zinc-65 is assumed to spread in two dimensions along vectors radiating from the river mouth. The transport rate is taken to be constant along each vector and proportional to the distance from the river mouth to the 0.5 nCi/m^2 contour line. The "age" of sediment (time since entering the sea) at this line would then be only 32 days. Transport rates between the river mouth and the 0.5 nCi/m^2 contour would amount to 3050 km/yr (10 cm/sec) northward parallel to the coastline and 425 km/yr (1.4 cm/sec) westward offshore. This northward rate is in the range of reported surface currents (Gross and Nelson, 1966) and is surely an upper limit.

Other means for estimating mean transport rates based on radionuclides have been used. For example, Gross and Nelson (1966) used Zn-65 concentration in sediments and Zn-65:Co-60 activity ratios in sediments for such estimates (Table 4). A fourth method, assumes that changes in specific activity of Zn-65 are due only to decay of Zn-65 and that input specific activities have been constant. This method yields a minimum transport rate (maximum age) since dilution of Columbia River sediment with shelf sediment will also lower specific activity by adding stable zinc. Transport rates calculated using specific activity or the no-burial model are considerably higher than those given by Gross and Nelson (1966) (Table 4).

Bottom current speeds on the Washington shelf have been estimated by Gross, Morse and Barnes (1969). They report that bottom drifters move onshore when released where depths are less than 40 m and northward at greater depths. "Typical speeds for these long-distance northward movements were from 1 to 2 km/day, ranging from 0.4 to 3.2 km/day." (One to two km/day equals 365 to 730 km/year. Four-tenths to 3.2 km/day equals 150 to 1200 km/year.

Discussion

Columbia River Zn-65 and, by inference, Columbia River sediment are transported predominantly northward along the continental shelf after

Table 4. Estimates of transport rates for shelf sediments

Method	Rate, km/year Northward Alongshore	Westward Offshore	Reference
Zn-65 Content of sediment (minimum rate)	20-25	12	Gross and Nelson, 1966
Zn-65:Co-60 ratio	30	10	Gross and Nelson, 1966
No Burial Zn-65 Model	3050	425	This work
Zn-65 Specific Activity (minimum rate)	123	20	This work
Seabed Drifters (Bottom current measurement)	365-730	--	Gross, Morse & Barnes, 1969

entering the sea as previously reported by Gross (1966). Although Zn-65 is spread across the full width of the shelf off Washington, no radionuclide evidence yet available would indicate transport onto the slope or the abyssal plain.

Only a relatively small fraction of the total sediment inventory of Zn-65 predicted for the ocean from input data is found in the uppermost one cm of shelf sediment. Neither the extreme cases of complete burial nor total transport outside the study area account for the remainder when taken alone. In the complete burial case, profiles of Zn-65 versus depth of burial would need to have lower slopes than are observed. In the no-burial case, transport rates would have to be improbably high. It seems likely that some combination of burial and transport outside the 0.5 nCi/m^2 contour is needed in order to account for the total sediment inventory of Zn-65. Observed Zn-65 profiles confirm that significant burial of Zn-65 does occur. This burial cannot represent simple deposition, however. The mean deposition rate inferred from Zn-65 specific activity profiles in sediment is 6.7 cm/yr. If extended over the area within the 0.5 nCi/m^2 contour, $\sim 10^{10} m^2$, this would require the supply of 6.7×10^{11} kg/yr (1.8×10^6 metric tons/day) assuming a waterfree, in situ density of 1.0 g/cc. The Columbia River discharged an average of 2.3×10^4 metric tons/day during 1963 (Haushild, et al. 1966). Any other source of sediment would cause excessive dilution of Zn-65 and is therefore ruled out.There does not appear to be sufficient sediment supply to account for Zn-65 burial. We conclude that vertical mixing, either by currents or by organisms, within the upper few centimeters of sediment must be responsible for Zn-65 at depths greater than 1 cm.

Zinc-65 Accountability

Only 8.7% of the calculated sediment inventory of Zn-65 has been accounted for by direct analysis of the topmost one cm of shelf sediment off Oregon and Washington. Another portion is buried at depths below one cm. If the half-depth calculated from the mean regression coefficients of 6 profiles (4.5 cm) is representative of the entire area inside the 0.5 nCi/m^2 contour, another 52% is buried at depths greater than 1 cm. This leaves 39% of the total which must have been transported outside the area bounded by the 0.5 nCi/m^2 contour.

When this new estimate of the fraction contained within the 0.5 nCi/m^2 contour (61%) is used to estimate age at the contour and transport rates, more reasonable values are obtained. The calculated age at the contour is then 330 days and the corresponding northward alongshore transport rate is 290 km/yr which compares very favorably with seabed drifter data (Table 4).

Recapitulation and Possible Future Study

The regime of sediment transport on the continental shelf has been greatly oversimplified. Many assumptions have been necessary in order to allow manipulations of available data. These assumptions range from probably valid, though dubious, to obviously false. The extreme cases of no deposition and total deposition lead to improbable conclusions. However, when the extreme cases are combined to yield an intermediate model, inferred Zn-65 distribution on the shelf is made more reasonable and transport rates are in gratifying agreement with seabed drifter data.

Refinement of the absolute calculated numbers is possible with improved Columbia River Zn-65 discharge data and with a broader set of vertical profiles on the shelf. Allowance for Zn-65 retained in the 14 miles of estuary between Astoria and the river mouth would also affect the calculated values. Sorting of different particle sizes during transport may be indicated by analysis of various particle sizes of sediment for Zn-65 specific activity along a north-south transect. Continued measurement of Zn-65 in shelf sediments during declining input by the river may place further constraints upon transport considerations.

ACKNOWLEDGMENTS

We appreciate sampling assistance from the officers and crew of R/V YAQUINA and many graduate assistants. Messrs. I. L. Larsen and J. J. Wagner have carefully and reliably accomplished the radionuclide and stable zinc analyses. Mr. W. E. Bishop assisted in the determination of Zn-65 extraction rates. We are especially grateful to Dr. M. G. Gross for the opportunity to read his paper "Sediment-Associated Radionuclides from the Columbia River, 1961-1963" prior to its publication.

This work was supported by U.S. Atomic Energy Contract No. AT(45-1) 2227, Task Agreement 12 and is assigned publication number RLO-2227-T12-4.

REFERENCES

Alexander, G. V. and R. H. Rowland. 1966. Estimation of zinc-65 background levels for marine coastal waters. Nature 210(5032):155-157.

Gross, M. G. 1966. Distribution of radioactive marine sediment derived from the Columbia River. J. Geophy. Res. 71(8):2017-2021.

Gross, M. G. Sediment-associated radionuclides from the Columbia River, 1961-1963. In: Bioenvironmental Studies of the Columbia River Estuary and Adjacent Ocean Region. U. S. Atomic Energy Commission. (in press)

Gross, M. G., B. Morse and C. A. Barnes. 1969. Movement of near-bottom waters on the continental shelf off the Northwestern United States. J. Geophy. Res. 74(28):7044-7047.

Gross, M. G. and J. L. Nelson. 1966. Sediment movement on the continental shelf near Washington and Oregon. Science 154:879-885.

Haushild, W. L., R. W. Perkins, H. H. Stevens, Jr., G. R. Dempster, Jr. and J. L. Glenn. 1966. Radionuclide transport in the Pasco to Vancouver, Washington reach of the Columbia River July 1962 to September 1963. Portland, Ore. U. S. Geological Survey Openfile Report. 187 pp.

Johnson, V. G. 1966. Retention of zinc-65 by Columbia River sediment. M.S. Thesis. Corvallis, Oregon State University. 56 numb. leaves.

Johnson, V. G., N. H. Cutshall and C. L. Osterberg. 1967. Retention of zinc-65 by Columbia River sediment. Water Resources Research. 3(1): 99-102.

Kharkar, D. P., K. K. Turekian and K. K. Bertine. 1968. Stream supply of dissolved silver, molybdenum, antimony, selenium, chromium, cobalt, rubidium and cesium to the oceans. Geochim. et Cosmochim. Acta. 32:285-298.

Lowman, F. G., D. K. Phelps, R. McClin, V. Roman de Vega, I. Oliver de Padovani and R. J. Garcia. 1966. Interactions of the environmental and biological factors on the distribution of trace elements in the marine environment. In: Disposal of Radioactive Wastes into Seas, Oceans and Surface Waters. IAEA. Vienna. pp. 249-265.

Murata, K. J. 1939. Manganese in river and ocean muds. Amer. Jour. of Science. 237:725-735.

Osterberg, C. L., L. D. Kulm and J. V. Byrne. 1963. Gamma emitters in marine sediments near the Columbia River. Science. 139(3558): 916-917.

Osterberg, C. L., J. Pattullo and W. Pearcy. 1964. Zinc-65 in euphausiids as related to Columbia River water off the Oregon coast. Limnol. Oceanogr. 9(2):249-257.

Smith, W. and A. D. McIntyre. 1954. A spring-loaded bottom sampler. J. Mar. Biol. Assoc. 33(1):257-264.

U.S. Geological Survey. Pacific Northwest water resources summary. Water Year 1968, Water Year 1969.

Wolfe, D. A. 1970. Levels of stable Zn and ^{65}Zn in *Crassotrea virginica* from North Carolina. J. Fish. Res. Bd. Canada. 27(1): 47-57.

APPENDIX

In order to conserve space and maintain continuity in the above text we have omitted many equations and calculations. These are briefly summarized below:

Zinc-65 Discharge. Monthly discharge of Zn-65 by the Columbia River was estimated by multiplying single monthly concentrations at Astoria (unpublished data) by mean monthly water discharge values (U.S. Geological Survey). Total Zn-65 discharged during each month was corrected for decay to 1 January 1970 using the decay equation, $A = A_o e^{-\lambda t}$. Zinc-65 discharge values thus estimated may be in error because both the concentration of Zn-65 and the water discharge rate vary on a time scale of days. Greater sampling frequency would improve accuracy of the discharge estimates.

Total Burial Model. Zinc-65 constant specific activity is considered to deposit at a constant rate for a sufficiently long time that decay of the deposited activity equals the deposition rate. In addition, the sediment deposition rate, S, is also considered to be constant so the depth below the surface is equivalent to the product of time since deposition and sediment deposition rate. The activity concentration (or specific activity) at depth, x , is then related to the surface activity concentration by:

$$A_x = A_s \; e^{-\lambda t} = A_s \; e^{-\frac{\lambda}{s} x} \qquad (1)$$

The cumulative total activity above depth x is:

$$A_c = \int_0^z As \; e^{-\lambda \frac{x}{S}} \, dx$$

$$= \frac{As \cdot S}{\lambda} \left(1 - e^{\frac{-\lambda x}{S}}\right) \qquad (2)$$

and the total activity present at steady state $(x \to \infty)$ is:

$$A_t = \frac{As \cdot S}{\lambda} \quad . \qquad (3)$$

The fraction of total steady state activity which is found above depth x is:

$$F_x = \frac{Ac}{A_t} = 1 - e^{-\frac{\lambda x}{S}} \qquad (4)$$

Solving equation (4) for x,

$$X = -\frac{S}{\lambda} \cdot \ln\left(1 - F_x\right) \; . \qquad (5)$$

The half-value depth $x_{\frac{1}{2}}$ is the depth where $F_x = 0.5$ or:

$$X_{\frac{1}{2}} = - \frac{S}{\lambda} \ln (1 - 0.5) \tag{6}$$

Combining (5) and (6) and solving for $x_{\frac{1}{2}}$,

$$X_{\frac{1}{2}} = \frac{\ln 0.5}{\ln (1 - F_x)} \cdot X \ . \tag{7}$$

The value of F determined for x = 1 cm is 0.087 so that:

$$X_{\frac{1}{2}} = \frac{\ln 0.5}{\ln (1 - 0.087)} \cdot 1 \text{ cm} = 7.6 \text{ cm}.$$

No Burial Model. In the above case we have equated time with the ratio of depth in sediment to sedimentation rate. In the no burial case we treat time as "age" or elapsed time since entering the sea and further assume the isopleths of activity per unit area are also isopleths of age. Age or t is then equivalent to λ/S in equation (4) so that

$$F_x = (1 - e^{-\lambda t}) \tag{8}$$

Solving for t,

$$t = \frac{- \ln (1 - F_x)}{\lambda}$$

$$= \frac{- \ln \ (1 - 0.087)}{2.83 \times 10^{-3} \ d^{-1}} = 32 \text{ d}. \tag{9}$$

Transport rates are then calculated by dividing the distance between the river mouth and the 0.5 nCi/m^2 contour by the age, t.

Zinc-65 Accountability. In this case equation (4) is rearranged so that the total activity within the 0.5 nCi/m^2 boundary, (A_t) can be estimated in terms of the activity found in the upper one cm (A_c = 45 Ci) and the experimental mean regression coefficient ($\lambda/S = 0.154 \text{ cm}^{-1}$):

$$A_t = \frac{A_c}{1 - e^{-(\lambda/S)x}}$$

$$= \frac{45 \text{ Ci}}{1 - e^{-0.154 \text{ cm}^{-1} \cdot 1 \text{ cm}}} = 315 \text{ Ci}.$$

This is 315/520 or 0.61 of the estimated total sediment inventory of Zn-65 and the fraction buried below one cm is 0.61 - 0.087 = 0.523. The new transport rate is calculated as in the no burial model.

SEASONAL RADIONUCLIDE INVENTORIES IN ALDER SLOUGH, AN ECOSYSTEM IN THE COLUMBIA RIVER ESTUARY

by William C. Renfro

From 1944 to early 1971 plutonium production reactors at Hanford, Washington, added small, but measurable, amounts of neutron-induced radionuclides to the Columbia River. Perkins, Nelson, and Haushild (1966) measured ^{46}Sc, ^{51}Cr, ^{54}Mn, ^{58}Co, ^{65}Zn, ^{95}Zr, ^{95}Nb, ^{106}Ru, ^{124}Sb, and ^{140}Ba in river water and suspended particulates by multidimensional gamma-ray spectrometry between Hanford and Vancouver, Washington. Farther downstream in the Columbia River Estuary we routinely measure ^{46}Sc, ^{51}Cr, and ^{65}Zn (and less frequently ^{54}Mn and ^{60}Co) in estuarine samples. The presence of these readily detectable radionuclides in water, sediments, plants, and animals provides an excellent opportunity to study the partitioning of elements in an estuary. This paper evaluates the relative importance of a number of ecosystem components as reservoirs of radionuclides. An attempt is made to determine how each reservoir varies in importance in time and, finally, to briefly consider interactions (transfers) of the components one with another.

The distributions of various stable and radioactive metals in estuarine ecosystems have been studied by a number of investigators. Duke, Willis, and Price (1966) created their own estuarine communities by adding plants, shellfish, and fishes to two concrete-walled ponds then spiking the water with ^{65}Zn. Within 24 hours most of the ^{65}Zn was lost from the water to sediments or through tidal exchange. One hundred days after addition of the ^{65}Zn, 94-99% of the ^{65}Zn present in the experimental ponds was in the top 6 cm of the sediments.

Pomeroy, Johannes, Odum, and Roffman (1969) followed the distributions of ^{32}P and ^{65}Zn spikes added simultaneously to the water of the Duplin River, part of a Georgia salt marsh. Both radionuclides were rapidly lost from the water to the sediments. Phosphorus-32 apparently remained in the upper layer of the sediments, and the dominant marsh plant, Spartina alterniflora, did not take up ^{32}P from its subsurface roots. Various mollusks, crustaceans, and fishes accumulated both radionuclides with ^{65}Zn being lost from the animals much more slowly than ^{32}P. However, the major reservoir for ^{65}Zn was shown to be the sediments.

Parker (1962) studied the distribution of stable Zn in the water, sediments, and biota of Redfish Bay in Texas. He found that although the fishes and shrimp contained several thousand times the Zn concentration of the bay water, their biomass was small compared to that of the vegetation and sediments. His inventory for Zn in this grass flat showed that sediments and vegetation constitute the major reservoirs.

Paper presented at Third Symposium on Radioecology, Oak Ridge, Tennessee 10-12 May 1971. RLO 2227-T12-6.

Cross, Duke, and Willis (1970) measured the concentrations of Mn, Fe, and Zn in the Newport River Estuary, North Carolina. They observed that all three elements in the sediments varied with time and sediment composition but decreased in a seaward direction. Concentrations of Mn, Fe, and Zn in six species of polychaete worms suggested that the worms were capable of regulating their trace metal content.

Phelps (1967) studied the partitioning of stable Fe, Zn, Sc, and Sm in benthic communities of Anasco Bay, Puerto Rico. He observed that Fe was present in highest amounts in both fauna and sediments but that Zn was concentrated in animals to higher levels than in the sediments. He concluded that the density and species composition of the infauna has a direct influence on the partitioning of Fe, Zn, Sc, and Sm in the community. For example, Fe was concentrated in polychaete worms which feed selectively on specific sizes of the most recently settled particulate matter. In contrast, polychaetes which move throughout the upper sediment layers feeding less selectively tend to concentrate Zn to the exclusion of Fe.

To investigate the behavior and distribution of radionuclides in all the components of such a large, complex region as the Columbia River Estuary would be a major undertaking. For this reason, Alder Slough (Fig. 1), a discrete portion of the estuary small enough to adequately sample on a reasonable time scale, was chosen for the study. This small, "L-shaped" arm of a tidal flat on the southern shore of the estuary has a number of desirable features: (a) it is accessible by land or water, (b) it is shallow enough to seine, yet deep enough to retain water at all tide levels, and (c) it is a protected site of relative calm even during storms.

Three times of the year appeared to be most important for making inventories. In midsummer the total biomass of all the plants and animals is greatest. The sedges and algae grow in rank profusion throughout the intertidal zone. Large numbers of small crustaceans and fishes take advantage of the relatively warm productive slough waters and these, in turn, attract larger carnivores to the area. As winter approaches, the solar insolation and water temperatures diminish. By December most of the sedges and algae have died and only a few animals remain in the area so that the total biomass of the biota is minimal. Spring is a transition season between the barren winter period and the high standing stocks of the summer, so this period represents an intermediate stage between the two extreme seasons.

METHODS

The general approach to estimating total amounts of the radionuclides in the arbitrarily delimited inventory area (Figure 1) involved taking representative composite samples from measured areas and then multiplying by the total area. A 12.7 x 12.7 cm. NaI (Tl) well crystal and photo-

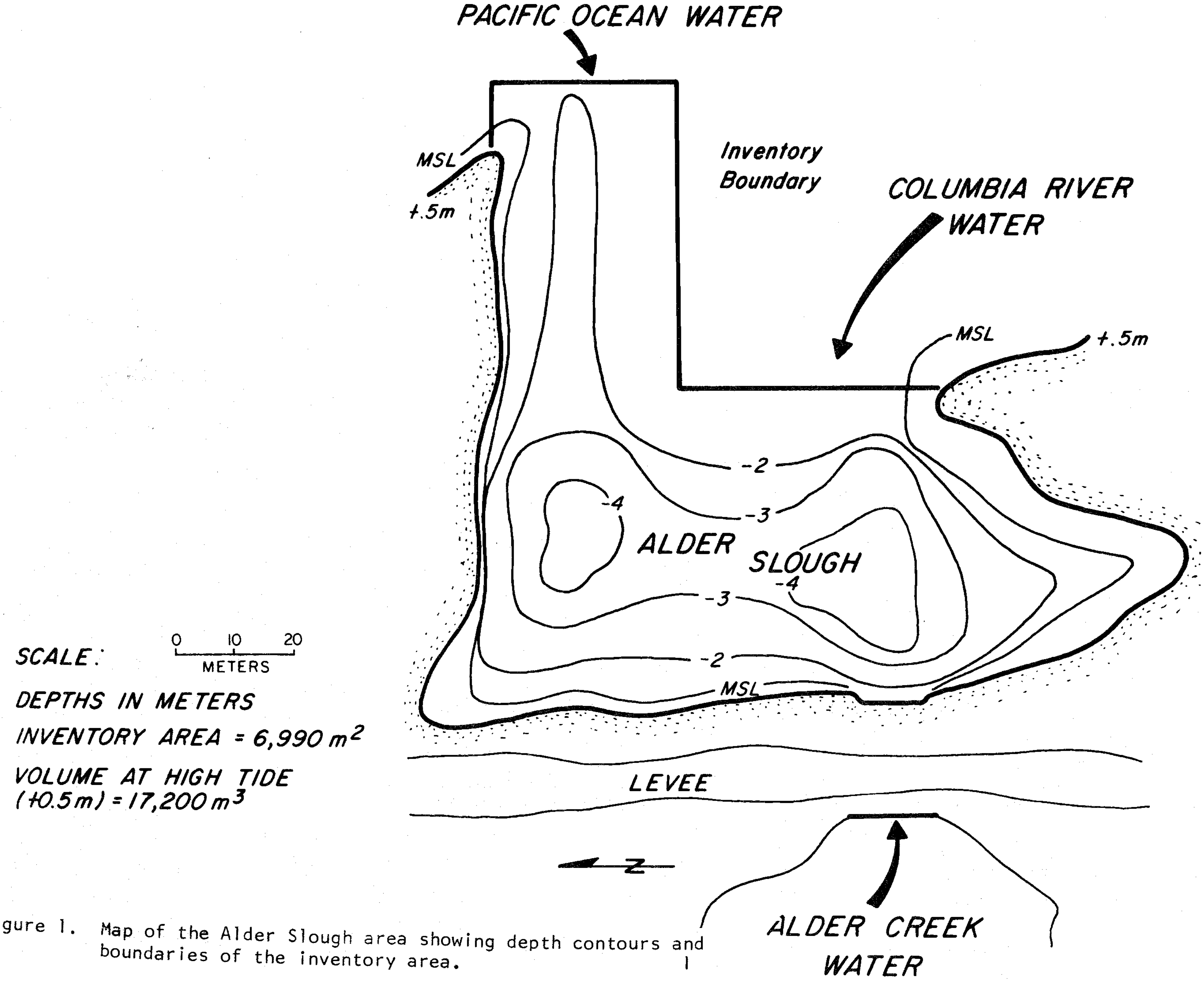


Figure 1. Map of the Alder Slough area showing depth contours and boundaries of the inventory area.

multiplier coupled to a 512 multichannel analyzer was used for all radionuclide analyses. The resultant gamma ray spectra were resolved by a least-squares computer program.

Sediments were obtained at ten locations in the slough by inserting an inverted glass Petri dish into the mud surface and extracting the mud-filled dish by hand. The ten samples were thoroughly mixed in a plastic bag then returned to the laboratory. Subsamples of the sediment were dried at 60-70C and packed in plastic counting tubes for radioanalysis. Activities of replicate subsamples from the well-mixed mud samples were in close agreement so that lack of sample homogeneity did not appear to be a problem.

Detritus was taken from the uppermost 1 cm of sediments at three points in the inventory area. A circular dipnet was pressed 1 cm into the surface of the mud and all the material within the circle was removed and strained through the 0.5 mm meshes of the net. The resulting detritus, consisting mainly of decaying plant particles, was washed briefly to remove mud, dried, ashed at 450 C, and radioanalyzed.

The biomass of green algae in the inventory area was estimated by scraping all the algae from a measured area of the tide gate wall. The weight of this sample multiplied by the total number of equal areas in the slough covered by algae of similar density produced an estimate of total weight.

The total weights of the intertidal sedges, *Carex* and *Scirpus*, were determined by counting the number of "average" plants in three randomly selected quadrats and estimating the total area covered by the plants on scale maps. An "average" plant of each species with root system intact was washed, dried, ashed and radioanalyzed.

The biomasses of the small crustaceans which inhabit the slough throughout the year are difficult to estimate. Numerous counts of the ubiquitous amphipod, *Corophium salmonis*, over several years of study in Alder Slough suggested that this tube-dwelling animal is present at a density of about one adult per square cm. Using this number as the best estimate of population density together with estimates of the weight of individual amphipods, the total ash weight of *C. salmonis* was set at 6,990 g. The biomasses of the amphipod, *Anisogammarus confervicolus*, and the isopod, *Gnorimosphaeroma oregonensis*, were each arbitrarily assumed to be one-tenth that of *C. salmonis*.

The total weights of fishes and larger crustaceans were determined from seine collections. During each inventory, a small mesh 15 m bag seine was used to capture animals from an area of the bottom representing 4.5% of the total inventory area. The biomass of each age class of each species taken in the seine was projected to the total area and appropriate radioanalyses were carried out.

The total activities of the gamma emitting radionuclides ^{65}Zn, ^{51}Cr, ^{46}Sc, ^{60}Co, and ^{54}Mn in each of the Alder Slough ecosystem components are presented in the figures and tables which follow. Confidence limits in the form of single standard deviations are shown. In all cases, the standard deviations are based on errors due to counting statistics, weighing, and biomass extrapolations. When the single standard deviation exceeded 33% of the nominal value, a dashed line was used. In those cases in which the activity of the radionuclide was less than 0.01μ Ci, a zero was recorded on the inventory.

RESULTS AND DISCUSSION

Water

The radioactivity of Alder Slough water is influenced by the mixing of waters from three different sources: the Columbia River, Alder Creek and Pacific Ocean (Fig. 1). The mixed, semi-diurnal tidal cycle results in two high and two low water levels each day. Coupled with these tidal exchanges are seasonal variations in the discharge rates of the river and the creek. The net result of the varied inputs of water into the inventory area is a constantly changing mixture of ocean, creek, and radioactive river waters to produce a continuous change in the concentrations of radionuclides in the slough water.

On the first inventory in July, 1968, the concentrations of ^{65}Zn, ^{51}Cr,and ^{46}Sc in both particulate and ionic forms were measured in surface and near bottom waters at two hour intervals for 24 hours. The concentrations of these radionuclides in both ionic and particulate form in the slough water had the following ranges: ^{65}Zn. . . 0-16 pCi/l, ^{51}Cr. . . 50-246 pCi/l, and ^{46}Sc. . . 2-5 pCi/l. If the 24-hour mean activities per liter are multipled by the high tide volume of the inventory area (17.2×10^{6}l), the resultant totals constitute substantial fractions of the total activities of the three major radionuclides: ^{65}Zn . . .2.2%, ^{51}Cr. . . 22.0%, ^{46}Sc. . . 6.0%. Except for July, 1968, sampling and inventories were done within an hour or so of low tide. As a result, the slough surface water was dominated by Alder Creek water and radioactivities were low, hence, not representative of the conditions prevailing throughout the day. For this reason, estimates of the radionuclide totals in water were not attempted although the water may be an important reservoir of the system.

Sediment

Figure 2 shows how the radioactivity in sediments varied seasonally and over the period of the study. Both ^{65}Zn and ^{46}Sc declined steadily throughout the 2-1/2 year period, probably due to shutdown of single-pass nuclear reactors at Hanford. In February 1968, Reactor B was shutdown

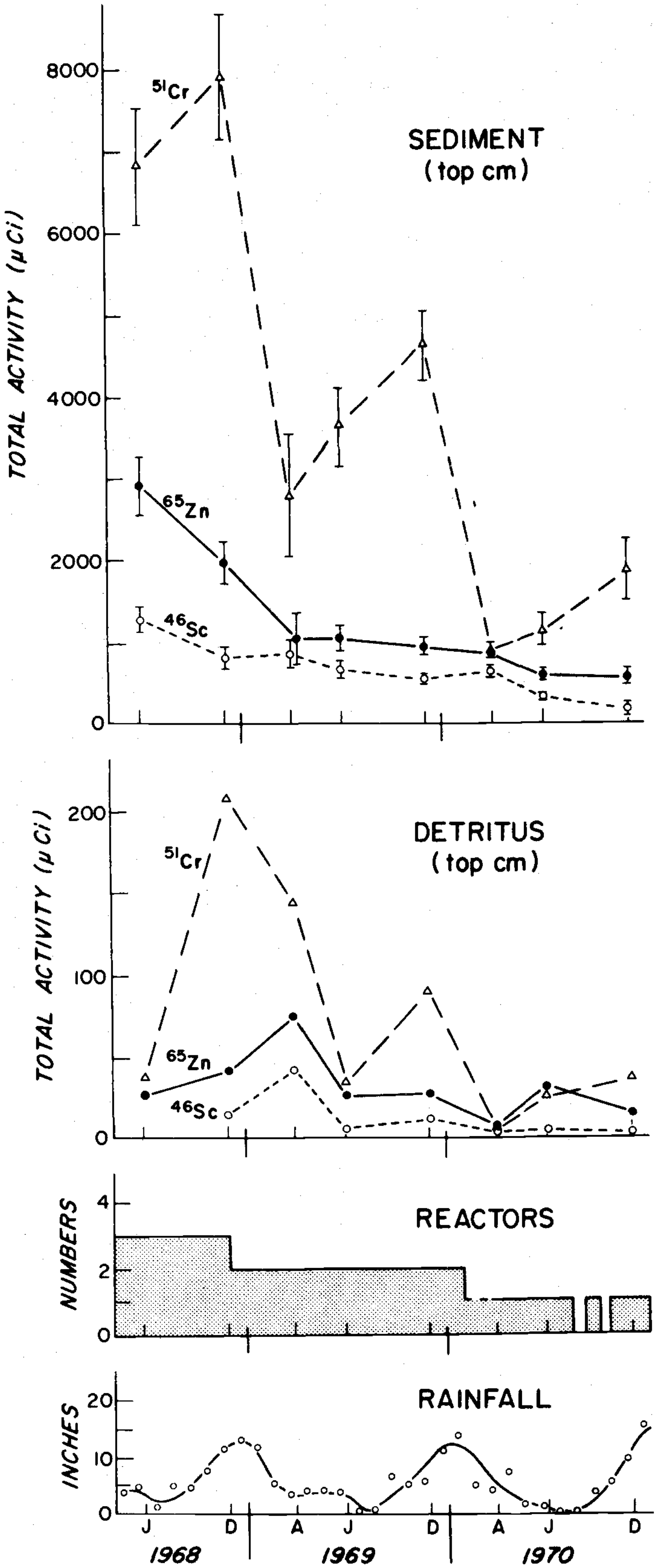


Figure 2. Total microcuries of ^{51}Cr, ^{65}Zn, and ^{46}Sc in sediment and detritus within the inventory area. (Below) Numbers of plutonium production reactors operating at Hanford and monthly rainfall in the Alder Creek Watershed.

leaving three plutonium production reactors in operation. Figure 2 shows the subsequent history of reactor operations at Hanford.

Chromium-51 levels in sediment of the inventory area also diminished drastically from 1968 to 1970, but in an interesting fashion. In each year the total ^{51}Cr dropped sharply from December of the previous year to April, but then increased through December. The rapid drop in total activity of ^{51}Cr in sediments from December to April may result from seasonal flooding of the slough with non-radioactive creek water. During the winter rainy season (November through January) the discharge of fresh water from Alder Creek is at its annual peak, dominating the hydrography of the slough (Fig. 2). This creek water is deeply colored and appears to be highly concentrated in organics dissolved from the peat bogs and alder thickets in its 5 km^2 watershed. The large volumes of this water may displace some of the radioactivity associated with sediments. Hence, some radionuclides in the sediments may be lost during winter creek flooding to be replaced during the remainder of the year.

Detritus

Detritus in Alder Slough consists largely of broken and decaying plant material resulting from the die-off of the large biomass of sedges in and around the slough. This detrital material is not highly visible, often being covered with sediment, but it is an important reservoir of radionuclides and undoubtedly forms the energy base for some of the food webs in the slough. The total amounts of ^{65}Zn and ^{46}Sc associated with detritus of the inventory area remained roughly constant during the 2-1/2 year study.

As in the sediments, ^{51}Cr declined drastically over the study period but reached peak totals in the detritus during December of each year. The total mass of detritus in the upper centimeter of sediment (Table 1) varied widely and without pattern around 1,000 kg. Hence, the decline in the total activity of ^{51}Cr was not merely due to changes in the quantities of detritus present, but to seasonal changes in the amount of ^{51}Cr in the detritus.

Although ^{65}Zn and ^{46}Sc in the sediments and detritus generally declined, ^{51}Cr increased to peak values in December of each year. One hypothesis regarding the increase of ^{51}Cr in detritus and sediment to a peak in December is that detrital plant matter in the sediment acts as a "big black sponge" to continually reduce ionic hexavalent ^{51}Cr to the trivalent state and sequester it to sediments (Cutshall, Johnson and Osterberg, 1966) and to living or dead organisms (Curl, Curshall, Osterberg, 1965).

To test the "big black sponge" hypothesis large quantities of living sedges from the slough were chopped into small pieces and secured in bags made from 0.4 mm mesh nylon plankton netting. The bags were weighted with

TABLE 1. ALDER SLOUGH RADIONUCLIDE INVENTORIES (in microcuries)

SEDIMENT	^{65}Zn	^{51}Cr	^{46}Sc	^{60}Co	^{54}Mn
July 68	2913±343*	6823±709	1259±152	----	----
Dec 68	1973±239	7912±751	794±111	----	----
Apr 69	1023±322	2795±770	844±182	----	----
July 69	1013±142	3630±475	645± 78	----	----
Dec 69	924± 95	4628±425	541± 56	116±27	88±19
Apr 70	832± 60	884± 84	612± 40	184±19	59±10
July 70	622± 66	1139±180	316± 39	98±22	59±17
Dec 70	576± 81	1865±367	168± 50	95±29	0

DETRITUS	Dry Wt. (kg)	^{65}Zn	^{51}Cr	^{46}Sc	^{60}Co	^{54}Mn
July 68	693	27.4±2.9	36.7±8.7	------	5.2±1.0	0
Dec 68	1,093	41.7±5.4	208.5±19.8	15.1±2.6	----	7.9±2.6
Apr 69	1,355	74.0±11.0	144.0±24.2	42.3±5.5	----	----
July 69	481	27.1±2.1	34.2±3.8	6.6±0.7	1.7±0.4	1.2±0.4
Dec 69	1,018	22.9±2.4	89.6±7.8	10.6±1.1	2.6±0.6	2.2±0.5
Apr 70	483	10.2±0.6	9.5±2.0	5.4±0.5	----	1.2±0.2
July 70	1,945	31.1±3.8	26.3±5.9	7.0±1.2	4.5±0.8	----
Dec 70	943	15.0±1.7	36.8±6.6	4.4±1.0	1.9±0.5	2.1±0.5

GREEN ALGAE	Dry Wt. (kg)	^{65}Zn	^{51}Cr	^{46}Sc	^{60}Co	^{54}Mn
July 68	4.94	0.5±0.1	2.0±0.3	0.5±0.1	0.1±0.03	0.04±.01
Dec 68	0	0	0	0	0	0
Apr 69	0.29	0.01±0.001	0	0.02±0.002	----	------
July 69	1.53	0.39±0.08	1.29±0.21	0.38±0.05	----	0.09±.02
Dec 69	0	0	0	0	0	0
Apr 70	0.43	0.01±0.002	------	0.01±0.002	----	0
July 70	0.77	0.02±0.004	0.03±.006	0.02±0.002	0	0
Dec 70	0	0	0	0	0	0

CAREX	Dry Wt. (kg)	^{65}Zn	^{51}Cr	^{46}Sc	^{60}Co	^{54}Mn
July 68	355	101.8±21.9	145.7±44.7	46.9±5.5	6.7±1.7	0
Dec 68	542	7.4±0.9	15.8±2.4	------	------	----
Apr 69	599	1.3±0.2	1.9±0.3	0.4±0.1	0.1±0.03	----
July 69	779	3.8±0.7	12.0±2.3	1.2±0.4	------	----
Dec 69	149	3.0±0.6	12.1±2.0	0.9±0.3	1.0±0.2	----
Apr 70	683	3.7±0.4	2.7±0.7	1.5±0.2	------	0.4±0.1
July 70	874	3.3±0.4	4.5±1.1	1.0±0.2	0.2±0.04	0.1±.02
Dec 70	101	0.3±0.1	0.7±0.2	------	0.1±0.03	----

SCIRPUS	Dry Wt. (kg)	^{65}Zn	^{51}Cr	^{46}Sc	^{60}Co	^{54}Mn
July 68	1,722	53.2±6.3	207.0±23.2	37.9±4.4	5.5±1.4	0
Dec 68	0	0	0	0	0	0
Apr 69	95	1.6±0.2	14.8±3.2	0.4±0.1	0.2±0.04	----
July 69	479	7.9±1.3	36.7±4.9	6.9±0.9	-----	1.1±0.3
Dec 69	0	0	0	0	0	0
Apr 70	0	0	0	0	0	0
July 70	1,845	8.5±1.5	15.9±3.6	3.3±0.7	4.0±0.7	0.2±0.4
Dec 70	688	2.7±0.4	4.0±1.1	-----	0.9±0.2	----

ENDEMIC CRUSTACEANS (Detrital Feeders)	Species	^{65}Zn	^{51}Cr	^{46}Sc	^{60}Co	^{54}Mn
July 68	CAG	11.10±0.27	-----	-----	0	0
Dec 68	CAG	0.77±0.13	3.43±0.50	025±0.06	0.19±0.05	0.10±0.03
Apr 69	CAG	1.33±0.24	3.48±0.61	0.37±0.10	0	0
July 69	CAG	6.52±1.16	0	0	0	1.83±0.34
Dec 69	CAG	0	0	0	0	0
Apr 70	CAG	1.50±0.20	0	0	0	0
July 70	CAG	-----	0	0	0	0
Dec 70	CAG	0.05±0.001	0	0.01±0.002	0.01±0.001	0

C ... Corophium salmonis, A ... Anisogammarus confervicolus,
G ... Gnorimosphaeroma oregonensis

ENDEMIC CARNIVORES	Species	^{65}Zn	^{51}Cr	^{46}Sc	^{60}Co	^{54}Mn
July 68	PCL	0.04±0.01	-----	------	0	0
Dec 68	C	0	0	0	0	0
Apr 69	PL	0.03±0.01	-----	------	0	0
July 69	PCLCa	0.05±0.01	-----	------	0	0
Dec 69	PCL	0.01±0.001	-----	------	0	0
Apr 70	PCL	0.01±0.001	0	0	0	0
July 70	PCLCa	0.02±0.002	0	0	0	0
Dec 70	PC	0	0	0	0	0

P ... Platichthys stellatus, C ... Crangon franciscorum
L ... Leptocottus armatus, Ca ... Cottus asper

OCCASIONAL CARNIVORES AND HERBIVORES	Species	^{65}Zn	^{51}Cr	^{46}Sc	^{60}Co	^{54}Mn
July 68	MC	0.35±0.04	------	------	0	0
Dec 68		0	0	0	0	0
Apr 69	MN	0.20±0.03	------	------	0	0
July 69	OMCMs	0.52±0.06	------	------	0	0
Dec 69	M	0.01±0.001	------	------	0	0
Apr 70	ON	0	0	0	0	0
July 70	OMCG	0.03±0.004	0	0	0	0
Dec 70	G	0	0	0	0	0

O ... Oncorhynchus tshawytscha, M ... Mylocheilus caurinus
C ... Cymatogaster aggregata, N ... Neomysis mercedis
P ... Pacifastacus trowbridgii, Ms... Micropterus salmoides
G ... Gasterosteus aculeatus

* Single Standard Deviation based on errors in counting, weighing, and biomass estimations.

-- ... Standard Deviation > 33%.

stones and placed on the bottom of the slough to be covered by a thin layer of sediment. Monthly samples of the incipient detritus were obtained and radioanalyzed. Figure 3 shows the result of detritus bag experiments carried out over two winter periods. Zinc-65 concentrations in the plant material remained constant but ^{51}Cr declined sharply in December and January of both winters. Since the hypothesis required a continual reduction of dissolved ^{51}Cr (VI) to ^{51}Cr (III) followed by sorption from water to detritus, the concentrations of ^{51}Cr in the decaying plant material should have continually increased. Instead, the activity of ^{51}Cr per unit weight declined rapidly after November of each year. Hence, the hypothesis is rejected. However, these experiments do confirm the sharp decline in ^{51}Cr associated with detritus in the inventory area.

Plants

The dominant plants found in the inventory area are the intertidal sedges *Carex* sp., *Scirpus* sp., and the green alga, *Enteromorpha intestinalis* (sometimes mixed with another unidentified green alga). In early spring these plants begin a gradual increase in biomass which culminates in midsummer with dense stands of vegetation around the edges of the slough. The green algae hangs like a dense curtain from various surfaces. In fall much of the plant material begins to slough off the main plant and by mid-winter little algae or *Scirpus* remain, although the decaying roots and stubble of *Carex* persist into the following spring. The algal biomass (Table 1) is low in April, highest in July, and negligible in December. *Carex* and *Scirpus* biomasses were also generally highest in July, lowest in December, and of intermediate weight in April.

Although the intertidal green algae greatly concentrates many radionuclides from the water, its biomass in the slough inventory area was not great enough to constitute a large reservoir (Table 1). However, the amounts of *Carex* and *Scirpus* were seasonally high and significant amounts of radionuclides were tied up with these plants although the radionuclides were not so greatly concentrated as in algae. Total amounts of all the radionuclides declined somewhat during the study period, although the effect of decline is accentuated by the initially high total activities for plants in the July 1968 estimates.

Animals

In general, the animals inhabiting the inventory area are small species or the young stages of larger species. One group of organisms, the small detrital-feeding crustaceans, are present in fairly constant numbers throughout the year. These include the tube building amphipod, *Corophium salmonis*, the gammarid amphipod, *Anisogammarus confervicolus*, and the small isopod, *Gnorimosphaeroma oregonensis*. These small omnivores constitute a major

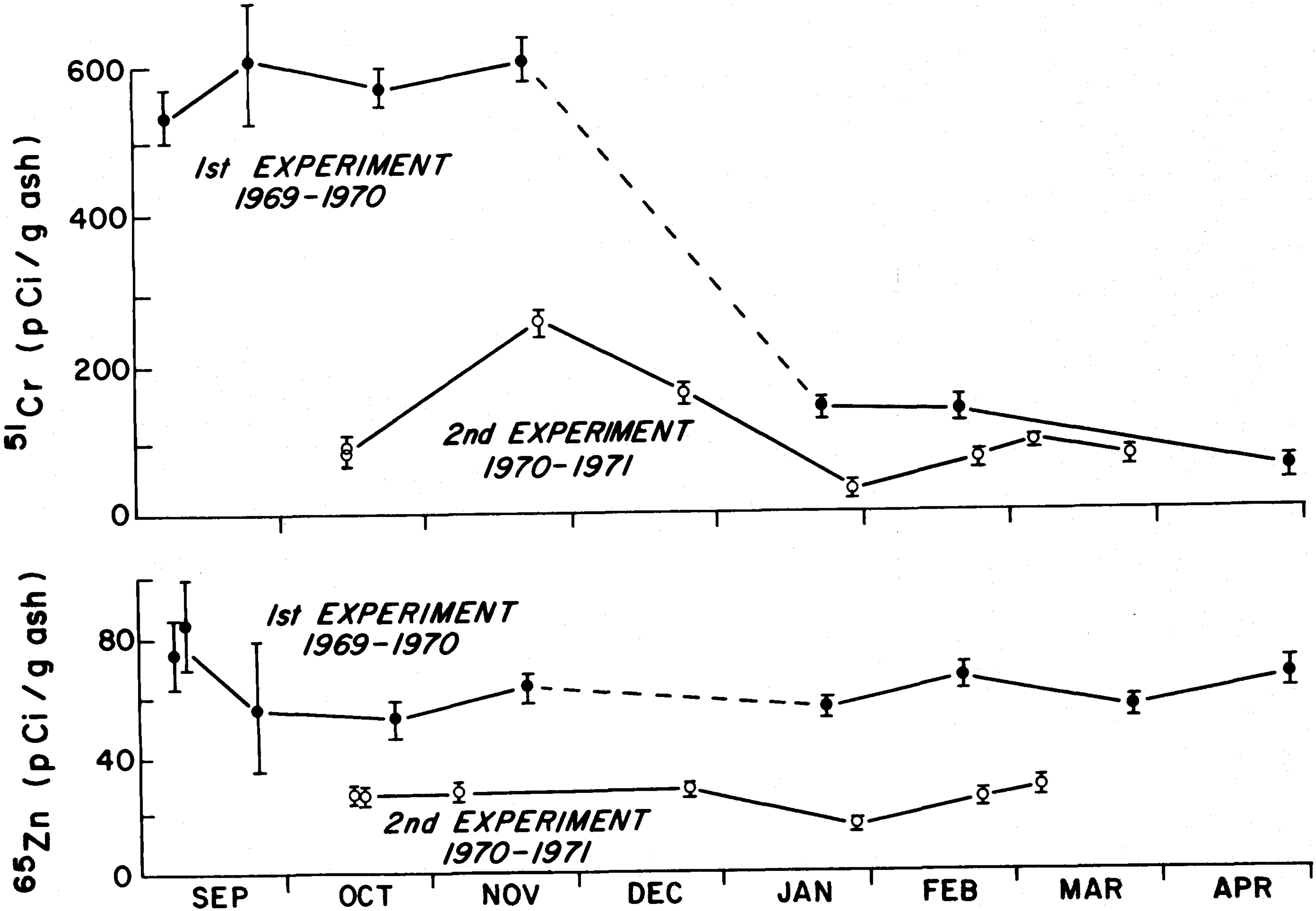


Figure 3. Radionuclide concentrations in dead plant material held in nylon bags in Alder Slough.

part of the diets of the other animals in the slough. They are a vital link in the transfer of energy from detritus up the food webs. Except for a few instances, when small amounts of other radionuclides were measured in (or on) these animals, only ^{65}Zn was present in significant amounts. The total activities of ^{65}Zn in the endemic crustaceans decreased sharply over the course of the inventories with seasonal highs occurring in July and lows in December as the result of changes in activity concentrations.

Carnivorous fishes and sand shrimp which inhabited the slough during most seasons include juvenile starry flounder, Platichthys stellatus; young prickly sculpin, Cottus asper; juvenile sand shrimp, Crangon franciscorum, and all age classes of Pacific staghorn sculpin, Leptocottus armatus. Without exception, only small amounts of ^{65}Zn were associated with these organisms.

A number of fishes and crustaceans live in the inventory area for only a portion of the year. These animals, a mixture of both carnivores and herbivores, include the Chinook salmon, Oncorhynchus tshawytscha; the peamouth, Mylocheilus caurinus; the shiner perch, Cymatogaster aggregata; the opossum shrimp, Neomysis mercedis; the crayfish, Pacifastacus trowbridgii; the largemouth bass, Micropterus salmoides; and the threespine stickleback, Gasterosteus aculeatus. As was the case with the endemic animals of the slough, these occasional visitors contained only small total amounts of ^{65}Zn.

Table 2 summarizes the estimates for the total activities of each radionuclide in the major components of the ecosystem. Had the numbers of plutonium production reactors at Hanford remained constant over the study period, it would be reasonable to attribute fluctuations from one inventory to the next to seasonal changes. However, each year began with the shutdown of one reactor (and, presumably, a corresponding reduction in the input of radionuclides) so that the reservoirs were continually responding to the reduced inputs. The sections which follow consider each radionuclide in turn.

^{65}Zn

Most of the ^{65}Zn in the inventory area is in the top cm of the sediments. Radioanalyses of core samples (unpublished data) indicate that lower, but measurable, quantities of ^{65}Zn are also found in the second and third cm layers. Thus, the total activity in the area is conservatively estimated by limiting the inventory to the top cm. During the 2-1/2 year period of this study the total activity of ^{65}Zn declined five-fold (Table 2) primarily due to reductions in the levels of ^{65}Zn in the sediments. Total levels of ^{65}Zn in detritus, plants, and animals did not show such large declines.

TABLE 2. SUMMARY OF ALDER SLOUGH INVENTORIES

	Sediment µ Ci	Detritus µ Ci	Plants µ Ci	Animals µ Ci	Total µ Ci	Sediment %	Detritus %	Plants %	Animals %
^{65}Zn									
July 68	2913	27.4	155.5	1.5	3097	94.1	0.9	5.0	0*
Dec 68	1973	41.7	7.4	0.8	2023	97.5	2.1	0.4	0
Apr 69	1023	74.0	2.9	1.6	1102	92.8	6.7	0.3	0.2
July 69	1013	27.1	12.1	7.1	1059	95.6	2.6	1.1	0.7
Dec 69	924	22.9	3.0	0	950	97.3	2.4	0.3	0
Apr 70	832	10.2	3.7	1.5	847	98.2	1.2	0.4	0.2
July 70	622	31.1	8.8	0.1	662	94.0	4.7	1.3	0
Dec 70	576	15.0	3.0	0	594	97.0	2.5	0.5	0
^{51}Cr									
July 68	6823	36.7	354.7	0	7214	94.5	0.5	5.0	0
Dec 68	7912	208.5	15.8	3.4	8140	97.2	2.6	0.2	0
Apr 69	2795	144.0	16.7	3.5	2959	94.4	4.9	0.6	0.1
July 69	3630	34.2	40.0	0	3704	98.0	0.9	1.1	0
Dec 69	4628	89.6	12.1	0	4730	97.8	1.9	0.3	0
Apr 70	884	9.5	2.7	0	896	98.6	1.1	0.3	0
July 70	1139	26.3	20.4	0	1186	96.1	2.2	1.7	0
Dec 70	1865	36.8	4.7	0	1906	97.8	1.9	0.3	0
^{46}Sc									
July 68	1254	0	85.3	0	1344	93.7	0	6.3	0
Dec 68	794	15.1	0	0.3	809	98.1	1.9	0	0
Apr 69	844	42.3	0.8	0.4	888	95.1	4.8	0.1	0
July 69	645	6.6	8.4	0	660	97.7	1.0	1.3	0
Dec 69	541	10.6	0.9	0	552	98.0	1.8	0.2	0
Apr 70	612	5.4	1.5	0	619	98.9	0.9	0.2	0
July 70	316	7.0	4.3	0	327	96.6	2.1	1.3	0
Dec 70	168	4.4	0	0	172	97.4	2.6	0	0
^{60}Co									
July 68	0	5.2	12.5	0	17.7	0	29.3	70.7	0
Dec 68	0	0	0	0.2	0.2	0	0	0	100
Apr 69	0	0	0.3	0	0.3	0	0	100	0
July 69	0	1.7	0	0	1.7	0	100	0	0
Dec 69	115.9	2.6	1.0	0	119.5	96.9	2.2	0.9	0
Apr 70	184.0	0	0	0	184.0	100	0	0	0
July 70	98.3	4.5	4.2	0	107.0	91.8	4.2	4.0	0
Dec 70	95.0	1.9	1.0	0	97.9	97.0	1.8	1.2	
^{54}Mn									
July 68	0	0	0	0	0	0	0	0	0
Dec 68	0	7.9	0	0.1	8.0	0	98.8	0	1.2
Apr 69	0	0	0	0	0	0	0	0	0
July 69	0	1.2	1.2	1.8	4.2	0	28.6	28.6	42.8
Dec 69	88.3	2.2	0	0	90.5	97.6	2.4	0	0
Apr 70	58.9	1.2	0.4	0	60.5	97.3	2.0	0.7	0
July 70	58.8	0	0.4	0	59.2	99.3	0	0.7	0
Dec 70	0	2.1	0	0	2.1	0	100	0	0

* Total < 0.1 µCi.

^{51}Cr

The total amounts of ^{51}Cr decreased almost four-fold during the study with abrupt declines after December each year in the sediment and detritus. In contrast, the activity of ^{51}Cr associated with plants was highest in July. Animals did not appear to be a significant reservoir of ^{51}Cr.

^{46}Sc

An eight-fold decrease was observed in the total activities of ^{46}Sc in the inventory area. Most of the loss was due to sharp drops in ^{46}Sc levels in the sediments. Scandium-46 totals in the detritus and plants exhibited no regular trends during the study.

^{60}Co and ^{54}Mn

Both ^{60}Co and ^{54}Mn became more apparent in the gamma-ray spectra in the latter part of the study when the levels of the more abundant radionuclides diminished. These radionuclides also were predominantly associated with sediments.

CONCLUSIONS

The percentages in Table 2 show that almost all the radioactivity in Alder Slough was contained in the sediments. With few exceptions, more than 95% of the total activity of each radionuclide was associated with sediments regardless of season. It is clear then that for these radionuclides and others which behave similarly, we must consider the sediments carefully in attempting to understand the final disposition of radioactivity released to estuaries.

Waldichuk (1961) described sedimentation as ". . . abstraction of dissolved and particulate material from sea water and its disposition on the sea bottom." He stated that sedimentation is a concentrating process in opposition to the desired processes of dilution and dispersion. Hence, the physico-chemical characteristics of estuarine contaminants which may lead to their sedimentation should be carefully considered before their release. This is true whether the contaminants are radionuclides, toxic metals, or harmful organic compounds.

ACKNOWLEDGEMENTS

Much of the field work involved in this project was accomplished by the careful and diligent effort of Norman Farrow. I am indebted to him and to I. Lauren Larsen, who radioanalyzed the samples. Thanks also go to Drs. Norman Cutshall and William G. Pearcy for review of the manuscript and constructive comments. This project was supported by USAEC Contract AT(45-1)2227 Task Agreement 12 (Manuscript No. RLO-2227-T12-6).

REFERENCES

Cross, F. A., T. W. Duke, and J. N. Willis. 1970. Biogeochemistry of trace elements in a coastal plain estuary: Distribution of manganese, iron, and zinc in sediments, water, and polychaetous worms. Chesapeake Science 11(4): 221-234.

Curl, H., N. Cutshall, and C. Osterberg. 1965. Uptake of Chromium (III) by particles in sea water. Nature 205(4968): 275-276.

Cutshall, N., V. Johnson, and C. Osterberg. 1966. Chromium-51 in sea water: Chemistry. Science 152(3719): 202-203.

Duke, T. W., J. N. Willis, and T. J. Price. 1966. Cycling of trace elements in the estuarine environment. I. Movement and distribution of Zinc-65 and stable zinc in experimental ponds. Chesapeake Science 7(1): 1-10.

Parker, P. L. 1962. Zinc in a Texas Bay. Publ. Inst. Mar. Sci. 8: 75-79.

Perkins, R. W., J. L. Nelson, and W. L. Haushild. 1966. Behavior and transport of radionuclides in the Columbia River between Hanford and Vancouver, Washington. Limnol. Oceanog. 11(2): 235-248.

Phelps, D. K. 1967. Partitioning of the stable elements Fe, Zn, Sc, and Sm within a benthic community, Anasco Bay, Puerto Rico. In B. A. Aberg and F. P. Hungate eds. Radioecological Concentration Processes. Pergamon Press. p. 721-734.

Pomeroy, L. R., R. E. Johannes, E. P. Odum, and B. Roffman. 1969. The phosphorus and zinc cycles and productivity of a salt marsh. In D. J. Nelson and F. C. Evans eds., Symposium on Radioecology, CONF-670503 USAEC. p. 412-419.

Waldichuk, M. 1961. Sedimentation of radioactive wastes in the sea. Fish. Res. Bd. Canada, Circular No. 59: 1-24.

THE RATE OF ZINC UPTAKE BY DOVER SOLE IN THE NORTHEAST PACIFIC OCEAN: PRELIMINARY MODEL AND ANALYSIS

by Henry A. Vanderploeg

ABSTRACT

This paper presents a specific-activity (SA) model that describes the relationship between the SA of a fish (or any predator) and the SA of its prey. The model serves as the basis for the hypothesis that lowered feeding intensity is the major factor causing the decreased excretion rate constant observed with increasing body weight for zinc and some other elements.

The model is applied to a free-living population of Dover sole to calculate the zinc uptake constant for the population. The value obtained for the population is lower than the values obtained from the laboratory retention studies of other workers. The feeding-intensity hypothesis "predicts" these differences.

ACKNOWLEDGMENTS

The data, results, and conclusions of this paper are part of a doctoral dissertation in progress, under the direction of Dr. William G. Pearcy at Oregon State University. I am especially grateful to Dr. Pearcy for both his scientific guidance and personal encouragement.

I want to thank both Dr. John L. Saugen and Dr. W. Scott Overton for their advice on statistical analysis of the data.

Dr. Norman H. Cutshall and Dr. William C. Renfro generously gave time to read the manuscript and made many useful comments.

I am indebted also to Mr. I. Lauren Larsen for the gamma-ray spectrometry analyses and to Mr. Jerome Wagner for the atomic absorption spectrophotometry.

Mr. Robert L. Demory of the Oregon Fish Commission kindly provided valuable information on the biology of the Dover sole.

The funds were provided by U.S. AEC contract No. AT(45-1) 2227 Task Agreement 12 and is assigned publication No. RLO-2227-T12-7.

Paper presented at Third Radioecology Symposium, Oak Ridge, Tennesee, 10 - 12 May 1971.

RLO 2227-T12-7

INTRODUCTION

The Hanford reactors, until just recently, produced a number of radionuclides that entered the Columbia River and eventually reached the surface waters of the northeast Pacific Ocean. One of the radionuclides, zinc-65, was produced in large enough quantity, has a long enough half-life, and is sufficiently concentrated by the biota to appear in measureable concentration in the biota of the northeast Pacific Ocean. This study attempts to evaluate the important factors affecting ^{65}Zn specific activities $\left(\frac{\mu Ci\ ^{65}Zn}{g\ total\ zinc}\right)$ of benthic fishes on Oregon's continental shelf. To accomplish this goal, a dynamical model was derived. This model provides a method of quantifying the important factors that affect the specific activities (SA) of the different species. It can also be used to estimate the rate of uptake of a particular element by a predator from its prey.

The purpose of this paper is to present the model and discuss its three principal uses:

(1) to provide a new explanation for the decrease in the excretion-rate constant of assimilated zinc and some other elements with increasing size of the organism,

(2) to identify important proximate factors affecting SA differences among species that accumulate the radionuclide and stable element from their food, and

(3) to allow calculation of food-chain uptake rates of different elements.

The model is applied to a free-living population of Dover sole (*Microstomus pacificus*) to determine the population uptake constant.

METHODS

Dover sole were collected at NH-23, a 200 m deep station 23 nm west of Newport, Oregon. The fish were collected in a 7 m semi-balloon shrimp trawl with a 0.5 cm mesh liner in the cod-end to prevent contact of the fish with the ship's deck. Samples were immediately frozen and were kept frozen until analysis ashore. Digestive tracts were sampled to provide "prey" of the Dover sole. Gut contents from different sections of their very long digestive tracts were pooled from all fish collected on a particular sampling date. The fish and their gut-content samples were each dried at 65C for two weeks, ashed at 420C for 72 hours, ground with mortar and pestle and packed into 13 cc counting tubes for gamma-ray counting. A portion of the ash was retained for stable Zn measurement by atomic absorption spectrophotometry. Radioanalyses were done on a 12.7 x 12.7 cm NaI (Tl) well crystal coupled to a 512 channel analyzer. Each fish and gut content sample was counted usually for four 400-minute periods to get desired precision of about ± 5%. The counts were corrected for physical decay to the date of collection. The portion of ash was digested in concentrated HNO_3, then diluted with 0.36N HCl and analyzed by atomic absorption spectrophotometry.

THEORY

Basic Model

Foster (1959) in his specific activity approach to understanding radionuclide dynamics noted the utility of SA in comparing different compartments, e.g., sediment and organisms having different stable element concentrations. He wrote a differential equation to describe the change of SA in an organism and emphasized its applicability for determining the biological turnover constant:

$$\frac{dS}{dt} = \beta C - (\lambda + \beta)S \qquad (1)$$

where C = specific activity of the organism's source of radioactivity,
S = specific activity of the organism,
λ = physical decay constant, and
β = biological turnover or excretion constant.

Foster's equation motivated the development of the SA equation derived here.

The equation for change in the amount of zinc-65 in a fish acting as a single compartment and obtaining all zinc-65 from its food is:

$$\frac{dX}{dt} = r\ F(t) - r'\ \frac{X}{Z} - X\lambda \qquad (2)$$

where X = amount of zinc-65 in the body of the fish,
r = rate of input of total zinc into the fish (actually assimilated),
F(t) = specific activity of prey $\left(\frac{\mu Ci\ ^{65}Zn}{g\ total\ zinc}\right)$, a function of time,
r' = rate of excretion of total zinc from fish ($\mu g\ day^{-1}$), and
λ = physical decay constant ($0.00283\ day^{-1}$).

Justification for food-chain uptake comes from the experiments of Hoss (1964) and Baptist and Lewis (1969). The material that goes in must be conserved, so

$$r = r' + \frac{dZ}{dt} \qquad (3)$$

where Z = total zinc in fish.

(Note: ^{65}Zn decays to stable Cu, but the amount of total zinc lost in this way is negligible).

Substituting for r' from equation (3) into equation (2),

$$\frac{dX}{dt} = r\,F(t) - \frac{X}{Z}\left(r - \frac{dZ}{dt}\right) - X\lambda \quad . \qquad (4)$$

Defining the uptake "constant" α by

$$r = \alpha Z \qquad (5)$$

and from placing this relation for r in equation (4),

$$\frac{dX}{dt} = \alpha Z F(t) - \frac{X}{Z}\,\alpha Z + \frac{X}{Z}\frac{dZ}{dt} - X\lambda \quad . \qquad (6)$$

We want a specific-activity relationship, i.e., an expression for $\frac{d(\frac{X}{Z})}{dt}$.
By the quotient rule,

$$\frac{d\left(\frac{X}{Z}\right)}{dt} = \frac{1}{Z}\,\frac{dX}{dt} - \frac{X\,dZ}{Z^2dt} \qquad (7)$$

Dividing expression (6) by Z and using this result for $\frac{1}{Z}\frac{dX}{dt}$ in (7),

$$\frac{d\left(\frac{X}{Z}\right)}{dt} = \alpha F(t) - \alpha\,\frac{X}{Z} - \frac{X}{Z}\,\lambda \quad . \qquad (8)$$

Replacing($\frac{X}{Z}$) by S for specific activity of the fish,

$$\frac{dS}{dt} = \alpha(F(t) - S) - S\lambda \quad . \qquad (9)$$

If the derivation had proceeded using β instead of α , a more complex relation than equation (9) involving terms containing $\frac{dZ}{dt}$ would have been obtained. By using the uptake constant α ($\frac{\text{zinc input}}{\text{body burden}}$ / unit time), a simpler relation is obtained. If $\frac{dZ}{dt} = 0$, i.e., no "growth", then $\alpha = \beta$; and equation (9) is equivalent to Foster's equation. From equations (3) and (5) it can be shown that $\alpha = \beta + \frac{1dZ}{Zdt}$. For rapidly growing organisms the term $\frac{1dZ}{Zdt}$ could be significant relative to β (as will be seen below).

An Interpretation of α

An examination and discussion of α is necessary for two reasons. Firstly I shall hypothesize a new mechanism for the observed relationship between body weight and turnover time (Eberhardt and Nakatani, 1968; Golley et al., 1965). Secondly, the hypothetical relationship will predict the magnitude of the effect of body weight on the excretion constant, which will then be used to assess the danger of lumping some of the fish of different sizes and also allow comparison of the resulting α with the β's from experiments performed with smaller fishes. The balanced equation of Winberg (1956) relates temperature, growth, and metabolism in fishes:

$$\rho R = T + \frac{\Delta W}{\Delta t} \tag{10}$$

where R = food intake per unit of time,
T = total metabolism,
W = body weight, and
ρ = constant for correction of ingested to utilizable energy of food.

Also consider Winberg's relationship between respiration and weight:

$$T = AW^{\gamma} \tag{11}$$

where A = a constant, a function of temperature, and $\gamma = 0.8$. Assume that

$$r = abR \tag{12}$$

where a is a constant for the assimilation efficiency of zinc and b is a constant that adjusts for different concentrations of zinc in the fish and its food. Then

$$\alpha = \frac{r}{Z} = \frac{ab(AW^{0.8} + \frac{\Delta W}{\Delta t})}{\rho Z} \quad . \tag{13}$$

In Figure 1, Z is plotted against body weight, W. Placing the expression for Z in equation (13) results in

$$\alpha = \frac{ab(AW^{0.8} + \frac{\Delta W}{\Delta t})}{\rho(4.83\ W^{1.08})} \quad . \tag{14}$$

If $\frac{\Delta W}{\Delta t}$ is small compared to $AW^{0.8}$ (as will be justified later for some of fish in the experiment), equation (14) may be simplified to

$$\alpha = C(AW^{-0.3}) \tag{15}$$

where C is a constant. If the assumptions leading up to equation (15) are correct, then α and concomitantly β (if $\frac{\Delta W}{\Delta t}$ is small) will follow this weight relationship. According to the assumptions that lead to this interpretation, the rate of food consumption is the factor most directly influ-

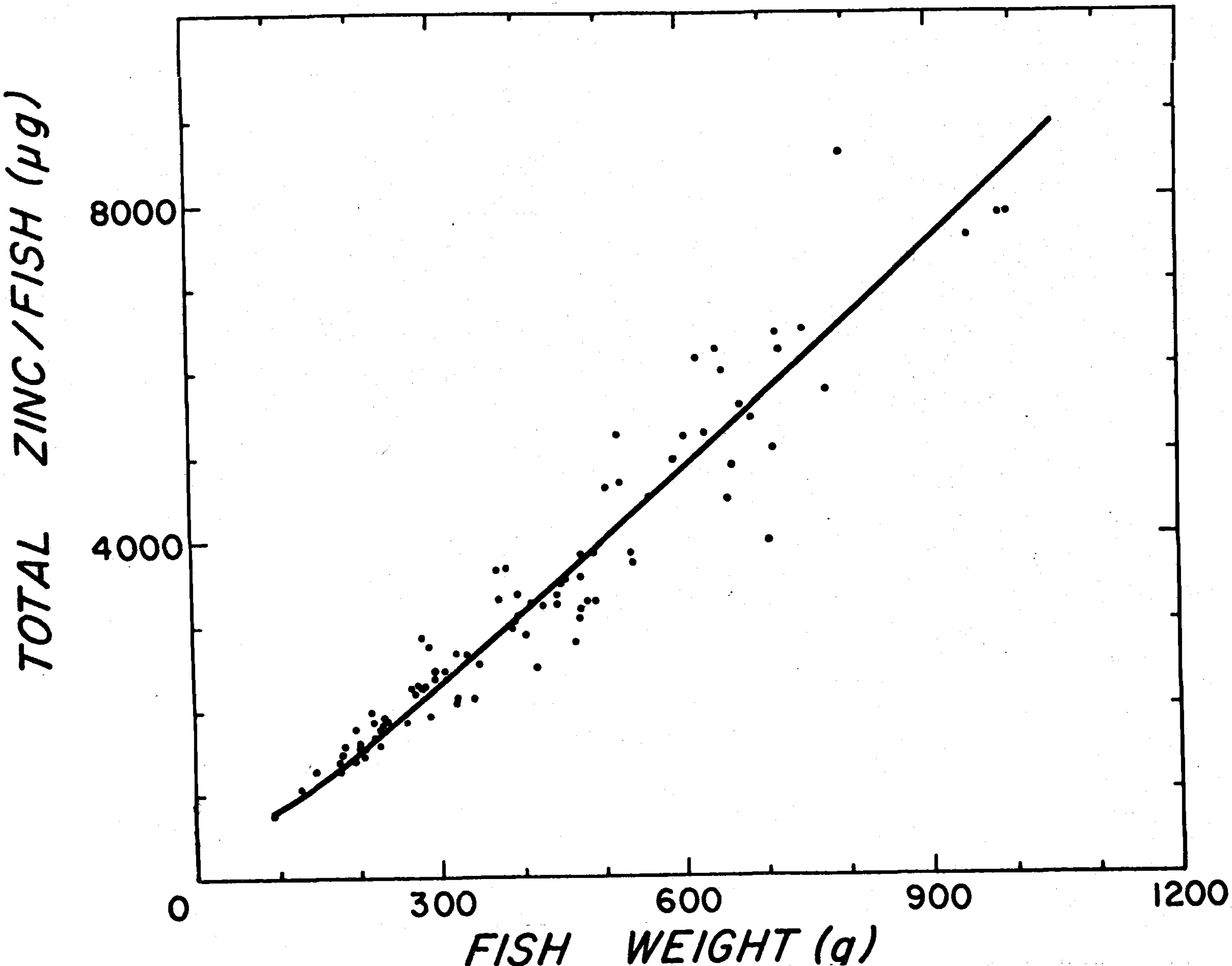


Figure 1. The relationship between total zinc in a fish and its body weight. $Z = 4.8387W^{1.0798}$; the standard error of the exponent $\pm$ 0.0403.

encing the zinc uptake constant, α . If the zinc binding sites are saturated at a given input rate and there is no growth, then it follows that the excretion rate constant will follow this pattern. Mishima and Odum (1963) observed that the excretion rate constant for the assimilated pool of zinc-65 in the snail Littorina irrorata could be correlated with temperature and size. They tentatively concluded the excretion rate reflects the activity of the organism. Edwards (1967), working with young plaice, showed that the zinc excretion constant he observed for the early phase of zinc-65 excretion could be correlated with respiration. He also found that excretion was independent of the feeding level although the levels were not defined quantitatively. It should be noted this correlation applied only to roughly 10% of the assimilated zinc. Pequegnat et al. (1969) estimated that zinc is accumulated in concentrations many times the marine organism's need for it in enzymes and suggested that adsorption-exchange is the main mechanism of concentration. This lends support to my contention. Since only a small amount of zinc is bound to enzymes, only a small fraction can be expected to be influenced directly by metabolic rate. Given that organisms are really adsorption exchange systems, feeding intensity could possibly be the major factor causing the observed size-turnover relationship, if the assimilation constant is indeed a constant.

The Problem of Multiple Compartments

Often radioecologists hypothesize that organisms excrete radionuclides not as if they were single compartments but rather a sum of a number of compartments or groups or organs (Eberhardt and Nakatani, 1969).

Perhaps the best evidence for multiple compartment excretion of zinc in fish comes from Nakatani's (1966) long-term uptake and retention study of zinc-65 in trout. He noted an initial fast decline of zinc-65, possibly the sum of several fast components, that lasted for a period of five weeks followed by a later slower decline. Since we usually analyze whole fish to determine SA, and since we must usually work with a non-zero and often non-constant F(t) as well as a non-zero starting value for S in equation (9), we are forced to work with a single compartment α or β , i.e., a composite α or β for a possibly multicompartment system. We must ask what the α we estimate really represents.

Consider α for a two compartment system. Let the amount of radioactive zinc in the first and second compartments be denoted respectively as X_1 and X_2. The change in radioactivity for the whole organism is the sum of the changes in X_1 and X_2, i.e.,

$$\frac{dX}{dt} = \frac{dX_1}{dt} + \frac{dX_2}{dt} \quad . \tag{16}$$

Writing expressions for $\frac{dX_1}{dt}$ and $\frac{dX_2}{dt}$ analogous to $\frac{dX}{dt}$ in equation (9) and substituting them into equation (16) gives:

$$\frac{dX}{dt} = (r_1 + r_2)F(t) - [(r_1 - \frac{dZ_1}{dt})\frac{X_1}{Z_1} + (r_2 - \frac{dZ_2}{dt})\frac{X_1}{Z_2}] - (X_1 + X_2)\lambda. \quad (17)$$

Substituting the right-hand side of equation (9) for $\frac{dX}{dt}$, substituting αZ, $\alpha_1 Z_1$, $\alpha_2 Z_2$ for r, r_1, r_2, and solving for α leads to

$$\alpha = \frac{\alpha_1 X_1 + \alpha_2 X_2}{X} + \left\{ \left(\frac{dZ}{dt}\right)\left(\frac{1}{Z}\right) - \left[\left(\frac{dZ_1}{dt}\right)\left(\frac{\frac{X_1}{X}}{Z_1}\right) + \left(\frac{dZ_2}{dt}\right)\left(\frac{\frac{X_2}{X}}{Z_2}\right) \right] \right\} \quad (18).$$

In equation (18) the expression in braces is probably insignificant in most cases as it represents the difference between two small, nearly identical quantities. Thus, α is very nearly a weighted average of α_1 and α_2, where the weighting factors are the amounts of radioactivity in each compartment.

THE EXPERIMENT

Further Assumptions

Before we can actually use equation (9) for determining α, more assumptions must be examined; these are:

1. Lumping of the different sized fish in the experiment will not markedly affect the estimate of α.
2. The fish do not immigrate from great distacces, particularly with reference to depth after sampling has begun.
3. The specific activity available to the fish in the food is actually equal to the specific activity measured for the food as a whole.

Lumping fish of different sizes could potentially lead to error (Fig. 1 and 2) because the fish spanned one order of magnitude (from 96 g to 1049 g) in weight. Before we can predict the hypothetical importance of this range, the importance of the $\frac{\Delta W}{\Delta t}$ term relative to $AW^{0.8}$ in equation (14) must be determined for Microstomus. This can be approximated by utilizing the metabolism and feeding relationships established by Winberg (1956), and later corrorborated by Mann (1967). From Winberg's equation $A = .3W^{0.8}$, the oxygen consumption of a fish weighing 100 g in a closed vessel would be 11.94 ml per hour or 287 ml per day at 20 C.

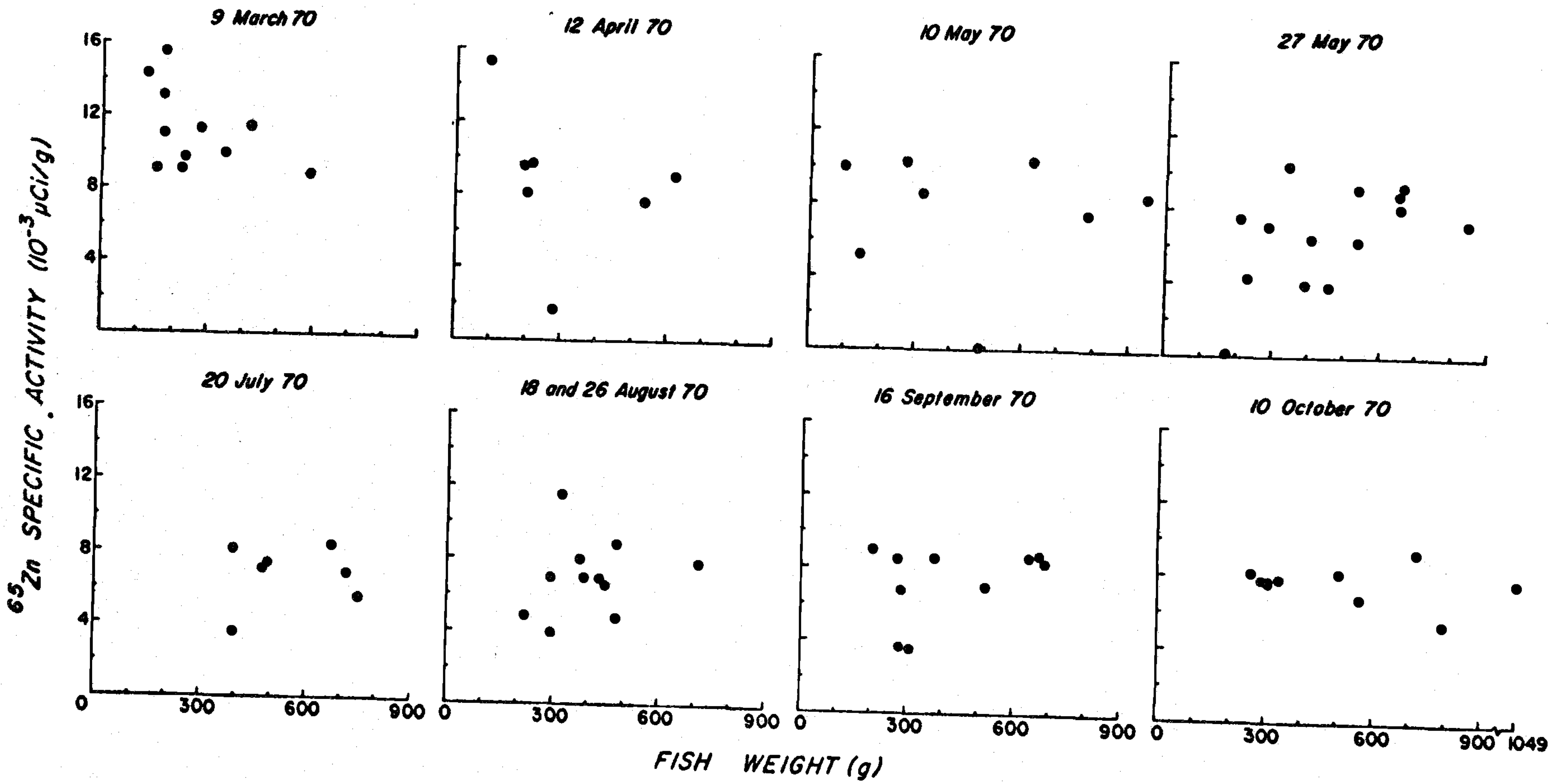


Figure 2. The relationship between specific activity and body size at NH-23 for different collections in 1970.

Microstomus was caught at a depth of 200 m where the temperature remains nearly constant at 8C. Correcting for temperature by "Krogh's normal curve" gives an expenditure of 82.3 ml of oxygen equivalent to 82.3 mg of dry material per day (Winberg, 1956). Multiplying this value by 2 to account for the fish's extra activity in nature gives the expenditure of 164 mg per day (Winberg, 1956; Mann, 1967). From the data of Hagerman (1952) the rate of growth of a 100 g (yearling) Dover sole is roughly 0.33 g fresh wt. or 50 mg dry wt. per day. Thus $\frac{\Delta W}{\Delta t}$ is about 23% of the sum $(AW^{0.8} + \frac{\Delta W}{\Delta t})$. For the 200 g fish (age 2+ years) $\frac{\Delta W}{\Delta t}$ is less than 15% of the sum, and this percentage decreases rapidly with size so that for fish above 200 g we can ignore the $\frac{\Delta W}{\Delta t}$ factor in predicting the effect of weight on α.

Equation (15) predicts that an order of magnitude increase in a fish's weight would cause α to be halved even if the growth term is ignored. Also, if the larger fish were five times the weight of the smaller, it would have an α 61% of the smaller. It would appear then that size as well as growth effects could be important as Eberhardt and Nakatani (1968, 1969) believed. If α decreases with size, we should expect that SA would decrease with size under equilibrium conditions. Figure 2 shows SA plotted against body weight for each month. For March and April there appears to be a decrease in SA with increasing size. However, this trend is not seen for later months, and if the fish less than 200 g are excluded, the trend is not apparent. What is apparent, however, is the great scatter in some of the SA data that could mask any SA-weight trends. It should also be noted that an SA-weight relationship may not be observed for fish that are not in equilibrium with the SA of their food. Evidence for lack of equilibrium will be given below.

If, after the initiation of the experiment, fish immigrate to station NH-23 from a distant place, they could bias the results assuming the SA of their prey -- invertebrate infauna, mostly polychaetes, -- had been different. Carey (1969) noted a marked decrease in SA of echinoderms with increasing depth (25% per 100 m) and a gradual decrease in SA with increasing distance south of the Columbia River. Dover sole are thought to be local populations which migrate shoreward during early spring and offshore during October and November (Hagerman, 1952). Although most Dover sole tend to remain in a single locality, tagging studies indicate a few individuals may move as far as 48-580 km (Westrheim and Morgan, 1963). During the winter the mature Dover sole usually spawn at depths greater than 250 m whereas juveniles and some immatures (mostly smaller fish than used for this study) remain at depths shallower than 200 m (R. Demory, personal communication). For this experiment it is assumed that all the fish originated from the same depth migrated to the 200 m stations before initiation of the experiment in March and that other fish did not immigrate into the study area during the experimental period March through October.

The possibility that fish might absorb a different SA from their food than measured for the food as a whole was thought to be a potential problem. For example, less easily digestible parts of the prey (such as a clam shell) could have a different SA from the softer parts having a higher turnover rate. To test for this problem and to determine whether pooling of the gut contents from the entire length of the alimentary tract biased the calculations, I divided the gut into a number of sections and determined specific cctivity for each section to see if SA of the contents increased or decreased with distance away from the stomach. Table 1 shows that no consistent trend appeared.

The Uptake Rate

Figure 3 shows the SA of the fish and the pooled SA of their prey, i.e., the weighted average of all gut contents sampled on a particular date where the weighting factors are the amounts of total zinc per sample.

Data from March through October 1970 were used to calculate α. The September 1969 data are included to show that the fish probably are not in equilibrium with their food during the experimental period. This would rationalize the decrease in SA of the fish with time during this period.

To determine the best α for a given $F(t)$, a general solution of equation (9) is helpful. Initial estimates of α and of the initial condition on S, i.e., $S(0)$ can be utilized by a least-squares-minimization program. Estimates of α and $S(0)$ are used to generate a solution for S. Each estimate is changed by the program until an α and an $S(0)$ are obtained that minimize the sum of squares around S and the data points for some convergence criterion.

To simplify the mathematics, $F(t)$ was assumed to be a constant, the "true" mean F of $F(t)$, that is

$$F = \frac{\int_{t_i}^{t_f} F(t)\, dt}{t_f - t_i}$$

where $F(t)$ is the function represented by the dashed lines connecting the values for specific activity of the food in Figure 3, and t_i and t_f are initial and final times, respectively. Then the solution to equation (9) is

$$S(t) = \frac{\alpha F}{\alpha + \lambda} + \left(S(0) - \frac{\alpha F}{\alpha + \lambda}\right) e^{-(\alpha + \lambda)t}$$

The non-linear least squares program *CURVFIT[1] was used for calculation of α. For the first analysis, all fish (except the two exhibiting

[1] Available from Oregon State University Computer Center.

Table 1. Specific Activity of Food in Different Sections of Gut

Date	No. of Fish Analyzed	Section of Gut	Zinc-65 Specific Activity
12 April 1970	11	Foregut[1]	0.0235
12 April	11	Hind gut[2]	0.0254
10 May	9	Foregut	0.0170
10 May	9	Hind gut	0.0234
27 May	8	Stomach and first 1/3[3]	0.0160
27 May	8	Second 1/3	0.0181
27 May	8	Last 1/3	0.0118
20 July	8	Stomach	0.0222
20 July	8	First 1/3	0.0213
20 July	8	Second 1/3	0.0206
20 July	8	Last 1/3	0.0210
18 August	5	Stomach and first 1/3	0.0198
18 August	5	Second and last 1/3	0.0215
26 August	8	Stomach and first 1/3	0.0199
26 August	8	Second and last 1/3	0.0168
16 September	11	Stomach and first 1/3	0.0179
16 September	11	Second and last 1/3	0.0190
10 October	10	Stomach and first 1/3	0.0179
10 October	10	Second and last 1/3	0.0196

[1] Stomach contents plus first one-fourth of intestine.

[2] Last three-fourths of intestine.

[3] First 1/3 is first one-third of intestine.

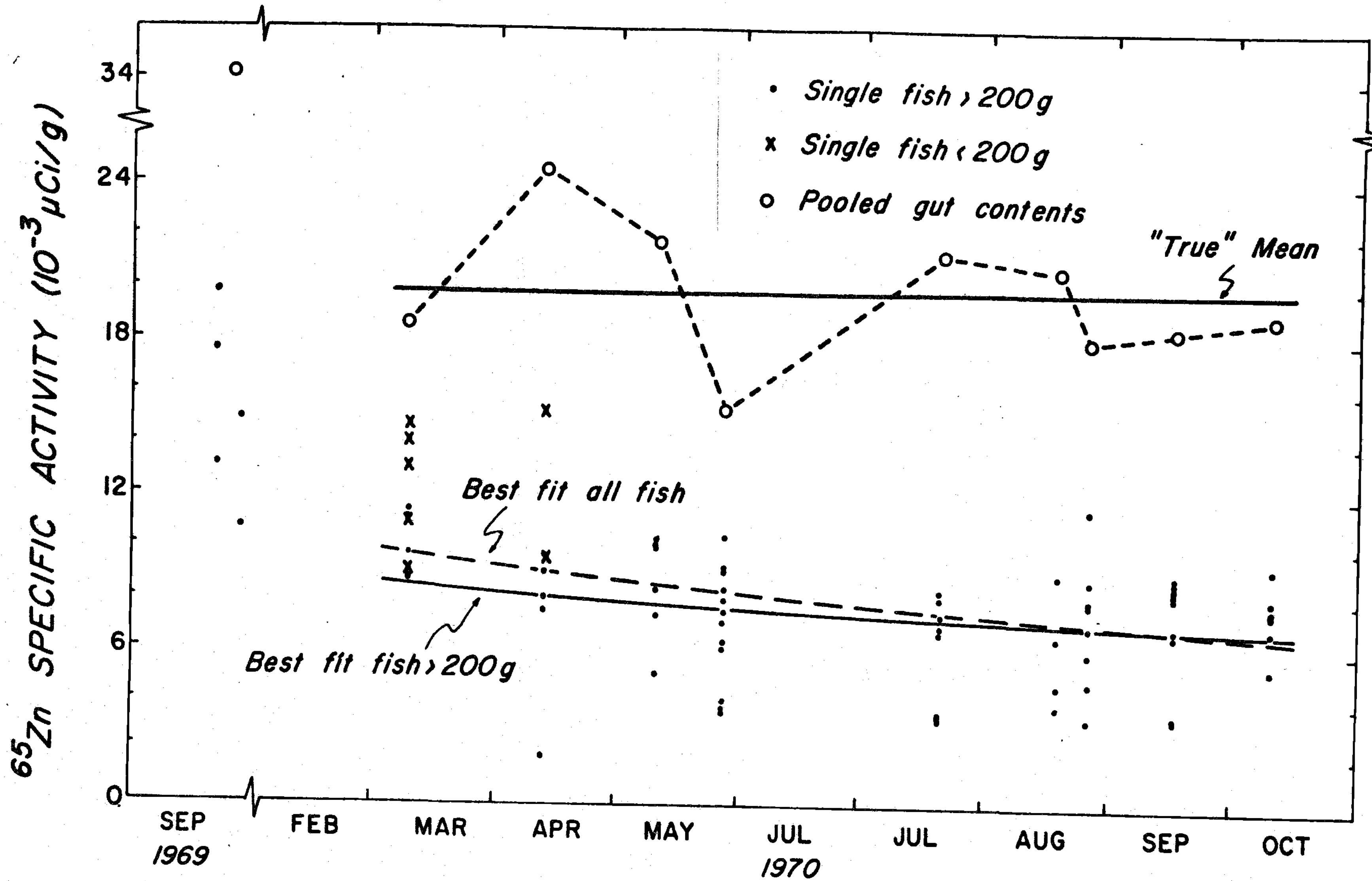


Figure 3. This specific activity of the Dover sole and its prey at NH-23 during the sampling period.

extremely low values in Figure 2) were included. Figure 2 shows that fish less than 200 g had much higher specific activities than the other fish. This could be owing to the size and growth rate phenomena already discussed or to the possibility that in the fall before the experiment the smaller fish did not migrate into deeper water (where the SA is lower) with the larger fish. The higher SA's could be a combination of all three factors. For these reasons another determination of α was made for the fish greater than 200 g. The best least-squares fit for these two cases is shown in Figure 3. Another regression was computed for the fish less than 200 g. Then, the sum of squares (SSE) about the regression of all the fish was partitioned into two subsets: the first, the sum of the SSE for the fish > 200 g and the SSE for the fish < 200 g, and the second, the difference between the SSE of all fish and the first subset.

An F-test showed that the mean square of the difference subset was significantly greater than the mean square of the first subset SSE at the 1% level. Therefore, the α for the fish > 200 g is reported. The value of α calculated for fish > 200 g is 1.0922×10^{-3} with a standard error of 2.845×10^{-4}. Considering the standard error on α, the approximation of F(t) seems reasonable, although further analyses using a more exact representation of F(t) should be tried.

DISCUSSION

Assuming $\alpha \cong \beta$, we can compare the results of this experiment with others. Table 2 compares the values of β, calculated from effective half lives given by other authors, with the α calculated for Microstomus in this study. The value for α is lower than the values for β of the other experients, although it is not far from the lowest value of Renfro and Osterberg (1969).

A comparison of the α of Microstomus with the β's of the small flounders of Renfro and Osterberg can be made, assuming size and temperature are the factors causing these differences. Krogh's curve predicts food consumption of fish at 15C would be 2.2 times higher than at 8C. The size difference between Microstomus and the little flounders (about two orders of magnitude) predicts that the α of Microstomus should be 25% of the smaller fish. Taking both size and temperature into consideration leads to the conclusion that Microstomus of a size (ignoring growth) comparable to Renfro's flounders and maintained at similar temperatures would have an α about 0.0097, slightly larger than the largest β he observed. This corrected α and others are shown in the last column of Table 2.

For Nakatani's trout the temperature factor of 3.5 between 8C and 20C implies that the α for Microstomus is 0.0038 at 20C. Caution, however, must be exercised when comparing the trout to Microstomus because the trout exhibited rapid growth (and are freshwater fish). It must be remembered that $\alpha = \beta + \frac{1}{Z}\frac{dZ}{dt}$. The magnitude of the $\frac{1}{Z}\frac{dZ}{dt}$ term is not known for Nakatani's

Table 2. Comparison With Other Results

Author	Species	Size	Temperature °C	Comments	α or β	Corrected α
Renfro and Osterberg (1969)	*Platichthys stellatus*	0.3 g dry wt	15	Fish Emaciated, β's are highest & lowest of 3 individual fish	0.00954	0.0097
					0.00145	0.0097
Rice (1963; calculated by Renfro & Osterberg, 1969)	Paralichthys sp.	post-larval	--		0.00212	---
Nakatani (1966)	*Salmo gairdneri*	100 g at start 1000 g at finish	11-22	Chronic dose	0.00234	0.0038
Nakatani (1966)	*Salmo gairdneri*	336 g	20	Single oral dose	0.00212	0.0038
This study	*Microstomus pacificus*	200-1049 g	8	Free-living population	0.00109	0.00109

trout, but an approximation can be made from $\frac{1}{W}\frac{dW}{dt}$. The trout exhibited exponential growth (Eberhardt and Nakatani, 1968) and thus a straight-line relationship for a semi-log plot of weight against time. Then, $\frac{1}{W}\frac{dW}{dt} = 0.013$, a constant which was estimated from the slope of their plot. Adding the value for β (actually an underestimate for growing fish) gives $\alpha \cong 0.015$, a relatively large value. From this it follows that application of equation (1) to a population of rapidly growing fish would be misleading. From these rough comparisons, no definite conclusions can be made about the feeding intensity hypothesis, although it (or some other metabolic function) seems to work. Nevertheless, it is a hypothesis that can be easily tested in the laboratory.

Given the principle of biological similitude, it is apparent that this model has identified the important or, hypothetically important, quantifiable factors affecting SA differences among species. Currently, we are applying the model to other benthic fishes in an effort to explain the differences in SA observed among them.

REFERENCES

Baptist, J. P. and C. W. Lewis. 1969. Transfer of ^{65}Zn and ^{51}Cr through an estuarine food chain, p. 420-430. In: D. J. Nelson and F. C. Evans [ed.] Proceedings of Second National Symposium on Radioecology. USAEC CONF 670503.

Carey, A. G. 1969. Zinc-65 in echinoderms and sediments in the marine environment off Oregon In: D. J. Nelson and F. C. Evans [ed.] Proceedings of Second National Symposium on Radioecology. USAEC CONF 67503.

Eberhardt, L. L. and R. E. Nakatani. 1968. A postulated effect of growth on retention time of metabolites. J. Fish. Res. Bd. Canada 25(3): 591-596.

Eberhardt, L. L. and R. E. Nakatani. 1969. Modeling the behavior of some radionuclides in some natural systems, p. 87-109. In: D. J. Nelson and F. C. Evans [ed.] Proceedings of the Second National Symposium on Radioecology. USAEC CONF-670503.

Edwards, R. R. C. 1967. Estimation of the respiratory rate of young plaice (*Pleuronectes platessa* L.) in natural conditions using zinc-65. Nature 216(5122):1335-1337.

Foster, R. F. 1959. Radioactive tracing of the movement of an essential element through an aquatic community with specific reference to radiophosphorus. Publications Stazione Zoologica Napoli 31:34-69.

Golley, F. B., R. G. Wiegert, and R. W. Walter. 1965. Excretion of orally administered zinc-65 by wild small mammals. Health Physics 11:719-722.

Hagerman, F. B. 1952. The biology of the Dover sole *Microstomus pacificus*. Calif. Fish and Game Fish. Bull. 85:1-48.

Hoss, D. E. 1964. Accumulation of zinc-65 by flounder of the genus Paralichthys. Trans. Amer. Fish. Soc. 93(4):364-368.

Mann, K. H. 1967. Cropping the food supply, p. 243-257. In: S. D. Gerking [ed.] The biological basis of freshwater fish production. Blackwell Scientific Publications, Oxford.

Mishima, J. and E. P. Odum. 1963. Excretion rate of zinc-65 by *Littorina irrorata* in relation to temperature and body size. Limnol. and Oceanog. 8(1):31-38.

Nakatani, R. E. 1966. Biological response of rainbow trout (*Salmo gairdneri*) ingesting zinc-65, p. 809-823. In: Disposal of Radioactive Wastes into Seas, Oceans and Surface Waters. IAEA, Vienna.

Pequegnat, J. E., S. W. Fowler, and L. F. Small. 1969. Estimates of zinc requirements in marine organisms. J. Fish. Res. Bd. Canada 26:145-150.

Renfro, W. C. and C. Osterberg. 1969. Radiozinc decline in Starry flounders after temporary shutdown of Hanford reactors, p. 372-378. In: D. J. Nelson and F. C. Evans [ed.] Proceedings of the Second National Symposium on Radioecology. USAEC CONF-670503.

Rice, T. R. 1963. Review of zinc in ecology, p. 619-631. In: V. Schultz and A. W. Klement, Jr. [eds.] Radioecology. Reinhold, New York.

Westrheim, S. J. and A. R. Morgan. 1963. Results from tagging a spawning stock of Dover sole *Microstomus pacificus*. Pac. Mar. Fisheries Comm. Bull. 6:14-21.

Winberg, G. G. 1956. [Rate of metabolism and food requirements of fishes.] Belorusskovo Nauchnye Trudy Belorusskovo Gosudarstvennovo Universiteta imeni V. I. Lenina, Minsk, 235 p. [Transl. Fish. Res. Bd. Canada, No. 194]

SIZE STRUCTURE AND GROWTH RATE OF *Euphausia pacifica* OFF THE OREGON COAST[1]

MICHAEL C. SMILES, JR.,[2] AND WILLIAM G. PEARCY[3]

ABSTRACT

Euphausia pacifica (Hansen) off Oregon has a maximum life expectancy of about 1 year. During this time it grows rapidly to a length of 22-24 mm. Furcilia larvae were found throughout the year but were most abundant during the autumn months. The population density and the proportion of juveniles was higher within 25 miles of the coast than in offshore oceanic waters.

Growth rates off Oregon are about twice those previously reported for this species from other regions. Spawning also appears to be later in the year. All these features may be explained by the high primary production which is extended throughout the summer by coastal upwelling and by the lack of wide seasonal fluctuations of water temperatures along the Oregon coast.

Euphausia pacifica is one of the most abundant euphausiids in the North Pacific Ocean. Dense populations are found in Subarctic and Transitional waters (Brinton, 1962a; Ponomareva, 1963) and off the Oregon coast (Hebard, 1966; Osterberg, Pearcy, and Kujala, 1964; Pearcy and Osterberg, 1967).

Euphausiids are important food for many marine carnivores (see Mauchline and Fisher, 1969, and Ponomareva, 1963, for reviews), and *Euphausia pacifica* is no exception. It is preyed upon by salmon (Ito, 1964), baleen whales (Nemoto, 1957, 1959; Osterberg et al, 1964), herring (Ponomareva, 1963), sardine and mackerel (Nakai et al, 1957, as cited by Ponomareva, 1963; Komaki, 1967), rockfish (Pereyra, Pearcy, and Carvey, 1969), pasiphaeid and sergestid shrimp (Renfro and Pearcy, 1966), pandalid shrimp (Pearcy, 1970), and myctophid fishes (Tyler, 1970).

Studies on the growth of several species of euphausiids are reviewed in the monograph by Mauchline and Fisher (1969). Data on the growth and life history of *E. pacifica* are limited. Nemoto (1957) presented some growth data for *E. pacifica* from the Japanese-Aleutian area. Ponomareva (1963), in her study on the distribution and ecology of euphausiids of the North Pacific, estimated the growth of *E. pacifica* from plankton samples collected during the winter and spring. Lasker (1966) determined the growth of *E. pacifica* reared in the laboratory. Preliminary growth rates of *E. pacifica* based on some of our data were also presented by Small (1967).

Because growth rates are needed to understand the ecology and energetics of a species, we undertook this study on the abundance, size structure, and growth rate of *E. pacifica* off Oregon.

COLLECTION METHODS

We made a total of 174 collections using 1-m mouth diameter plankton nets between June 1963 and July 1967 at stations located 15, 25, 45, and 65 miles off Newport, Oreg. In addition, 25 collections were obtained from stations 85-285 miles off Newport. These provided samples of *E. pacifica* for all seasons of the year over a 4-year period. Nets had 0.571-mm mesh openings and were used with a flowmeter placed in

[1] This research was supported by the National Science Foundation (GB-5494) and the Atomic Energy Commission (AT(45-1)-1750; RLO 1750-50).

[2] Formerly, Department of Oceanography, Oregon State University; present address: Biology Department, State University of New York, Farmingdale, N.Y. 11735.

[3] Department of Oceanography, Oregon State University, Corvallis, Oreg. 97331.

Manuscript received September 1970.
FISHERY BULLETIN: VOL. 69, NO. 1, 1971.

the mouth to measure the amount of water filtered.

The first 20 samples were from oblique tows, and the other 154 were from vertical tows. This change to vertical tows was made to ensure equal sampling at all depths throughout a tow. Comparison of the catches of several oblique and vertical tows taken during the same night indicated little difference in the number and size of *E. pacifica* per unit volume filtered.

Because euphausiids may avoid nets in the daytime, all tows were taken during nighttime when visual avoidance would be minimal (Brinton, 1967). This is also a period when *E. pacifica* presumably has migrated into the upper 100 m of the water column. *E. pacifica* captured in several 6-ft Isaacs-Kidd midwater trawls were measured to see if large euphausiids that were possibly avoiding the small vertical meter net could be captured. There was no indication that the maximum size of trawl-caught was larger than meter net-caught euphausiids.

The maximum depth of our tows was usually 200 m. Because Ponomareva (1963) suggested that *E. pacifica* adults inhabit the 200-500-m layer in their second winter and no longer migrate daily to the surface, tows were taken to 1000 m with both the midwater trawls and vertical meter nets. These deeper tows, however, did not contain any larger animals. Twelve vertical meter net samples from depths of 200 m or 1000 m to the surface did not show appreciable differences in size structure. Therefore, we assumed that a representative sample of the *E. pacifica* population was caught in the upper 200 m at night.

The entire plankton sample was preserved at sea in neutralized 10 % Formalin. In the laboratory ashore, all euphausiids were removed from each sample unless the number of euphausiids was large (more than 200 individuals). In such cases the sample was usually divided in half with a Folsom plankton splitter (McEwen, Johnson, and Folsom, 1954), and euphausiids were sorted from only one-half the sample. Males and females were not differentiated.

The length of each individual *E. pacifica* was measured to the nearest 0.1 mm from behind the eye to the posterior margin of the carapace, and each animal was then assigned to a 0.3-mm size-group. Total lengths (from the posterior of the eye to the tip of the telson) were also measured from randomly selected individuals of various lengths to enable comparisons of our data with those of others. A least squares fit of 146 comparisons gave the equation:

$$Y = 2.54\ X + 0.66$$

where Y = total length and X = carapace length. The variance was 248.19. Our measurements are all given as total lengths.

RESULTS

RECRUITMENT AND ABUNDANCE

Although larval *E. pacifica* occurred during almost all months of the year, definite trends in abundance were evident over the 4-year period (Fig. 1). Larvae were usually most abundant between October and December. During some years recruitment began as early as June and was also prominent in the summer months. No major concentrations of larvae were found during winter or spring.

These larval forms of *E. pacifica* were furcilia of about 7 mm or less, agreeing with Boden's (1950) size measurements and description of *E. pacifica* furcilia. Furcilia are found 16-18 days after spawning, usually within the upper 100 m of the water column (Ponomareva, 1963; Brinton, 1967).

Catch curves (Fig. 2) show the average number of different size-groups of *E. pacifica* collected during the entire study. All sizes of *E. pacifica* were much more abundant per m^3 inshore over the continental shelf than in oceanic offshore waters. Individuals larger than 15 mm were rare at station 65 miles or farther offshore. Our finding that larvae were less abundant at offshore than inshore stations agrees with Brinton (1962b), who also noted that *E. pacifica* was more abundant inshore than offshore of California. Thus, despite the wide oceanic distribution of *E. pacifica*, the density of near-

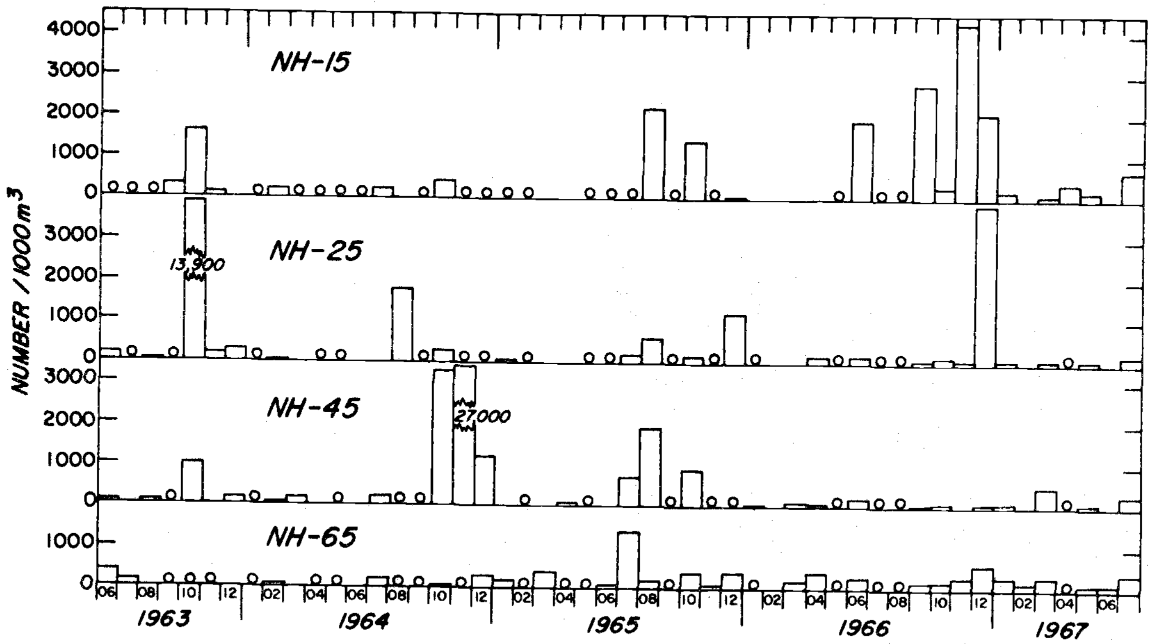


FIGURE 1.—Number of furcilia of *E. pacifica* collected at four stations off Newport, Oregon (NH-15, 25, 45, 65) during 1963-67. "0" indicates no sample taken for that month.

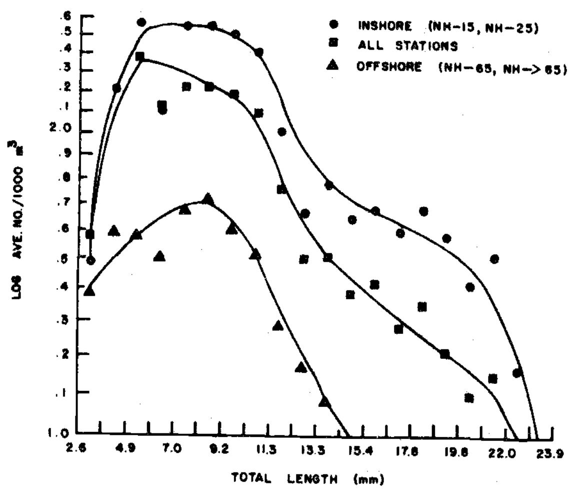


FIGURE 2.—Catch curves: the logarithm of the average number of various sizes of *E. pacifica* caught per 10^3 m^3 for all samples during the study.

shore populations may be considerably higher than offshore populations in the same region.

Although inshore tows were generally made only to 50 m and 130 m at the 15- and 25-mile stations respectively because of depth of water, euphausiid abundance at these stations was approximately 10 times greater than at offshore stations. This difference is too great to be explained by the differences in sampling depths even assuming that all euphausiids were concentrated in the upper 50 m at night.

GROWTH RATE

The extended spawning season and variability of catches of *E. pacifica* made interpretation of growth difficult. Three related methods, all based on progressions of size-frequency histograms, generally gave similar growth rates (Table 1) and led to the same conclusion: *E. pacifica* lives for a period of about 1 year and attains a maximum size of about 22-24 mm total length. We tenuously assumed for all these analyses that we sampled the same population, or populations with similar age structures and growth rates.

Two illustrations of growth based on monthly

TABLE 1.—Summary of average growth rate estimated from the progression of modes or means (see Figs. 3 and 4).

Year class	Recruitment month	Number months followed	Growth rates		
			Modes (Fig. 3 for 1965 and 1966 year classes)	Modes (Fig. 4)	Means
			Mm/month		
1963	09	10	1.6	1.9	1.6
1964	10	9	2.0	2.0	1.9
1965	10	8	2.1	2.2	2.0
1966	11	5	2.9	2.5	2.4
1967	03	3	2.6	2.5	2.5

size-frequency histograms of all stations combined (Fig. 3) illustrate the increasing modal lengths between December and June for the 1965 and 1966 year classes. Recruitment of small *E. pacifica* is also obvious during the spring of 1966 and 1967 and also shows a shift in modes with time. The 1963 and 1964 year classes (not shown here) showed similar trends.

A modified histogram plot (Fig. 4) was used to show the data for all 4 years and all 4 stations together. The advantage of this method is that one can follow the main modes of different sizes throughout the 4-year period. A disadvantage is that these plots are distorted by the arbitrary constraints that (1) at least 50 individuals per 10^3 m^3 of water within one size-group had to be present for plotting and (2) concentrations above $5000/10^3$ m^3 were plotted only as $5000/10^3$ m^3. All of the years represented in Figure 4 show some similarity. The main recruitment pulses are in the fall and summer, and the maximum size attained is approximately 22-24 mm length. After about 1 year, late in the second summer or fall, these large individuals disappeared from our collections. Interestingly, many of the modes that were composed of small euphausiids during the spring and early summer disappeared or were undiscernible by the fall. Either these individuals were subjected to higher mortality than the fall recruits or were transported out of the area. Apparently they made no major contribution to the local adult population.

Average lengths of size modes were also calculated for each collection using the computer techniques described by Hasselblad (1966). The means were generally close to the values for the modal lengths of various collections shown in Figures 3 and 4 and, therefore, are not illustrated here but are given in Table 1.

Our estimates of the growth of *E. pacifica* by all these methods are summarized in Table 1. As expected, estimates are similar for the same year classes. Growth varied from 1.6 to 2.9 mm per month among year classes, averaging about 2.0 mm per month. Growth rates were fastest for young stages. Year-classes 1963 and 1964 had slower average rates (1.6 and 2.0 mm/month) and were calculated over a longer period. Year-classes 1966 and 1967, on the other hand, were represented for the shortest periods of time and had the fastest average rates (2.9 and 2.6 mm/month). This deceleration of growth at the larger sizes is also apparent in Figure 3 where the growth rate from January to March 1966 was about 3.2 mm/month, while from March to June it was about 2.0 mm/month.

Our estimates are biased in several ways. They favored the recruitment pulses of the fall because the smaller modes of young that appeared earlier (June through September) did not comprise a good series of modal sequences. Moreover, the modes and means of the smaller sizes of *E. pacifica* are probably slightly overestimated since catch curves (Fig. 2) indicate escapement from our nets of individuals below 6 mm. This may cause an underestimation of growth rates.

DISCUSSION

Generalized growth curves of *E. pacifica* for three regions of the North Pacific are contrasted in Figure 5. On the basis of bimodal size-frequency distributions of winter and spring samples, Ponomareva (1963) concluded that *E. pacifica* lives for a period of 2 years. She found predominantly 8 and 14-15 mm individuals in the winter and 12-13 mm (her 1-year olds) and 19 mm (2-year olds) in the spring. Off Oregon not only were 12-13 mm individuals rare or absent in spring samples, but also 13-14 mm individuals, the size that Ponomareva would expect to find in the summer and fall, were absent. Moreover, our data, unlike Ponomareva's, show no large seasonal fluctuations of growth with retarded growth of the 13-14 mm sizes

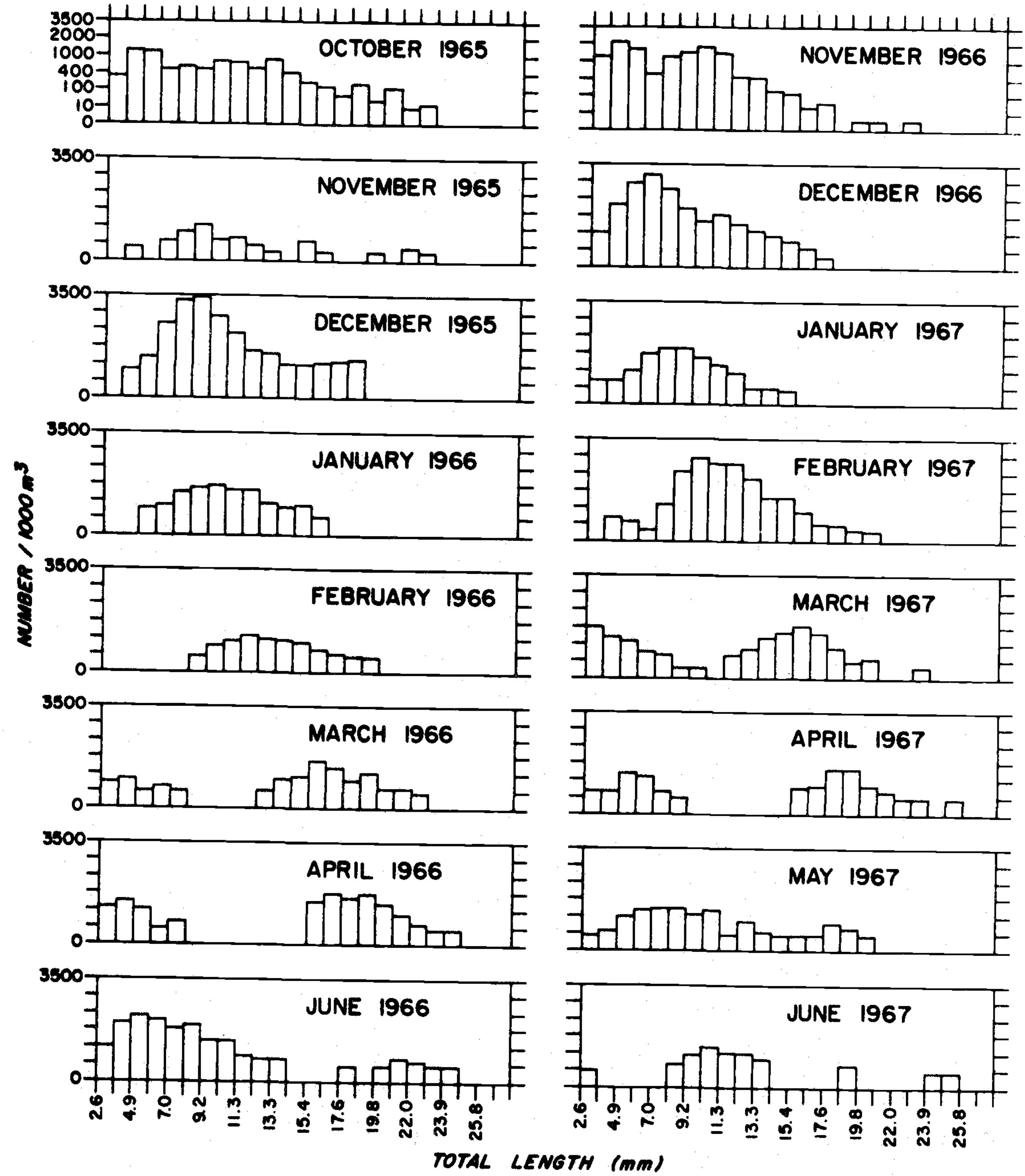


FIGURE 3.—Size frequency distributions of *E. pacifica* from all stations for the 1965 year class (left) and the 1966 year class (right).

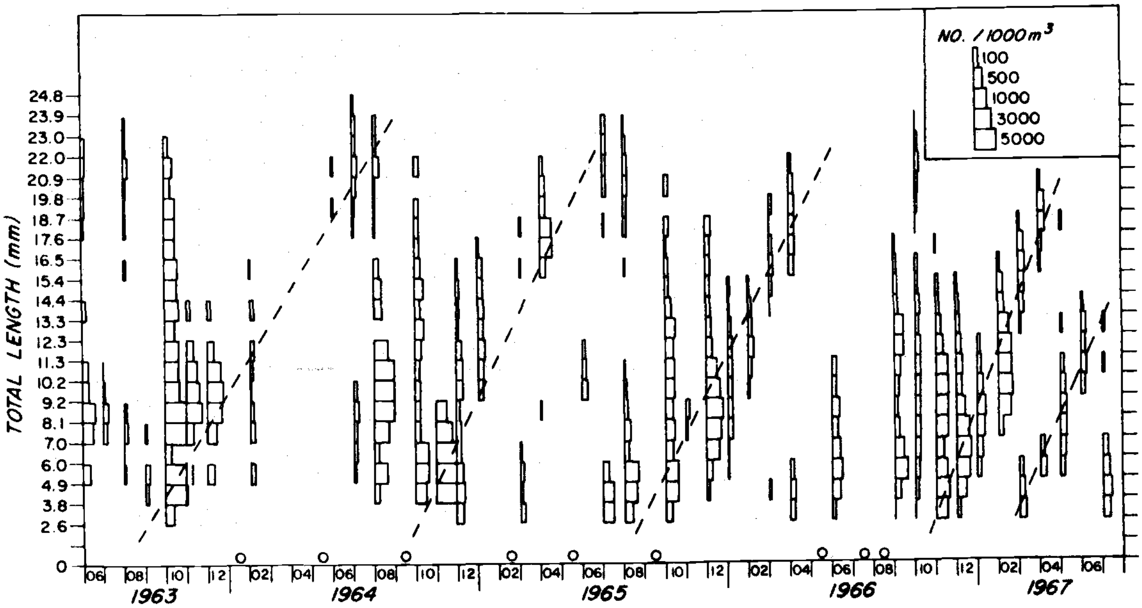


FIGURE 4.—Size frequency histograms for all stations, 1963-67. Dashed lines are an estimate of average growth of individual year classes. "0" indicates no samples for that month.

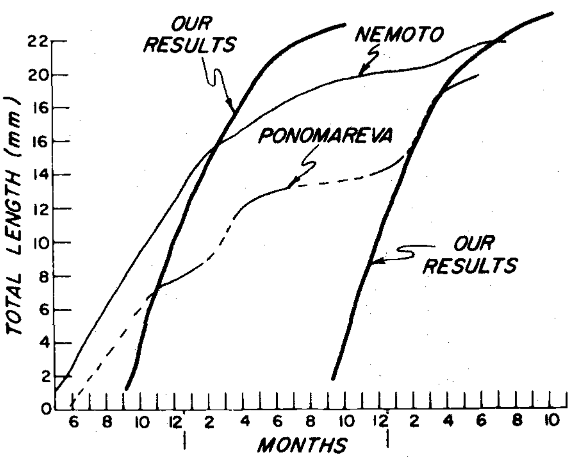


FIGURE 5.—Comparison of generalized growth curves of *E. pacifica*.

in the summer and fall. Nemoto (1957 and personal communication) believes that *E. pacifica* grows rapidly, reaching a length of 17-18 mm after 1 year. Many individuals spawn after 1 year and then may continue to live for another year, reaching a maximum of 22 mm after 2 years. We find no convincing evidence, however, for continuation of large adults through a second year. Large euphausiids disappeared from our samples by the winter (Fig. 4).

Thus our results indicate a faster growth rate and shorter life cycle than those of Ponomareva and Nemoto for the northwestern Pacific but a similar maximum size. Our growth rates off Oregon averaged 0.065 mm/day for the entire life span, about twice those for the other field studies of *E. pacifica*. Maximum rates for rapidly growing juveniles were 0.095 mm/day. These rates are higher than Lasker's (1966) maximum rates for juvenile *E. pacifica* reared in the laboratory, suggesting that growth in nature may exceed "optimal" conditions in the laboratory.

Although our estimates of the growth of *E. pacifica* are higher than previously reported, they approximate the estimates for several other species of euphausiids. A length of about 22 mm after 1 year was also found by Mauchline (1966) for *Thysanoessa raschii;* by Ruud (1936), Mauchline (1960), and Einarsson (1945) for *Meganyctiphanes norvegica;* by Einarsson (1945) for *Thysanopoda acutifrons;* by Ruud

(1932), Bargmann (1945), and Marr (1962) for *Euphausia superba;* and by Baker (1959) for *Euphausia triacantha.* Most of these species have a maximum life expectancy of 2 years, reproduce each year, and grow slowly during the winter. Other species are known to have a life expectancy of 1 year (Mauchline and Fisher, 1969).

Development, growth, and sexual maturity of the same species of euphausiid are known to vary among geographic populations (Einarsson, 1945; Nemoto, 1957; Ponomareva, 1963; Mauchline and Fisher, 1969). Mauchline and Fisher (1969) stress that this variability is probably directly related to differences in food and temperature. Hence, the rapid growth of *E. pacifica* off Oregon may be related to the high productivity of the region and the lack of large seasonal temperature fluctuations in nearshore waters.

Small, Curl, and Glooschenko[4] report high values for primary productivity in the coastal waters off Oregon. Curl and Small[5] found that standing stocks of chlorophyll-*a* averaged highest inshore and steadily decreased offshore. High production and stocks persist through the summer, the upwelling season, in inshore waters, whereas offshore waters have a typical summer productivity minimum (Anderson, 1964). Note that those seasonal and inshore-offshore gradients in phytoplankton are correlated in time and place with the spawning of *E. pacifica* off Oregon, mostly inshore and protracted over the summer and fall months. Ponomareva (1963) believes that phytoplankton is not only important as food for euphausiid larvae, but also may be necessary in the diet for development of reproductive products of *E. pacifica*.

Water temperatures along the Oregon coast are fairly uniform throughout the year and lack the extremes found along the eastern coasts of continents at similar latitudes. Advection of cool water to the surface (upwelling) during the summer and warm water toward shore during the winter moderates the usual seasonal variations. Pattullo, Burt, and Kulm (1969) observed that the seasonal range of heat content was twice as large offshore as inshore (within 65 miles) of the Oregon coast. The absence of severe winter temperatures may help to explain the rapid growth of *E. pacifica* throughout the year off Oregon. Conversely the slow and seasonally variable growth of *E. pacifica* found by Ponomareva (1963) was in the Far Eastern Seas of Asia where temperatures are often lower and where thermal variations are greater. The fact that *E. pacifica* is the only widespread euphausiid that spawns in the summer, when the phytoplankton bloom was almost over, indicates that this boreal species may be poorly adapted to the cold marginal Far Eastern Seas (Ponomareva, 1963).

The main pulses of larvae, hence spawning, of *E. pacifica* were in the fall, and not in the spring and summer as found by Ponomareva (1963), Nemoto (1957) off Japan, and Barham (1957) in Monterey Bay, Calif. Brinton (personal communication) notes larval recruitment throughout the year off Southern California. The later spawning off Oregon, like the rapid growth, may again be related to the prolonged production cycle caused by upwelling off Oregon and the moderate fall and winter water temperatures.

[4] L. F. Small, H. Curl, Jr., and W. A. Glooschenko. Seasonal primary production in a region of upwelling. III. Effects of solar radiation and upwelling on daily production. Unpublished MS.

[5] H. Curl, Jr., and L. F. Small. MS.

ACKNOWLEDGMENTS

We are grateful to J. Mauchline for his suggestions and to T. Nemoto for providing his growth curve for *E. pacifica*.

LITERATURE CITED

ANDERSON, GEORGE C.
1964. The seasonal and geographic distribution of primary productivity off the Washington and Oregon coasts. Limnol. Oceanogr. 9(3): 284-302.

BAKER, A. DE C.
1959. The distribution and life history of *Euphausia triacantha* Holt and Tatersall. Discovery Rep. 29: 309-340.

BARGMANN, HELENE E.
1945. The development and life-history of adolescent and adult krill, *Euphausia superba*. Discovery Rep. 23: 103-176.

BARHAM, ERIC GEORGE.
1957. The ecology of sonic scattering layers in the Monterey Bay area, California. Ph.D. Thesis, Stanford Univ. 192 p. Univ. Microfilms, Ann Arbor, Mich. Publ. 21, 564.

BODEN, BRIAN P.
1950. The post-naupliar stages of the crustacean *Euphausia pacifica*. Trans. Amer. Microsc. Soc. 69(4): 373-386.

BRINTON, EDWARD.
1962a. The distribution of Pacific euphausiids. Bull. Scripps Inst. Oceanogr. Univ. Calif. 8(12): 51-270.
1962b. Variable factors affecting the apparent range and estimated concentrations of euphausiids in the North Pacific. Pac. Sci. 16(4): 374-408.
1967. Vertical migration and avoidance capability of euphausiids in the California Current. Limnol. Oceanogr. 12(3): 451-483.

EINARSSON, HERMANN.
1945. Euphausiacea. 1. North Atlantic species. Dana Rep. Carlsberg Found. 27, 1-185.

HASSELBLAD, VICTOR.
1966. Estimation of parameters for a mixture of normal distributions. Technometrics 8(8): 431-444.

HEBARD, J. F.
1966. Distribution of Euphausiacea and Copepoda off Oregon in relation to oceanic conditions. Ph.D. Thesis, Oregon State Univ., Corvallis. 85 p.

ITO, JUN.
1964. Food and feeding habit of Pacific salmon (genus *Oncorhynchus*) in their oceanic life. Bull. Hokkaido Reg. Fish. Lab. 29: 85-97.

KOMAKI, YUZO.
1967. On the surface swarming of euphausiid crustaceans. Pac. Sci. 21(4): 433-448.

LASKER, REUBEN.
1966. Feeding, growth, respiration, and carbon utilization of a euphausiid crustacean. J. Fish. Res. Bd. Can. 23(9): 1291-1317.

MARR, JAMES.
1962. The natural history and geography of the Antarctic krill (*Euphausia superba* Dana). Discovery Rep. 32: 33-464.

MAUCHLINE, J.
1960. The biology of the euphausiid crustacean, *Meganyctiphanes norvegica* (M. Sars). Proc. Roy. Soc. Edinburgh, Sect. B. (Biol.) 67: 141-179.
1966. The biology of *Thysanoessa raschii* (M. Sars), with a comparison of its diet with that of *Meganyctiphanes norvegica* (M. Sars). *In* Harold Barnes (editor), Some contemporary studies in marine science, p. 493-510. George Allen and Unwin Ltd., London.

MAUCHLINE, JOHN, AND LEONARD R. FISHER.
1969. The biology of euphausiids. *In* Frederick S. Russell and Maurice Yonge (editors), Advances in marine biology. Vol. 7, 454 p.

MCEWEN, G. F., M. W. JOHNSON, AND TH. R. FOLSOM.
1954. A statistical analysis of performance of the Folsom plankton sample splitter, based on test observations. Arch. Meteorol. Geophys. Bioklimatol., Ser. A. 7: 502-527.

NEMOTO, TAKAHISA.
1957. Foods of baleen whales in the northern Pacific. Sci. Rep. Whales Res. Inst. 12: 33-90.
1959. Food of baleen whales with reference to whale movements. Sci. Rep. Whales Res. Inst. 14: 149-290.

OSTERBERG, CHARLES, WILLIAM PEARCY, AND NORMAN KUJALA.
1964. Gamma emitters in a fin whale. Nature (London) 204(4962): 1006-1007.

PATTULLO, JUNE G., WAYNE V. BURT, AND SALLY A. KULM.
1969. Oceanic heat content off Oregon: Its variations and their causes. Limnol. Oceanogr. 14(2): 279-287.

PEARCY, WILLIAM G.
1970. Vertical migration of the ocean shrimp, *Pandalus jordani*: A feeding and dispersal mechanism. Calif. Fish Game 56(2): 125-129.

PEARCY, WILLIAM G., AND CHARLES L. OSTERBERG.
1967. Depth, diel, seasonal, and geographic variations in zinc-65 of midwater animals of Oregon. Int. J. Oceanol. Limnol. 1(2): 103-116.

PEREYRA, WALTER T., WILLIAM G. PEARCY, AND FORREST E. CARVEY, JR.
1969. *Sebastodes flavidus*, a shelf rockfish feeding on mesopelagic fauna, with consideration of the ecological implications. J. Fish. Res. Bd. Can. 26(8): 2211-2215.

PONOMAREVA, LARISA NATAL'EVNA.
1963. Euphausiids of the North Pacific, their distribution and ecology. Akad. Nauk SSSR Inst. Okeanol. (Translated by Israel Program for Scientific Translations, Jerusalem 1966, IPST catalog no. 1368, 154 p.)

RENFRO, WILLIAM C., AND WILLIAM G. PEARCY.
1966. Food and feeding apparatus of two pelagic shrimps. J. Fish. Res. Bd. Can. 23(12): 1971-1975.

RUUD, JOHN T.
1932. On the biology of southern Euphausiidae. Hvalradets Skr. 2. 105 p.
1936. Euphausiacea. Rep. Dan. Oceanogr. Exped. 1908-1910 Mediter. Adjacent Seas 2D6(Biol.), 86 p.

SMALL, LAWRENCE F.
1967. Energy flow in *Euphausia pacifica*. Nature (London) 215(5400): 515-516.

TYLER, H. R., JR.
1970. The feeding habits of three species of lanternfishes (Myctophidae) off Central Oregon. Master's Thesis, Oregon State Univ., Corvallis. 64 p.

Growth and Reproduction of the Lanternfish *Stenobrachius leucopsarus*

WILLIAM SMOKER[1] AND WILLIAM G. PEARCY

Department of Oceanography
Oregon State University, Corvallis, Oreg. 97331, USA

SMOKER, W., AND W. G. PEARCY. 1970. Growth and reproduction of the lanternfish *Stenobrachius leucopsarus.* J. Fish. Res. Bd. Canada 27: 1265–1275.

Growth and reproductive patterns of the common lanternfish *Stenobrachius leucopsarus* (Eigenmann and Eigenmann) are described by length-frequency analysis, otolith analysis, and examination of ovaries. Length-frequency analysis showed that growth is approximately linear, 1.59 mm standard length per month, during the 2nd, 3rd, and part of the 4th year of life. Yearling fish average 23 mm long, 2-year-olds 41 mm, and 3-year-olds 59 mm.

Otolith analyses indicate that some fish may live to be 8 years old, but confidence in this method is limited to fish 5 years old or younger. Fitting mean lengths of age-groups defined by otolith analyses with the von Bertalanffy equation gave L_∞ = 85 mm, k = 0.34. Back calculation of lengths at the times of formation of otolith annuli gave another set of estimated mean lengths of age-groups, which, fitted by the von Bertalanffy equation, describes a growth curve similar to the one described by otolith analyses. The inflection in growth in weight occurs at about 4 years of age.

Time of spawning, determined from egg measurements, occurs from December to March. Reproductively mature individuals are 4 years old and older. Recruitment of young size groups is also seasonal, 20- to 25-mm individuals appearing in largest proportions in trawl samples in the winter, presumably about 8 months after spawning.

Comparison with other studies indicates that spawning may occur earlier in Monterey Bay, California, than off Oregon, but growth rates and sizes of age-groups I–V are similar. Comparisons with published results of otolith analyses show similar age determinations for the smaller size groups.

Received March 31, 1970

INTRODUCTION

STENOBRACHIUS LEUCOPSARUS is an abundant mesopelagic myctophid fish in the North Pacific Ocean. Aron (1962) reported it as the most abundant and most frequently caught fish in midwater trawl samples north of 45°N in the Pacific. Its zoogeographic range in the North Pacific extends north of about 35°N into the Gulf of Alaska and the Bering Sea (Parin, 1961). Paxton (1967) called the species Transitional-Subarctic in its water mass associations and presented further evidence for correlating its distribution with subarctic water.

The vertical distribution of *S. leucopsarus* is affected by the vertical stratification of water masses (Paxton, 1967; Aron, 1962), its ontogenetic development, and its vertical migrations. Fast (1960) and Ahlstrom (1959) reported that *S. leucopsarus* larvae are concentrated in the upper 100 m, localized particularly around 30–40 m. Fast's daytime observations in Monterey Bay, California,

[1]Present address: U.S. Coast Guard Cutter *Storis,* Fleet Post Office, Seattle, Washington.

Printed in Canada (J1752)

suggest that metamorphosis takes place at 400–500 m, juveniles rise to 200–300 m, and the fish gradually seek lower levels with increasing age. Taylor (1968) also indicated that during daytime, large individuals may occupy deeper levels than small individuals (455–595 vs. 230–275 m). During vertical migration, *S. leucopsarus* has also been associated with vertically migrating sound scattering layers (Taylor, 1968; Barham, 1957).

This paper describes growth, age, and season of spawning for *S. leucopsarus* off Oregon. Such knowledge is important to an understanding of the mortality, productivity, and ecology of a population.

Some information is available concerning age and growth of *S. leucopsarus*, but comprehensive data have not been published. Bolin (1956) and Fast (1960) determined growth by examining length frequency distributions from samples taken in Monterey Bay, California. Fast described a protracted spawning period from occurrence of larvae and mature females in these samples. Kulikova (1957) described growth by analyses of otoliths from 46 specimens collected in the Bering and Okhotsk seas and the Kuril–Kamchatka trench.

METHODS

Sampling

Fish used in this study were collected with a 6-ft Isaacs-Kidd midwater trawl (Isaacs and Kidd, MS, 1953; Aron, 1962) equipped with a 5-mm mesh liner and a 0.57-mm mesh codend. The trawl was equipped with depth–distance recorder, a pressure sensor and a propeller-driven device, which records on a smoked glass slide the distance travelled vs. depth (see Pearcy and Laurs, 1966).

Oblique tows of the trawl during nighttime hours were made to approximately 200 m depth at about monthly intervals from February 1964 to July 1967 at stations on a line running west from Newport, Oregon (44°39′N). Stations 15, 25, 45, and 65 nautical miles from shore were occupied regularly. Stations as far as 450 nautical miles from shore were sampled less frequently; one or more of these offshore stations was sampled in about one-third of the months. Normally one tow, sometimes two, but infrequently more, were made at a station. At stations 15 and 25 nautical miles from shore the trawl was towed to depths less than 200 m because of the shallowness of the water at these stations.

Specimens were fixed in 10% formalin in sea water at sea; later they were transferred to 36% isopropyl alcohol in the laboratory.

Determination of Reproduction State

Gonads were dissected from fish collected between July 1964 and November 1965. All available fish longer than 60 mm were examined. Fish longer than about 40 mm had gonads that could easily be categorized as either ovary or testis. Testes were lobate, white in color, and seminal vesicles were seen in more mature males at the posterior confluence of the seminal ducts. Ovaries were skeins of opaque yellow eggs, ranging from 0.05 to 0.70 mm in diameter.

Mean egg diameter was used as an index to reproductive state. At least 10 eggs were measured per ovary. The size distribution of developing eggs was similar in various parts of the ovary. When large developing eggs were in a matrix of small (less than 0.10 mm) eggs, only large eggs were measured. When two sizes of developing eggs (greater than 0.10 mm) were found in an ovary, 10 eggs of each size were measured to give two mean egg diameters for the fish.

Age Determination

LENGTH-FREQUENCY ANALYSIS

Fish were measured (standard length) to the nearest millimeter, grouped into 5-mm length categories, and the numbers of fish in each length category from all the tows during a given month were added together. Only fish greater than 20 mm in length were recorded in this part of the study because (1) the 20- to 25-mm length category is represented by the greatest numbers found for any length category, hence is probably the smallest size that is sampled adequately; and (2) according to Fast (1960), Pertseva-Ostroumova (1964), Ahlstrom (1963), and our own observations, *S. leucopsarus* larvae metamorphose at about 18 mm length. Thus 20- to 25-mm fish are the youngest juvenile fish.

The probability-paper method of graphical analysis of polymodal distributions, first suggested for aging members of a population by Harding (1949), was used to analyze length-frequency distributions. This method not only helps to separate overlapping size groups but also gives an estimate of the mean, standard deviation, and standard error of the mean for each size group.

OTOLITH ANALYSIS

Saccular otoliths were dissected from frozen fish, dried, immersed in xylene, and examined under a dissecting microscope at 66 magnifications using both transmitted and reflected light. Alternate use of both kinds of light aided the deciphering of the layers in larger otoliths. Annulus diameters were measured with an ocular micrometer along the longest dimension of the otolith.

RESULTS

Reproduction

The season of spawning and the size (hence age) at which *S. leucopsarus* matures were estimated primarily from egg diameters and changes in reproductive state and secondarily from pulses in the recruitment of small fish. Stages of gonad maturity followed Nikolsky's (1963) "universal scale":

Stage I	No eggs visible; not distinguishable as an ovary.	
Stage II	Less than 0.10 mm; eggs are yellow, opaque.	
Stage III*a*	0.10–0.20 mm	Eggs are yellow and opaque in stage III.
III*b*	0.20–0.40 mm	
III*c*	0.40–0.60 mm	
Stage IV	Greater than 0.60 mm; eggs are translucent, granular, and grey, containing globular yellow bodies.	

The maturity stages of fish in different length categories during various months of the year are entered in Table 1. When ovaries had two sizes of developing eggs, the stage of maturity indicated by the larger eggs was noted. During 1964–65 females greater than 40 mm in length were all in stage II until October when fish longer than 65 mm began to reach stage III. Stage III fish occurred from October to April. Only two ripe fish (stage IV) were observed, one each in December and March. By April 1965 only stage II and early stage III fish were found. From May to September 1965 only stage II fish were noted.

These results suggest that *S. leucopsarus* becomes reproductively mature when it reaches about 65 mm length (later results indicate that this length corresponds to 4 years of age), maturation of gonads begins in October, and spawning occurs between December and March.

The occurrence of ovaries with two sizes of developing eggs was high in December, January, and February, and intermediate in March (Table 2). Such ovaries were not found between March and December. Since no large eggs were observed in fish collected during summer months, the two sizes of eggs in an ovary do not indicate 2 years' spawn. More than one spawning

TABLE 1. Maturation stages of eggs and ovaries of *Stenobrachius leucopsarus* during 1964–65. Arabic numerals in parentheses indicate the number of fish examined for each entry.

	1964				1965						
Length (*mm*)	July–Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May–Sept.	Oct.	Nov.
91–95	(1)II					(1)III*c*					
86–90									(2)II		
81–85	(3)II	(1)II (1)III*a*		(2)III*b* (4)III*c*	(1)III*c*	(4)III*b* (2)III*c*	(1)III*b*	(2)II	(5)II	(1)III*b*	
76–80		(1)II (1)III*a* (1)III*b*	(2)III*b*	(2)III*b* (1)III*c* (1)IV	(2)III*c*	(1)III*b* (1)III*c*	(1)III*b*	(2)II	(10)II		(1)III*b* (1)III*c*
71–75		(1)III*b*	(1)III*b*	(4)III*b*	(1)III*b*	(4)III*b* (1)III*c*	(2)III*b* (1)III*c* (1)IV	(1)III*a*	(11)II	(1)II (1)III*b*	
66–70	(1)II	(1)II	(2)II	(2)II (5)III*b*	(1)II (5)III*b*	(2)III*a* (1)III*b* (1)III*c*	(4)II (1)III*b*	(1)III*a* (3)II	(7)II	(1)II	(1)II (1)III*a*
61–65	(1)II	(3)II	(4)II	(6)II	(1)III*a*	(4)II	(1)II	(3)II	(3)II		(1)II
41–60	(2)II	(9)II	(5)II	(21)II	(9)II	(3)II	(12)II	(15)II	(15)II	(14)II (3)I	(2)II
20–40									(10)I		

TABLE 2. Percent of females greater than 65 mm in length with two sizes of eggs in ovaries.

Month	No. females observed	No. ripening females observed	% with two sizes of eggs in ovaries
	1964		
July	5	0	0
Aug.	1	0	0
Oct.	6	4	0
Nov.	5	3	0
Dec.	21	19	28
	1965		
Jan.	10	10	40
Feb.	19	18	42
Mar.	14	9	14
Apr.	10	2	0
June	13	0	0
July	19	0	0
Aug.	3	0	0

during the same season is also unlikely because the decline in occurrence of ovaries with two sizes of eggs coincided with the general decline in occurrence of ripe females in March and April. The smaller eggs are probably either expelled as immature gametes during spawning or are resorbed (see Nikolsky, 1963).

Recruitment of young fish 20–25 mm in length into trawl samples is also seasonal (Fig. 1). This is additional evidence for seasonal spawning: if spawning

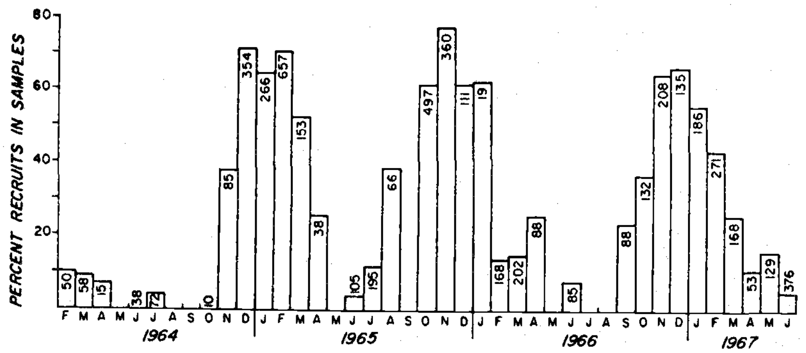


FIG. 1. Percent recruits (20- to 25-mm fish) in monthly midwater trawl samples. Numbers inside bars are the total number of *Stenobrachius leucopsarus* in the sample.

were spread over all seasons it would be expected that recruitment of young fish would continue throughout the year.

GROWTH

The average growth of *S. leucopsarus* was described by three methods: (1) the increase in mean length of year-classes from successive samples; (2) the mean lengths of fish aged by otolith analysis; and (3) the lengths of fish in different age-groups calculated back from the diameters of otolith annuli. In all methods a regression curve was fitted to the mean lengths.

LENGTH-FREQUENCY ANALYSIS

Length-frequency analysis is based on the tendency for the lengths of fish of one age to form a normal distribution; thus in a sample of a population each peak or length class corresponds to an age-group. This method assumes that: (1) spawning of year-classes is isolated enough in time so that the length frequencies of succeeding year-classes do not overlap too much; (2) members of a year-class all experience roughly the same growth conditions so that the length-frequency distribution of a year-class is not polymodal; and (3) all year-classes are represented in the samples well enough that incorrect ages are not assigned to length classes due to the absence of one or more year-classes in the sample (Rounsefell and Everhart, 1953).

Graphical analyses of monthly samples gave estimates of length-class means and their standard errors (Fig. 2). Recruitment of juveniles occurs in the early months of each year, and each year-class is discernible until sometime between its third and fourth birthday. The mean lengths less than 70 mm for each year-class were superimposed on a common time scale using January of

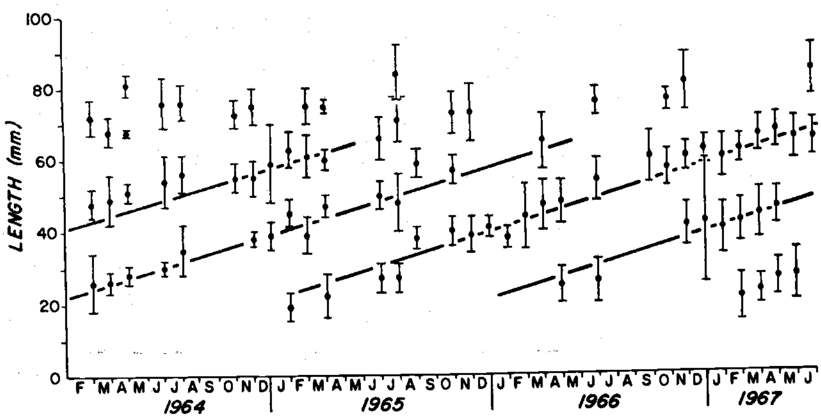


FIG. 2. Length group means from midwater trawl samples. Vertical lines indicate ±1 SD. Oblique lines are length = 20.78 × 1.59 (months) for fish under 70 mm.

the year following spawning for each year-class as the initial point. Linear regression of length with time gave:

$$\text{length} = 20.78 + 1.59X$$
$$r = 0.98$$

where r is Pearson's correlation coefficient and X is months numbered beginning with January of the year following spawning and length is in millimeters. This line is drawn in Fig. 2 as a reference line by repeating it with the same slope and "January intercept" for each of the year-classes represented. Attempts to fit a curvilinear relation to the mean lengths of age-groups I–III using computer techniques were unsuccessful because the means too closely approximated a straight line.

Comparison of the year-classes to this reference line shows that growth of *S. leucopsarus* is approximately linear during the 2nd, 3rd, and 4th years. Growth rates are similar. Each year-class passes through the same length categories during the same months of the year.

OTOLITH ANALYSIS

Otoliths consist of alternately opaque and translucent concentric layers. Age can be determined if an annular pattern of alternation of these layers exists, the number of alternations giving the fish's age. Such a pattern is demonstrated for *S. leucopsarus* in Table 3: the largest percentages of otoliths with opaque peripheries occurred during summer months, the largest percentages with translucent peripheries during winter. The reason that no month showed 100% opaque peripheries is that the otolith margin may appear to be translucent because of its thinness even though an opaque layer is forming.

Translucent layers are forming on otoliths during January, approximately the time of spawning of *S. leucopsarus* (Table 3). The outermost edge of opaque

TABLE 3. Percentage of otoliths with translucent or opaque peripheries or both during various months of the year.

Date	Translucent (%)	Opaque and translucent (%)	Opaque (%)	No. examined
Jan. 1966	100	0	0	2
Feb. 1966, 1969	70	18	13	55
Apr. 1966	62	13	25	8
June 1966, 1969	27	32	41	22
Oct. 1965, 1968	43	31	25	28
Nov. 1968	95	0	5	38
Dec. 1966	71	0	29	21

layers, however, is the most conveniently measured annual demarcation in otolith structure. These are called "annuli" even though their formation does not coincide with the birthdays of the fish. Opaque layers are formed in summer about 6 months before the corresponding birthday.

The opaque core of the otolith was considered to be deposited during the 1st year of life. Fish belonging to the recruit length category (20–25 mm) have an otolith consisting of an opaque center surrounded by some translucent material. Based on our length-frequency data (Fig. 1, 2) and those of Fast (1960), these individuals are about 1 year old.

Although otolith analyses indicated some fish may be 7 or 8 years old, otoliths from fish older than 5 years could not be analyzed with reliability owing to the merging of peripheral annuli. Photographs of otoliths from age-groups I–IV with both translucent and opaque peripheries are shown in Fig. 3.

The mean lengths of age-groups of fish aged by otoliths were fitted to the von Bertalanffy equation (von Bertalanffy, 1938) (Fig. 4A) giving these estimates:

$$L_\infty = 84.96, \quad \text{SE} = 2.79$$

$$L_\infty - L_0 = 79.32, \quad \text{SE} = 3.12$$

$$k = 0.34, \quad \text{SE} = 0.044.$$

Thus

$$L_X = 84.96 - 79.32e^{-0.34X}$$

$$\text{Variance} = 3.06$$

where L_X = the length at age X; L_∞ = the asymptotic length; L_0 = the length at age zero; e = the base of the natural logarithms; k = the rate at which length approaches the asymptote; and X = age in years.

Age-groups V–VII were included. Though confidence in these age determinations is less than for the first four age-groups, the mean lengths of fish in these age-groups are consistent with the trend established by the younger age-groups.

BACK CALCULATION OF AGE-GROUP LENGTHS

Diameters of otolith annuli were used to compute lengths of fish at earlier ages by deriving a formula relating the logarithm of annulus diameter to the logarithm of standard length (see Rounsefell and Everhart, 1953).

Mean lengths of age-groups I–IV calculated by this method were fitted to the von Bertalanffy equation (Fig. 4B) giving these estimates of the parameters:

$$L_\infty = 75.01, \quad \text{SE} = 5.00$$
$$L_\infty - L_0 = 84.17, \quad \text{SE} = 3.01$$
$$k = 0.377, \quad \text{SE} = 0.0629.$$

Thus

$$L_X = 75.01 - 84.17e^{-0.377X}$$
$$\text{Variance} = 1.468.$$

SYNOPSIS OF GROWTH DETERMINATIONS

The three growth curves, derived from length-frequency analysis, otolith analysis, and back calculations, are superimposed in Fig. 5. Agreement among the curves is good.

GROWTH IN WEIGHT

Fish from which otoliths were to be removed were dried to a constant weight on glass slides in an oven at 65 C (3 or 4 days), scraped from the slide, and weighed to the nearest milligram. Linear regression of the logarithm of weight (in grams) on the logarithm of length (in centimeters) gave:

$$\log \text{wt} = -2.898 + 3.595 \log \text{length}$$

or

$$\text{wt} = 0.001264 \, (\text{length})^{3.595}.$$

The growth curve obtained from otolith analyses is transformed into growth in weight in Fig. 6 by this relation.

DISCUSSION

Fast (1960), in his comprehensive study in Monterey Bay, California, found growth and reproduction patterns similar to those off Oregon (Fig. 7). He found ripening females during the entire year but concluded that spawning is seasonal in intensity from the seasonal variation in abundance of young size groups. Spawning occurred from November through August, compared with October through March off Oregon.

Fast estimated that age-group I fish (in their 2nd year) average 32 mm standard length; age-group II, 50 mm; and age-group III, 66 mm. These esti-

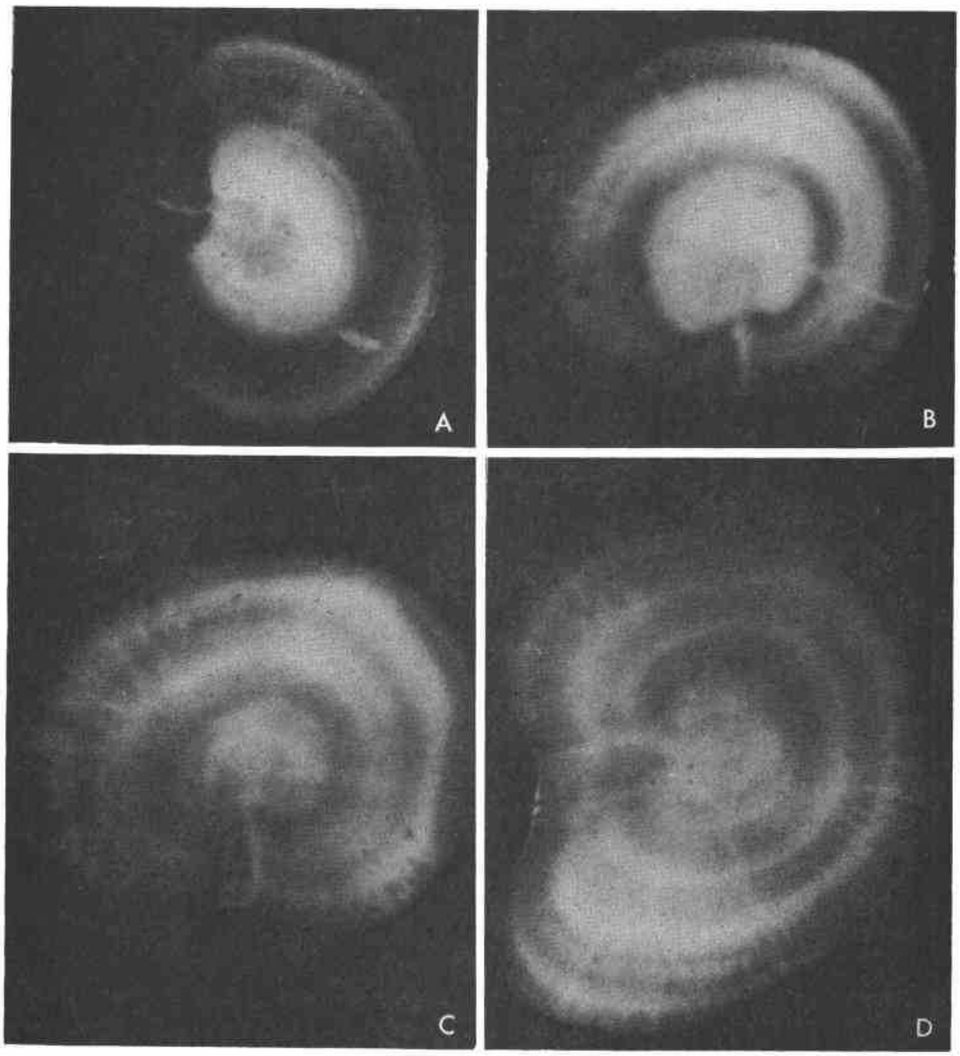


FIG. 3. *Stenobrachius leucopsarus* otoliths.

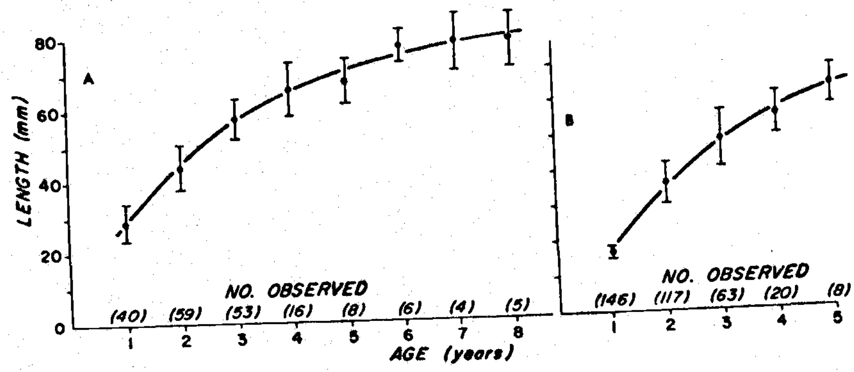


FIG. 4. (A) Means and standard deviations of lengths in otolith analysis age-groups. (B) Means and standard deviations of lengths of age-groups back-calculated from otoliths. Curves fitted using computer program CURVFIT at Oregon State University.

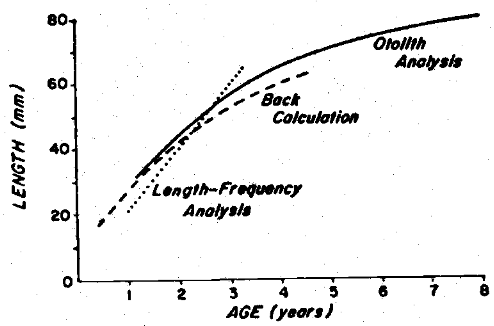


FIG. 5. Comparison of three growth curves, Fig. 2, 4A, B.

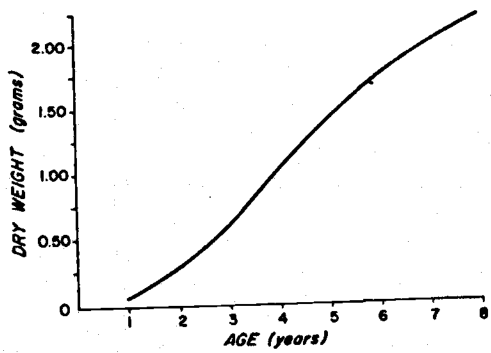


FIG. 6. Growth in weight.

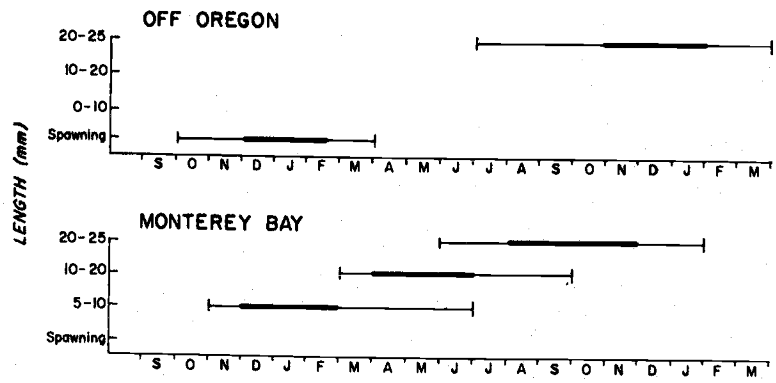


FIG. 7. Comparison of periods of spawning, catches of larvae, and catches of small juveniles in Monterey Bay and off Oregon. Thin lines indicate ranges of occurrence, thick lines periods of abundance.

mates agree precisely with the regression line fitted to length-frequency data from Oregon collections (Fig. 8). Although Fast did not assign ages to large fish, examination of his data suggests that age-group IV fish are about 72 mm and age-group V are about 76 mm. These estimates agree fairly well with our growth curve based on otolith analyses.

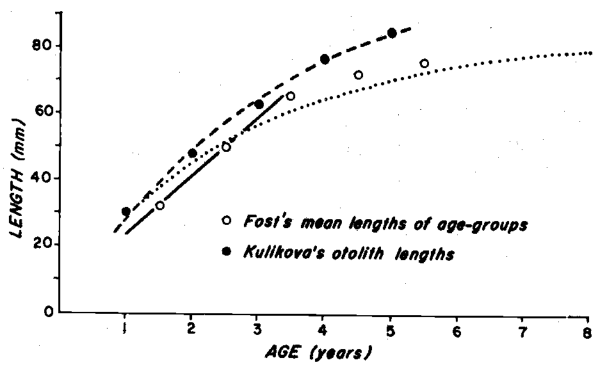


FIG. 8. Comparison of growth curves from Kulikova's otolith analysis, Fast's length-frequency analysis, our length-frequency analysis, and our otolith analysis. Broken line: fit of the von Bertalanffy equation to Kulikova's data, length $= 111 - 111\ e^{-0.29(\text{age})}$; dotted line: fit of the von Bertalanffy equation to our otolith analysis, length $= 85 - 79\ e^{-0.34(\text{age})}$; solid line: our length-frequency regression line, length $= 21 + 19\ (\text{age} - 1)$.

Kulikova (1957) examined otoliths from 46 *S. leucopsarus* collected in the western North Pacific. For comparison, the von Bertalanffy equation was fitted to the mean lengths of age-groups in Kulikova's study (Fig. 8). The estimate of L_∞ (111 mm) is much higher than in this study, the estimate of k (0.29) somewhat lower. Kulikova's age estimates are similar to ours and those of Fast for the first 3 years of growth but they indicate faster growth for age-groups IV and V (Fig. 8). Her estimates and Bolin's (1956) are similar for age-groups I–IV.

This discrepancy in size and growth of older fish as well as Fast's failure to age large fish is significant in pointing out the difficulty in assigning ages to large fish. Neither method, length-frequency analysis, or otolith analysis provides an entirely confident determination.

Odate (1966) and Halliday (1970) estimated the age and growth of the lanternfishes *Myctophum affine* (Lütken) and *Benthosema glaciale* (Reinhardt) respectively. *Myctophum affine* grows rapidly during the first year attaining a length of 36 mm; then growth slows down. It spawns at 3 years of age and reaches a maximum length of 78 mm. The growth rates of *B. glaciale* and *S. leucopsarus* are similar ($k = 0.36$ vs. 0.34), but *B. glaciale* spawns at only 2 years of age, and it attains a smaller maximum length (68 mm) and a lower maximum age ($4\frac{1}{2}$ years) than *S. leucopsarus* off Oregon. Halliday reached opposite conclusions, however, when comparing *B. glaciale* and *S. leucopsarus* because he only based his comparisons on Bolin's (1956) preliminary report.

ACKNOWLEDGMENTS

This work was supported by National Science Foundation Grant GB-1588 and GB-5494, and U.S. Atomic Energy Commission Contract AT (45-1)1750(RLO1750-63). We thank L. Coleman for identifying and measuring many of the specimens, W. S. Overton for assisting with curve-fitting techniques, and L. Small for comments on the manuscript.

REFERENCES

AHLSTROM, E. H. 1959. Vertical distribution of pelagic fish eggs and larvae off California and Baja California. U.S. Fish Wildlife Serv. Fish. Bull. 60: 107–146.

1963. Kinds and abundance of fishes in the California Current region based on egg and larval surveys. Calif. Coop. Oceanic Fish. Invest. Rep. 10: 31–52.

ARON, W. 1962. The distribution of animals in the eastern North Pacific and its relationship to physical and chemical conditions. J. Fish. Res. Bd. Canada 19: 271–314.

BARHAM, E. G. 1957. The ecology of sonic scattering layers in the Monterey Bay area, California. Ph.D. Thesis. Stanford Univ., Stanford, Calif. 182 p. Univ. Microfilms, Inc., Ann Arbor, Mich. (Doctoral Diss. Ser. Publ. 21,564)

BERTALANFFY, L. VON. 1938. A quantitative theory of organic growth (inquiries on growth laws. II). Hum. Biol. 10: 181–213.

BOLIN, R. L. 1956. The age and growth of the myctophid fish *Lampancytus leucopsarus* (Eigenmann and Eigenmann). Proc. Int. Congr. Zool. 14: 541–542.

FAST, T. N. 1960. Some aspects of the natural history of *Stenobrachius leucopsarus* Eigenmann and Eigenmann. Ph.D. Thesis. Stanford Univ., Stanford, Calif. (Libr. Congr. Card No. Mic. 60-6729.) 107 p. Univ. Microfilms, Inc., Ann Arbor, Mich.

HALLIDAY, R. G. 1970. Growth and vertical distribution of the glacier lanternfish, *Benthosema glaciale*, in the northwestern Atlantic. J. Fish. Res. Bd. Canada 27: 105–116.

HARDING, J. P. 1949. The use of probability paper for graphical analysis of polymodal frequency distributions. Mar. Biol. Ass. 21: 311–318.

ISAACS, J. D., AND L. W. KIDD. MS, 1953. Isaacs-Kidd midwater trawl. Unpublished MS, Scripps Inst. Oceanogr. Reference 53-3: 21 p.

KULIKOVA, E. B. 1957. Growth and age of deep-water fishes, p. 284–290. *In* B. N. Nikitin [ed.] Marine biology. Tr. Inst. Okeanol. Akad. Nauk SSSR 20. (Transl. from Russian by Amer. Inst. Biol. Sci.)

NIKOLSKY, G. V. 1963. The ecology of fishes. Academic Press, Inc., London, England. 352 p. (Transl. from Russian by L. Birkett)

ODATE, S. 1966. Studies on the fishes of the family Myctophidae in the northeastern area of the Pacific coast of Japan. III. Determination of the age and growth of the susukihadaka lanternfish, *Myctophum affine* (Lütken). Bull. Tohoku Reg. Fish. Res. Lab. 26: 35–43. (Transl. from Japanese by Fish. Res. Board Can. Transl. Ser. No. 850, 1967)

PARIN, N. V. 1961. The distribution of deep-sea fishes in the upper bathypelagic layer of the subarctic waters of the northern Pacific Ocean. Tr. Inst. Okeanol. Akad. Nauk SSSR 45: 259–278. (Transl. from Russian by L. Penny)

PAXTON, J. R. 1967. A distribution analysis for the lanternfishes (family Myctophidae) of the San Pedro Basin, California. Copeia 1967: 422–440.

PEARCY, W. G., AND R. M. LAURS. 1966. Vertical migration and distribution of mesopelagic fishes off Oregon. Deep-Sea Res. Oceanogr. Abstr. 13: 153–165.

PERTSEVA-OSTROUMOVA, T. A. 1964. Some morphological characteristics of myctophid larvae (Myctophidae, Pisces), p. 75–97. *In* T. S. Rass [ed.] Fishes of the Pacific and Indian Oceans. Tr. Inst. Okeanol. Akad. Nauk SSSR 73. (Transl. from Russian by Israel Program for Sci. Transl., 1966)

ROUNSEFELL, G. A., AND W. H. EVERHART. 1953. Fishery science: its methods and applications. John Wiley & Sons, Inc., New York, N.Y. 444 p.

TAYLOR, F. H. C. 1968. The relationship of midwater trawl catches to sound scattering layers off the coast of northern British Columbia. J. Fish. Res. Bd. Canada 25: 457–472.

Slide Rule Conversion of Per Cent Transmittance to Absorbance

The calculation of absorbance which obeys Beer's Law may be quickly determined by using a slide rule which has both a logarithmic as well as a reciprocal scale (CI or DI scales).

Beer's Law [PINKERTON, RICHARD C., J. CHEM. EDUC., 41, 336 (1964)] may be stated as absorbance, $A = abc = \text{Log}_{10}\, P_0/P$ where P_0 is the initial incident radiation and P is the transmitted radiant energy. When the initial light intensity P_0 is adjusted to 100% the transmitted light P then can be expressed in terms of per cent of the initial intensity P_0. Thus, $A = \log_{10} (100\%/P\%)$.

By setting the per cent transmittance value on the Cl (or DI) scale of a slide rule, the absorbance A, can be read directly on the logarithmic scale. For per cent transmittance values from 10% to less than 100%, the number read on the logarithmic scale will be preceded by a decimal point; for per cent transmittance less than 10 to 1%, the number read should be preceded by a characteristic of 1, and so on. The accompanying table illustrates several examples.

%T	CI scale setting	Absorbance (Log scale reading)
65	65	0.187
6.5	65	1.187
0.65	65	2.187
0.065	65	3.187

DEPARTMENT OF OCEANOGRAPHY
OREGON STATE UNIVERSITY
CORVALLIS, 97331

INGVAR L. LARSEN

Journal of Chemical Education Vol. 48 (6), June 1971, p. 383

Zool. Anz., Leipzig 186 (1971) 1/2, S. 141–147

Two New Parasites (Protozoa: Telosporea) from the Spatangoid-Urchin *Brisaster latifrons*

By

Charles L. Brownell and James E. McCauley[1]

With 16 Figures

(Eingegangen am 5. Januar 1970)

During investigations of the biology of the spatangoid heart-urchin *Brisaster latifrons* (Agassiz, 1898), from waters off the coast of Oregon, several new gregarine parasites were encountered. Gametes and developmental stages of two of these species could be linked to their respective spores and are described below. The five gregarine species which have previously been reported from echinoids belong to the genera *Lithocystis* and *Urospora*. The genera are differentiated by male gametes: those of *Urospora* possess a flagellum, those of *Lithocystis* do not (Pixell-Goodrich 1915).

Seven species of *Lithocystis* are presently known: *L. schneideri* Giard, 1876 from *Echinocardium cordatum* (Pennant), *E. flavescens* (O. F. Müller), and *Spatangus purpureus* O. F. Müller; *L. minchini* Woodcock, 1906 from *Cucumaria saxicola* Brady and Robertson and possibly from *C. normani* Pace (Pixell-Goodrich, 1929); *L. foliacea* Pixell-Goodrich, 1915, from *E. cordatum; L. microspora* Pixell-Goodrich, 1915, from *E. cordatum; L. brachycercus* Pixell-Goodrich, 1925, from *Chirodota laevis* (Fabricius); *L. cucumariae* Pixell-Goodrich, 1929, from *Cucumaria saxicola;* and *L. lankesteri* Pixell-Goodrich, 1950, from *Sipunculus nudus* Linnaeus.

The species of *Lithocystis* reported here bring to seven the number of sporozoa described from echinoid hosts and are the first parasites of any kind reported from *Brisaster latifrons*.

Methods

Heart urchins were collected with otter trawl, beam trawl and biological dredge from depths of 100 to 840 meters off Oregon between December 1960 and August 1969, and preserved in alcohol or buffered formalin. Although Pixell-Goodrich (1915) found wet mounts of living specimens to be most useful, we found preserved material to differ from living material only in the appearance of the mass of crystals enclosed within the cysts and in the refringent granules in the spores. Since neither holds taxonomic value, the characteristics of the preserved specimens were considered to be reliable.

[1] Charles L. Brownell and James E. McCauley, Department of Oceanography, Oregon State University, Corvallis, Oregon (U.S.A.). Partially supported by the U.S. Atomic Energy Commission, Contract AT (45-1) 1750.

The parasites were removed from the urchins through a hole cut at the left anterior extremity, thus avoiding the loop of the intestine which lies on the right. Trophozoites and most of the unattached cysts were poured out with the coelomic fluid. Flushing removed all but the most tenacious cyst masses. This technique is similar to that described by PIXELL-GOODRICH (1915).

Cysts were teased apart and their spores were studied under a 100× oil immersion objective. Drawings were made with the aid of a camera lucida.

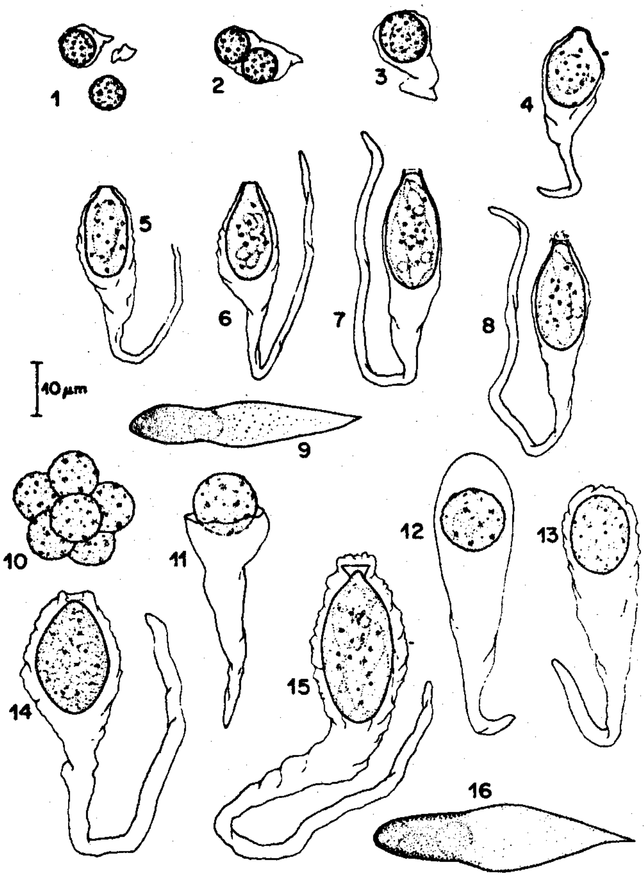
Many of the urchins contained mixed infections of gregarines and it was therefore necessary to select urchins infected with only one parasite to insure that stages were not mixed. At least 5 gregarine species are thought to be present, but only two could be satisfactorily traced through most of the developmental stages. Although numerous trophozoites were observed, none could by positively associated with the other stages.

Lithocystis latifronsi sp. n. (Figs. 1—9)

Description: Trophozoites not identified. Cysts spherical, 0.6 to 2.0 mm in diameter, enclosed in single transparent membrane; flagellated cell layer (presumably of host origin) enclosing cyst wall. Gametes 6 to 7 μm in diameter, non-flagellated. Zygotes spherical to ovoid. 8 to 10 μm long, non-flagellated, incipient tail extending from epispore. Spores often in rosettes, tails distal; endospore flask-shaped; 18 to 22 μm long by 7 to 9 μm wide; neck of mature spore gently tapering from equator. neck of immature spore more abrupt with distinct shoulders; distal portion of neck cylindrical, 2 μm in diameter, flaring only slightly if at all. Epispore thin and smooth in mature spores, thicker and wavy in immature spores, usually bearing bristle-like projections around funnel, particularly in immature spores. Tails long, 60 to 75 μm (rarely 80 μm) beyond endospore. tapering from level of endospore, narrow (1 to $1^1/_2$ μm). Mature endospore containing 8 sporozoites. Sporozoite spindle-shaped with rounded anterior. 13 to 14 μm long by 2 to $2^1/_2$ μm wide, nucleus anterior to middle, slightly constricted at level of nucleus, lightly pigmented, expelled from spores with slight pressure.

Host: *Brisaster latifrons* (Agassiz, 1898)
Location: Coelom
Locality: Pacific Ocean 22 to 78 km off Oregon, U. S. A., in depths of 100 to 840 meters

Remarks: *Lithocystis latifronsi* can be distinguished from other members of the genus by the spore alone. The tails of the spores of *L. schneideri* and *L. foliacea* are considerably broader than those of the new species. *Lithocystis microspora,* also from spantangoids, has an endospore length of 10 to 13 μm; *L. lankesteri,* an endospore length of 12 to 14 μm, both considerably smaller than *L. latifronsi*. The epispore of *L. latifronsi* is smooth when mature, ruffled when immature and differs greatly from the epispores of *L. minchinii* which bears conical projections, and *L. cucumariae* which has a "second funnel". *Lithocystis brachycercus* has a short flattened spore tail.



Figs. 1—9. ***Lithocystis latifronsi*** **sp. n. 1 and 2. gametes; 3. early zygote; 4 and 5. developing spores; 6. spore with developing sporozoites; 7 and 8. mature spores; 9. sporozoite (not to scale)**
Figs. 10—16. ***Lithocystis oregonensis*** **sp. n. 10. gametes; 11. zygote; 12. 13, and 14. developing spores; 15. mature spore; 16. sporozoite (not to scale)**

All figures have been drawn with a ***camera lucida*** **and are at the same scale except for figures 9 and 16 which are free-hand and enlarged about 3×**

Several features point to a close relationship between *L. schneideri* from *Echinocardium cordatum* and *L. latifronsi.* Both form large cysts, both have endospores of similar size and shape, both tend to form rosettes of spores inside the cyst. Differences in the appearance of the immature stages of the spore tails distinguish the two species.

The arrangement of mature spores of *L. schneideri* in rosettes was described by Giard (1876). He believed the attachment of the spores to one another was achieved by the secretion of an adhesive substance near the funnel. The same phenomenon is evident in this new species, but here, not only mature spores, but perhaps to a greater extent immature spores, assume clumped positions with tails projecting outwards. The "secretion" may take on a variety of appearances. It may look as though a small quantity of protoplasm has exuded from the spore neck; it may suggest the appearance of fine filaments of assorted lengths or sometimes coarse bristles (Fig. 8); or it may be entirely absent (Fig. 7). The tendency toward rosettes formation, however, correlates with the presence of some structure at the neck end of the spores. Whether the attachment is a result of physical entanglement of the filaments or bristles or by true adhesion of a secreted substance is unknown.

Each spore, when ripe, contains 8 elongate sporozoites. The sporozoites of *L. latifronsi* are separable from other still unidentified sporozoites from *B. latifrons* by their tenuity (Fig. 9). Other sporozoites of comparable length are considerably more robust.

An incipent spore tail becomes recognizable shortly after the zygote rounds off (Fig. 3). As development progresses, the zygote becomes more elongate, approaching in shape the long-necked endospore it is destined to become (Figs. 4, 5, 6). The epispore becomes thicker and ruffled, continually extending itself caudally until a tail of about 60 μm is formed. At this point the endospore contains 8 ovoid sporozoites (Fig. 6). By the time the sporozoites reach their final length of 13 to 14 μm, the spore tail has reached a length of 70 μm and the epispore has become thin and smooth (Fig. 7). The epispore does not differentiate into a large funnel as is the case with the new species described below. The endospore neck is long, cylindrical, and remains open ended. The name *latifronsi* refers to the name of the host species.

Lithocystis oregonensis sp. n. (Figs. 10—16)

Description: Trophozoites not identified. Cysts spherical, 0.9 to 1.6 mm in diameter, enclosed in single transparent membrane; flagellated cell layer (presumably of host origin) enclosing cyst wall. Gametes spherical, 8 to 10 μm in diameter, non-flagellated. Zygotes spherical, 10 to 13 μm in diameter, non-flagellate, with conical epispore. Spores large, occasionally in rosettes, funnels distally. Endospore 24 to 30 μm long by 11 to 13 μm wide. Epispore thick and wavy, usually extending as crown beyond funnel apex; funnel large, walls strongly divergent; tail long, extending 70 to 90 μm (rarely 115 μm) beyond endospore, moderately wide, $1^1/_2$ to 2 μm. Mature endospore containing 8 sporozoites. Sporozoites robust, 15 to 17 μm long by 3 to $3^1/_2$ μm wide, greatest width near middle, narrower anteriorly at level of nucleus. Nucleus surrounded by densely pigmented cytoplasm. Anterior blunt, posterior sharply pointed.

Host: *Brisaster latifrons* (Agassiz, 1898)
Location: Coelom
Locality: Pacific Ocean 22 to 78 km off Oregon, U. S. A., in depths of 100 to 840 m.

Remarks: *Lithocystis oregonensis* is easily distinguished from other species of *Lithocystis* thus far described by its larger spores and sporozoites. The sporozoites differ from *L. latifronsi* in their greater width, their heavier pigmentation in the anterior end, and in their more attenuated tails.

Inside the cysts the spores are occasionally arranged in rosettes with the funnels directed outwardly. The tails of these clumped spores are usually broken when the spores are separated, indicating that they had become entangled or perhaps even fused with each other. When unbroken, the tails of *L. oregonensis* are the largest of any Urosporidae seen in *B. latifrons*.

Gametes and zygotes of *L. oregonensis* were observed in various stages of development. The entire growth sequence from gamete production and union through the formation of immature spores takes place inside the viscous matrix of the cyst and does not lend itself to ready observation. Near the time of gamete union, small incipient spore tails are differentiated within the matrix. Their shape is that of a simple cone. The spherical zygote is situated near the opening of the cone (Fig. 11) and soon becomes enveloped by it (Fig. 12). Several events follow simultaneously: the epispore assumes a wavy appearance and extends caudally as a long tail; the zygote enlarges, becomes ovoid, and acquires smooth walls — on the way to becoming an endospore (Figs. 13, 14, 15); the funnel emerges from folds in the epispore, and comes to be situated over the small projection in the endospore wall which eventually breaks open to release the sporozoites.

Discussiòn

Trophozoites of various shapes and sizes were observed in both living and preserved states. Associated pairs occurred frequently. Pixell-Goodrich (1915) dismissed the trophozoite as a source of taxonomic characters. Although none have been identified in this study, several distinct types were observed. Such features as size, shape, myoneme organization, nucleoli and karyosomes, all have taxonomic potential.

By assuming that only mature trophozoites undergo syzygy, it would seem a simple matter to measure associated pairs, calculate the volume of their resultant cyst, and then link the associates to cysts of comparable size taken from the same host. Attempts to identify trophozoites in this manner were complicated by the fact that each host, on the average, harboured at least three different species of Urosporidae, the cysts of which frequently overlapped in size distribution. Three hosts out of 25 yielded 5 different species. The same problem largely prohibits identifying cysts purely on the basis of size. The two extremes are exceptional: cysts over 1.4 mm in diameter were almost always *L. latifronsi*, cysts under 0.2 mm were almost always one of those undescribed species whose developmental stages remain unidentified.

Some trophozoites were found covered with small amoebocytes similar to those described by Léger (1896) from *Echinocardium* sp. These same amoebocytes were omnipresent among the agglutinated coelomocytes at the bottom of a container used to collect coelomic fluid. Other trophozoites were found covered with a much larger (25 μm to 50 μm in diameter) variety of amoebocyte. The large amoebocytes, which give the trophozoites in which they occur a tuberculated appearance, were particularly rare, as they were not seen elsewhere in the coelomic fluid. They were seen to cover only the large trophozoites (probably *L. latifronsi* and/or *L. oregonensis*), never smaller ones. Several fresh hosts yielded still active trophozoites free from amoebocytic attack. In the same hosts, trophozoites that were covered by amoebocytes showed no signs of life. This supports Pixell-Goodrich's (1915) hypothesis that only dead or moribund trophozoites are susceptible to attack.

Viable trophozoites, after uniting in syzygy, round off to form spherical cysts. The cysts of several species are commonly found together in masses on the floor of the coelomic cavity. Externally they are enveloped by a layer of simple squamous flagellated cells, presumably derived from the host's coelomic epithelium. This layer is not mentioned in the literature of gregarines of the European spatangoids. It probably serves to prevent the cyst membrane from breaking and releasing the parasites into the coelom.

Gamete and zygote stages were encountered only rarely: out of almost 600 cysts opened, some 20 yielded gametes or zygotes. This ratio actually understates true conditions since the final 200-or-so cysts were preferentially selected for examination because of their immature appearance (more opaque cyst membrane, yellowish contents) in the hopes that more gametes and zygotes could be identified. At this time, developmental stages of only two species have been linked with their respective spores. Neither possesses flagellated stages and must therefore be placed in the genus *Lithocystis*. Flagellated gametes and zygotes of undescribed *Urospora* species were also encountered, but attempts to link them with their spores were unsuccessful.

The most useful taxonomic characters of the spores found in *B. latifrons* are endospore length, tail length, epispore shape and funnel shape. All change to some extent during maturation, particularly epispore and funnel shape. The degree of maturity of a spore is readily determined by the shape of the sporozoites inside: round sporozoites indicate a young spore, oval or elongate sporozoites indicate an intermediate stage, etc.

Pixell-Goodrich (1915) concluded that characters of the sporozoites were of little value in the taxonomy of the species she described. The sporozoites from cysts from *B. latifrons* showed differences in length, width, position of the nucleus, pigmentation, and overall shape. Because of the sporozoite's tendency to be deformed by former confinement in the spore, one may have to examine several before a typical shape is decided upon. For this reason, sporozoites presented in Figures 9 and 16 may be somewhat misleading; not enough, however, to render them useless.

During an investigation into the reproductive cycle of the host heart-urchin, many gonads were examined microscopically and found to contain what are almost certainly encysted sporozoites. The sporozoites, up to about 30 μm long, were invariably folded; they were individually enclosed in a spherical hyaline capsule, which in turn was imbedded in host connective tissue. The cysts are most common just beneath the gonad epithelium but have also been found in various other places in the host. The sporozoites inside these capsules may appear necrotic, partially decomposed, or at times, non-existent. It is extremely doubtful that encystment of the sporozoites is part of the parasite's normal life-cycle. More likely the sporozoites (or young trophozoites) come in contact with the host's coelomic epithelium (possibly even attempting to burrow through it for reasons unknown) and are trapped. Sometimes the gonads of the urchin bear so many encapsulated sporozoites that their normal structure is changed: the gonadal tissue is filled with phagocytes and cell detritus rather than the normal products of gametogenesis.

Summary

Lithocystis latifronsi and *L. oregonensis* are described from the coelom of *Brisaster latifrons* from the Pacific Ocean off Oregon, U.S.A. Spore characteristics differentiate each of the new species from all known species of *Lithocystis*.

References

Giard, M. A.: Sur une nouvelle espèce de Psorospermie (*Lithocystis schneideri*) parasite de l'*Echinocardium cordatum*. Comptes rendus des séances hebdomadaires de l'Académie des Sciences 82 (1876) 1208—1210; translated in Ann. Mag. Nat. Hist. 18 (1876) 192—194.

Leger, L.: L'évolution du *Lithocystis schneideri*, parasite de l'*Echinocardium cordatum*. Comptes rendus de séances hebdomadaires de l'Académie des Sciences 123 (1896) 702—705.

Pixell-Goodrich, H. L. M.: On the life-history of the Sporozoa of spatangoids, with observations on some allied forms. Quart. J. Microsc. Sci. 61 (1915) 81—104.

— The gregarines of *Cucumaria: Lithocystis minchinii* Woodc. and *Lithocystis cucumariae* n. sp. Quart. J. Microsc. Sci. 73 (1929) 275—287.

(Reprinted from Research Reports of the Fish Commission of Oregon, Volume 2, Number 1, December 1970)

DETERMINATION OF MOVEMENT AND IDENTITY OF STOCKS OF COHO SALMON IN THE OCEAN USING THE RADIONUCLIDE ZINC-65[1]

Robert E. Loeffel
Fish Commission of Oregon, Research Division
Clackamas, Oregon
and
William O. Forster[2]

Abstract

The radioisotope, ^{65}Zn, which occurs in the Columbia River plume because of the Atomic Energy Commission operations at Hanford on the Columbia River, is assimilated by coho and if retained long enough biologically has a sufficient half life (245 days) to serve as a natural mark for coho. Zinc-65 was studied as a marker by comparing ^{65}Zn levels in coho taken along the British Columbia-S.E. Alaska coast during the summer months north of the Columbia River plume, and in the suspected migratory path for Oregon-Washington coho during their first few months in the ocean. Bering Sea coho were included to provide a measure of ^{65}Zn that was not of Hanford origin. Samples were collected by the University of Washington Fisheries Research Institute and were passed on to the Oregon State University Department of Oceanography for radioanalysis.

Variation in activity between coho collected in time-space subdivisions within each year was observed. The variation was taken as evidence that coho originating from streams south of the area of collection were in the sample as well as coho from British Columbia and S.E. Alaska. The levels of activity appeared to be high enough that if coho so marked were caught 6 months later on the high seas they would be distinguishable from unmarked coho. Most fish contained some ^{65}Zn above background levels, which suggests that ^{65}Zn is carried farther north than the plume appears to take it. The presence of fish with high levels of ^{65}Zn in the northern samples supports the thesis that a northward migration of Oregon-Washington juvenile coho occurs.

Introduction

Recent information on coho movement suggested that this species makes an extensive migration in the ocean. Evidence regarding movements of Oregon-Washington coho (*Oncorhynchus kisutch* Walbaum) was obtained from tagging fish at distant points and recovering them near their suspected stream of origin. Complementary evidence obtained by recognizing fish captured at distant points was needed. This study sought to recognize coho from the amount of the radionuclide zinc-65 (^{65}Zn) they contained and to identify coho captured on the high seas using this technique. The effort was successful in showing variation in the ^{65}Zn content between coho from different areas, but the statistical significance of the variation was not evaluated. The findings gave support to the concept that coho from the Oregon-Washington coasts make a circular trip around the Gulf of Alaska during their first year of ocean life.

It has been known for 40 years that some chinook originating in the Columbia River system migrate into the northern Gulf of Alaska. Coho from the same river system and from Oregon and Washington coastal streams were believed to have stayed in coastal waters adjacent to their natal area. Tagging and fin marking studies on adult coho led to these conclusions because distances from the point of tagging or the point of recovery of fin-marked coho in the ocean were seldom more than 200 to 300 miles from their stream of origin. The possibility that coho might be migrating extensively during their first 9-12 months in the ocean was not investigated.

Recovery off the Oregon coast in June 1959 of a coho tagged off Kodiak Island,

[1] A study conducted by the Oregon Fish Commission and funded in part by the Bureau of Commercial Fisheries under the Anadromous Fisheries Act, PL 89-304.

[2] Department of Oceanography, Oregon State University, Corvallis, Oregon.

Alaska, 10 months earlier provided the first suggestion of a longer coho migration (Hartt, 1966). This was followed by salmon distribution and abundance studies made by the Fisheries Research Board of Canada (FRBC) and the Fisheries Research Institute (FRI), University of Washington, throughout the waters of the eastern North Pacific (32°-59° N, and 125°-165° W) in the years 1961-66. Although other species of salmon were the primary target of the study, coho were taken in surprising numbers during March, April, and May between the 42nd and 47th parallels and west to 160° W longitude. Tagging demonstrated that coho originating all along the eastern rim of the Pacific were spread over vast areas of the eastern Pacific, often 300-600 miles at sea (Fisheries Research Board of Canada, 1967) (Figure 1). More recently tagging of juvenile coho caught from June to September of their first ocean year along the British Columbia and southeast Alaskan coasts has produced recoveries in the Oregon troll fishery and in the Columbia River (U.S. Bureau of Commercial Fisheries, 1967) (Figure 2).

Because coho captured in the ocean during their last summer of life are generally near their stream of origin, the evidence above suggests a migration that takes juvenile Oregon and Washington coho northward along the coast into the Gulf of Alaska by the end of the first ocean summer. This is followed by a southward movement to waters several hundred miles off Oregon and Washington) and finally by an eastward migration back to the coast during their last spring in the ocean. Such a migration pattern could explain the "sudden appearance" that coho characteristically make in the coastal troll fisheries each spring and the scarcity of coho of first ocean year age in the Oregon troll catches. It is also consistent with the suggested patterns of ocean migration for coho and other species of salmon advanced by Royce, Smith and Hartt (1968).

A need to explore the above hypothesis developed in 1966 with the announcement by the Republic of Korea of intent to conduct high seas salmon fishing (Anon., 1966). That country, without treaty bindings, could fish east of the 175° W. longitude line that limits the Japanese, and on stocks of salmon of unknown origin. The possibility of Oregon coho being taken was cause for concern. It would not have led to further study, though, had not a potential means for identifying Oregon-Washington coho been available and the opportunity to sample fish as part of an ongoing program been present. A further inducement to do the study during the 1967-69 period was the planned release in 1967 and 1968 of several million fin-marked 1965- and 1966-brood coho from hatcheries in Oregon and Washington, which provided an opportunity to study coho of known origin.

Methods

The radionuclide ^{65}Zn is brought to the ocean by the Columbia River from the Atomic Energy Commission plant at Hanford, Washington. Once in the ocean it is carried north with the Columbia River plume during the winter and spring months, and south during the summer and fall (Osterberg, Cutshall and Cronin, 1965). Organisms in the ocean between southern Vancouver Island and northern California are exposed to ^{65}Zn and accumulate the material by direct assimilation or by consumption of animals containing ^{65}Zn. The amount accumulated depends on the availability of ^{65}Zn, the time spent in the plume and the organism's need for zinc. Since Oregon-Washington coho generally enter the ocean while the plume is to the north, they could concentrate ^{65}Zn sufficiently to distinguish them from fish that were never in the Columbia River plume. Validation of this thesis was planned by sampling at two points in the ocean, viz., along the British Columbia-Southeast Alaska coast and in the high seas several hundred miles west of Oregon and Washington; however, the high seas sampling was not accomplished.

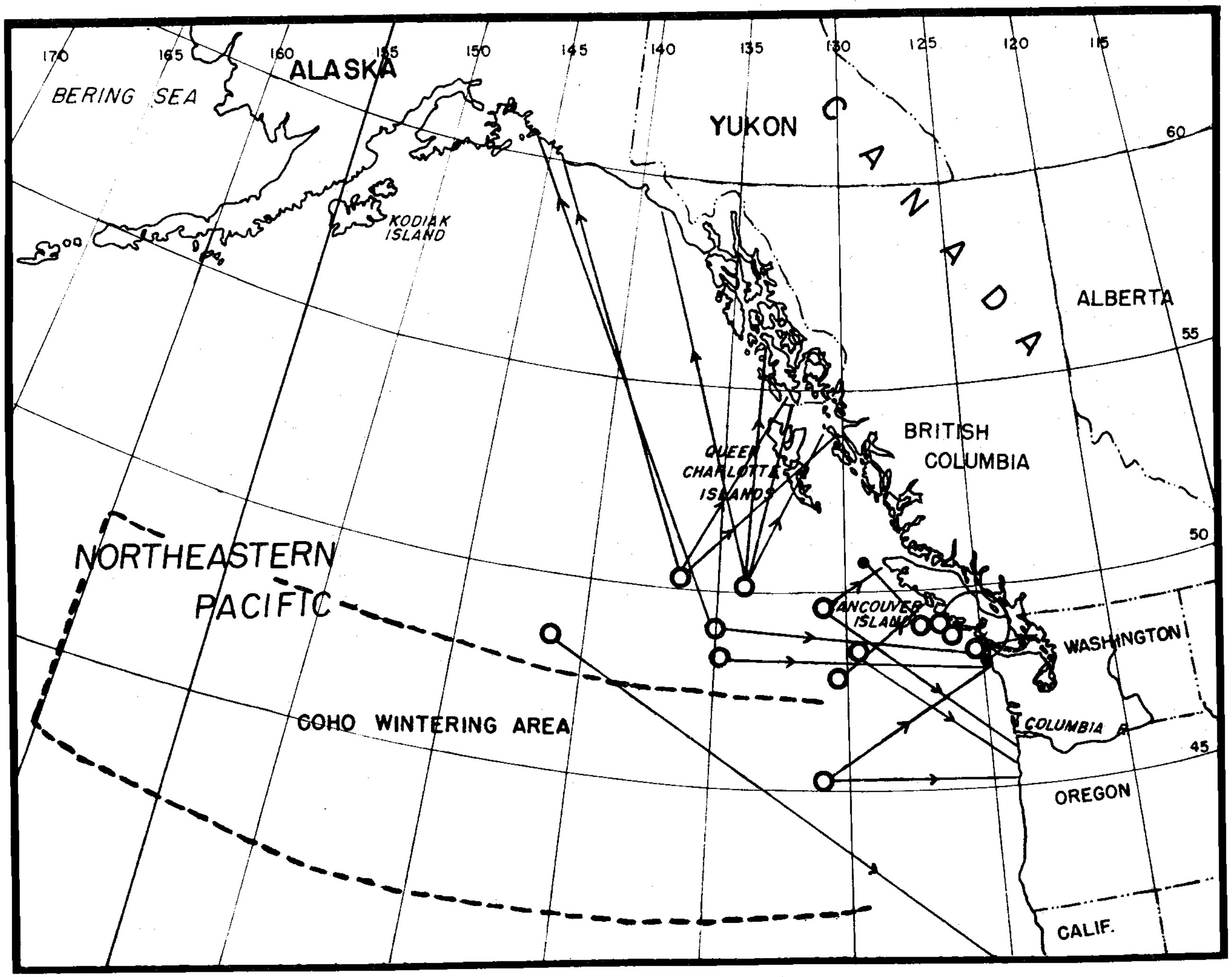


Figure 1. Northeast Pacific Ocean showing the points of tagging and recovery of coho on the high seas (1965) and the area of concentration of coho in late winter.

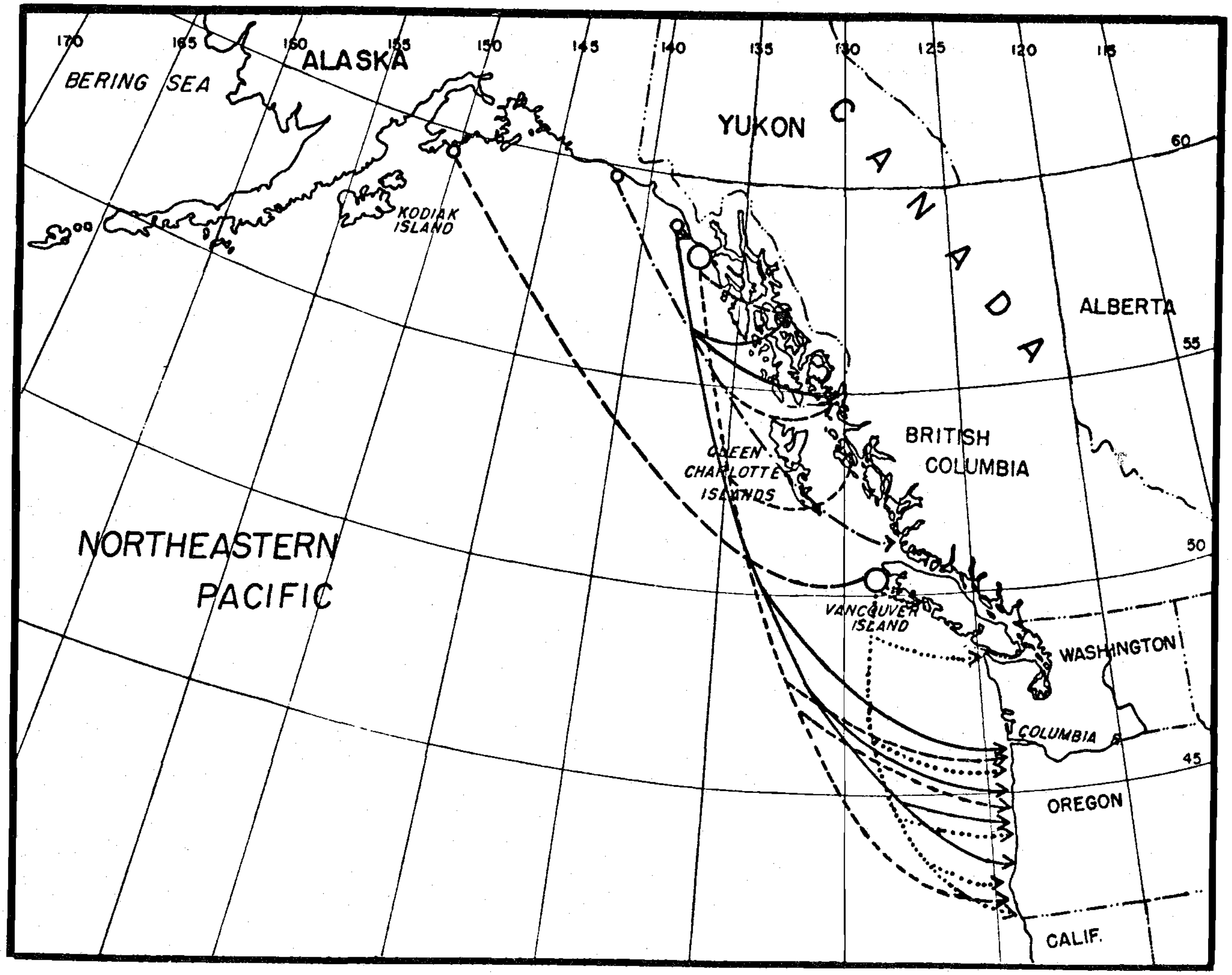


Figure 2. Northeast Pacific Ocean showing the points of tagging (1965) and recovery (1966) of juvenile coho.

Samples of juvenile coho salmon were provided by the FRI in 1967 and 1968. We requested 100 in 1967 and 200 in 1968 from their purse seine operations being carried out off British Columbia, and off the Gulf and Bering Sea shores of Alaska, to study the early ocean migrations of juvenile salmon of all species. In addition, all marked coho were to be kept for ^{65}Zn analysis. Larger samples were not requested due to limited time for analysis.

Sampling of maturing coho on the high seas was to be done by the FRBC, or the FRI, or both, had they continued high seas longline fishing in the area of interest. Unfortunately, the high seas longlining by both organizations was discontinued and examination of high-seas captured maturing coho was not possible.

Coho collected for radioanalysis were preserved in formalin and shipped to Astoria where, after removal of stomach contents, they were ground, dried to a constant weight, and charred. All fish were individually processed through ^{65}Zn analysis.

Evaluation of the ^{65}Zn activity was carried out by the Oregon State University Department of Oceanography, Radiobiology Section, following techniques described by Carey, Pearcy and Osterberg (1966). The charred material was ashed at 450° C and counted by Gamma-Spectroscopy. Counts were made for 100 minutes when ^{65}Zn was high and up to 400 minutes when it was low. All values obtained were adjusted to a standard counting time and corrected to time of collection for loss of activity due to decay (the half life of ^{65}Zn is 245 days).

Results

Sampling of juvenile coho during their first ocean summer fell short of design goals in both 1967 and 1968, and no samples were obtained from the high seas wintering area of coho. However, the fish provided by the FRI were sufficient in number and geographic distribution to permit a meaningful analysis.

Of the 212 coho received in 1967, 45 were analyzed for ^{65}Zn (Table 1). Those not used were in two large samples from which subsamples totalling 19 coho were drawn. The 1968 collection included 74 coho of which 20 carried assignable fin marks (Table 2).

Values for ^{65}Zn activity for the 1967 coho ranged from a low of 7 to 518 picocuries per gram ash (pCi/g ash). The 1968 samples, by contrast, had much lower activity levels ranging from 0.8 to 129.8 pCi/g ash, with the activity in only four fish exceeding 50 pCi/g ash. Stable zinc (^{64}Zn) levels, which indicate the fish's need for zinc, varied little by comparison. Over the 2 years, with the exception of one sample, they ranged from 893 to 2,359 micrograms per gram of ash for a variation of only 2.6 times.

The samples were grouped into 2° latitude intervals starting at 48° and going north. Variation both between and within groups was evident. In 1967 the highest values occurred in the "48°" collection, and activity in those fish having more than background① levels decreased with increasing latitude (Figure 3). Within-group variation great enough to suggest exposure difference was evident in the 48°, 54°, 56°, and 58° groups. Background levels of ^{65}Zn activity appeared to be less than 40, and possibly less than 20, pCi/g ash based on the portion of the samples (33%) with these comparatively low values.

The 1968 Gulf of Alaska samples presented a different but no less interesting picture than that observed in 1967. As mentioned, activity levels were generally in the range assigned as background in 1967. Variation in activity between samples was present but did not display the south to north decrease observed in 1967 (Figure 4). The "hottest" samples were collected at 53° latitude in June. Fish collected 1 month

① "Background" for the purposes of this paper refers to ^{65}Zn from all sources other than the Columbia River.

Table 1. Date and location of catch and ^{65}Zn activity for juvenile coho sampled during 1967①

Sample No.	Date	Location Long.	Location Lat.	^{65}Zn Picocuries/Gram of Ash	Stable Zinc Micrograms/Gram of Ash
B437	7/6	128° 16′ W	50° 26′ N	392	1,856
B438	7/6	128° 16′ W	50° 26′ N	385	2,033
B439	7/6	128° 16′ W	50° 26′ N	339	1,849
B440	7/14	132° 30′ W	54° 42′ N	186	1,847
B441	7/14	132° 30′ W	54° 42′ N	173	1,978
B442	7/20	137° 06′ W	58° 13′ N	23	2,359
B443	7/20	137° 06′ W	58° 13′ N	25	2,192
B444	7/20	137° 06′ W	58° 13′ N	24	1,980
B445	7/23	137° 33′ W	58° 24′ N	97	1,525
B446	7/23	137° 33′ W	58° 24′ N	140	1,759
B447	7/23	137° 33′ W	58° 24′ N	170	1,603
B448	7/24	136° 26′ W	57° 34′ N	231	1,633
B449	7/24	136° 26′ W	57° 34′ N	87	1,840
B450	7/24	136° 26′ W	57° 34′ N	207	1,947
B451	8/17	132° 11′ W	54° 32′ N	45	1,755
B451	8/22	135° 38′ W	56° 45′ N	216	1,752
B453	8/22	135° 38′ W	56° 45′ N	60	1,901
B454	8/28	136° 42′ W	57° 50′ N	28	1,510
B455	8/28	136° 42′ W	57° 50′ N	24	1,800
B456	9/1	136° 35′ W	56° 16′ N	149	1,150
B457	9/1	136° 55′ W	56° 16′ N	151	950
C4-1	6/15	127° 18′ W	49° 47′ N	434	2,074
C4-2	6/15	127° 18′ W	49° 47′ N	508	2,122
C4-3	6/15	127° 18′ W	49° 47′ N	505	2,264
C4-4	6/15	127° 18′ W	49° 47′ N	412	2,025
C4-5	6/15	127° 18′ W	49° 47′ N	490	2,181
C4-6	6/15	127° 18′ W	49° 47′ N	452	1,966
C4-7	6/15	127° 18′ W	49° 47′ N	513	2,164
C4-8	6/15	127° 18′ W	49° 47′ N	498	2,206
C4-9	6/15	127° 18′ W	49° 47′ N	442	1,993
C4-10	6/15	127° 18′ W	49° 47′ N	518	2,192
X57-1	8/27	137° 32′ W	58° 22′ N	132	1,262
X57-2	8/27	137° 32′ W	58° 22′ N	17	1,492
X57-3	8/27	137° 32′ W	58° 22′ N	22	1,926
X57-4	8/27	137° 32′ W	58° 22′ N	7	893
X57-5	8/27	137° 32′ W	58° 22′ N	10	1,093
X67-1	9/11	124° 02′ W	48° 14′ N	391	1,460
X67-2	9/11	124° 02′ W	48° 14′ N	278	936
X67-3	9/11	124° 02′ W	48° 14′ N	477	1,570
X67-4	9/11	124° 02′ W	48° 14′ N	317	1,260
X67-A	9/11	124° 02′ W	48° 14′ N	18	1,490
X67-B	9/11	124° 02′ W	48° 14′ N	17	1,320
X67-C	9/11	124° 02′ W	48° 14′ N	17	1,500
X67-D	9/11	124° 02′ W	48° 14′ N	15	1,280
X67-E	9/11	124° 02′ W	48° 14′ N	10	1,170

① ^{65}Zn values are for whole salmon less the digestive tract.

Table 2. Date and location of catch and ^{65}Zn activity for juvenile coho sampled during 1968[1]

Sample No.	Date	Location Long.	Location Lat.	^{65}Zn Picocuries/Gram of Ash	Stable Zinc Micrograms/Gram of Ash
X39-1	7/20	130° 23′ W	53° 42′ N	41.7	1,089
X39-2	7/20	130° 23′ W	53° 42′ N	39.3	1,193
X39-3	7/20	130° 23′ W	53° 42′ N	43.6	1,130
X39-4	7/20	130° 23′ W	53° 42′ N	114.4	1,151
X39-5	7/20	130° 23′ W	53° 42′ N	44.5	1,018
X39-6	7/20	130° 23′ W	53° 42′ N	31.5	1,203
X39-7	7/20	130° 23′ W	53° 42′ N	38.7	1,149
X39-8	7/20	130° 23′ W	53° 42′ N	129.8	1,041
X39-9	7/20	130° 23′ W	53° 42′ N	41.6	1,562
X39-10	7/20	130° 23′ W	53° 42′ N	45.3	1,548
X50-1	7/28	137° 02′ W	58° 17′ N	9.4	1,283
X50-2	7/28	137° 02′ W	58° 17′ N	7.2	1,278
X50-3	7/28	137° 02′ W	58° 17′ N	17.7	1,303
X50-4	7/28	137° 02′ W	58° 17′ N	7.1	1,642
X50-5	7/28	137° 02′ W	58° 17′ N	20.7	1,337
X50-6	7/28	137° 02′ W	58° 17′ N	12.1	1,288
X50-7	7/28	137° 02′ W	58° 17′ N	7.3	1,255
X50-8	7/28	137° 02′ W	58° 17′ N	9.8	1,478
X50-9	7/28	137° 02′ W	58° 17′ N	19.1	1,253
X50-10	7/28	137° 02′ W	58° 17′ N	5.3	1,095
X51	8/1	137° 04′ W	58° 13′ N	93.6	1,405
X55	8/6	135° 00′ W	56° 17′ N	6.1	1,899
X57	8/8	132° 33′ W	54° 42′ N	128.9	21,571
X61	8/11	124° 34′ W	48° 32′ N	24.5[2]	1,651
X64-1	8/12	124° 28′ W	48° 21′ N	15.7[2]	1,377
X64-2	8/12	124° 28′ W	48° 21′ N	22.4[2]	1,698
X64-3	8/12	124° 28′ W	48° 21′ N	20.9[2]	1,532
X65-1	8/13	124° 21′ W	48° 18′ N	9.1[2]	1,347
X65-2	8/13	124° 21′ W	48° 18′ N	17.8[2]	1,521
X65-3	8/13	124° 21′ W	48° 18′ N	14.4	1,583
X65-4	8/13	124° 21′ W	48° 18′ N	27.1[2]	1,424
X65-5	8/13	124° 21′ W	48° 18′ N	12.9[2]	1,321
X65-6	8/13	124° 21′ W	48° 18′ N	15.0	1,059
X65-7	8/13	124° 21′ W	48° 18′ N	14.9	1,454
X65-8	8/13	124° 21′ W	48° 18′ N	14.7	1,803
X65-9	8/13	124° 21′ W	48° 18′ N	8.2	1,462
X65-10	8/13	124° 21′ W	48° 18′ N	19.6	1,516
X67-1	8/14	124° 24′ W	48° 19′ N	14.4[2]	1,410
X67-2	8/14	124° 24′ W	48° 19′ N	12.6[2]	1,138
X67-3	8/14	124° 24′ W	48° 19′ N	8.2[2]	1,298
C69+70-1	8/18	161° 16′ W	56° 22′ N	2.5	1,168
C69+70-2	8/18	161° 16′ W	56° 22′ N	3.4	1,163
C69+70-3	8/18	161° 16′ W	56° 22′ N	1.6	1,075

Table 2. Continued

Sample No.	Date	Location		^{65}Zn	Stable Zinc
		Long.	Lat.	Picocuries/Gram of Ash	Micrograms/Gram of Ash
C69+70-4	8/18	161° 16′ W	56° 22′ N	1.1	1,062
C69+70-5	8/18	161° 16′ W	56° 22′ N	1.3	1,189
C69+70-6	8/18	161° 16′ W	56° 22′ N	0.8	1,146
C69+70-7	8/18	161° 16′ W	56° 22′ N	1.4	1,021
C69+70-8	8/18	161° 16′ W	56° 22′ N	0.3	1,153
C69+70-9	8/18	161° 16′ W	56° 22′ N	3.0	1,147
C69+70-10	8/18	161° 16′ W	56° 22′ N	2.0	1,286
X71-1	8/22	124° 31′ W	48° 22′ N	17.5	1,584
X71-2	8/22	124° 31′ W	48° 22′ N	19.7②	1,666
X71-3	8/22	124° 31′ W	48° 22′ N	17.4②	1,439
X71-4	8/22	124° 31′ W	48° 22′ N	22.9②	1,316
X71-5	8/22	124° 31′ W	48° 22′ N	20.3②	1,641
X71-6	8/22	124° 31′ W	48° 22′ N	29.0②	1,359
X72-1	8/23	124° 24′ W	48° 19′ N	14.5	1,798
X72-2	8/23	124° 24′ W	48° 19′ N	12.6②	1,553
X72-3	8/23	124° 24′ W	48° 19′ N	16.3②	1,561
X72-4	8/23	124° 24′ W	48° 19′ N	15.1	1,611
X72-5	8/23	124° 24′ W	48° 19′ N	19.4②	1,584
X72-6	8/23	124° 24′ W	48° 19′ N	12.5②	1,771
X80-1	9/2	135° 10′ W	56° 32′ N	44.1	1,429
X80-2	9/2	135° 10′ W	56° 32′ N	12.2	1,163
X80-3	9/2	135° 10′ W	56° 32′ N	31.7	1,234
X80-4	9/2	135° 10′ W	56° 32′ N	7.7	1,192
X83-1	9/9	137° 00′ W	58° 14′ N	11.7	2,055
X83-2	9/9	137° 00′ W	58° 14′ N	41.9	1,680
X95-1	9/30	135° 25′ W	58° 14′ N	4.0	1,420
X95-2	9/30	135° 25′ W	58° 14′ N	6.2	1,095
X100	10/5	132° 33′ W	54° 42′ N	13.4	1,562
X101-1	10/6	132° 34′ W	54° 42′ N	10.6	1,441
X101-2	10/6	132° 34′ W	54° 42′ N	9.0	1,600
X101-3	10/6	132° 34′ W	54° 42′ N	11.1	1,675

① ^{65}Zn values are for whole salmon less the digestive tract.

② This fish carried a double fin mark of Puget Sound origin.

later at 48° had activity levels only about half as great as the 53° collection and not much higher than the values observed at 58° latitude. Variation in activity again occurred within latitude groupings. Four coho had activity levels considerably higher than the rest. The tentative upper limit to background ^{65}Zn activity based on the Gulf of Alaska samples alone was similar to 1967. Bering Sea coho provide an alternate means of evaluation that suggests the upper limit may be no more than 4 pCi/g ash.

Marked fish were present in 1968 only. Those sampled were all from Washington's Puget Sound hatcheries and were taken near the western end of Juan de Fuca Strait. The activity levels were similar to unmarked coho in the same sample (Figure 4, shaded bars).

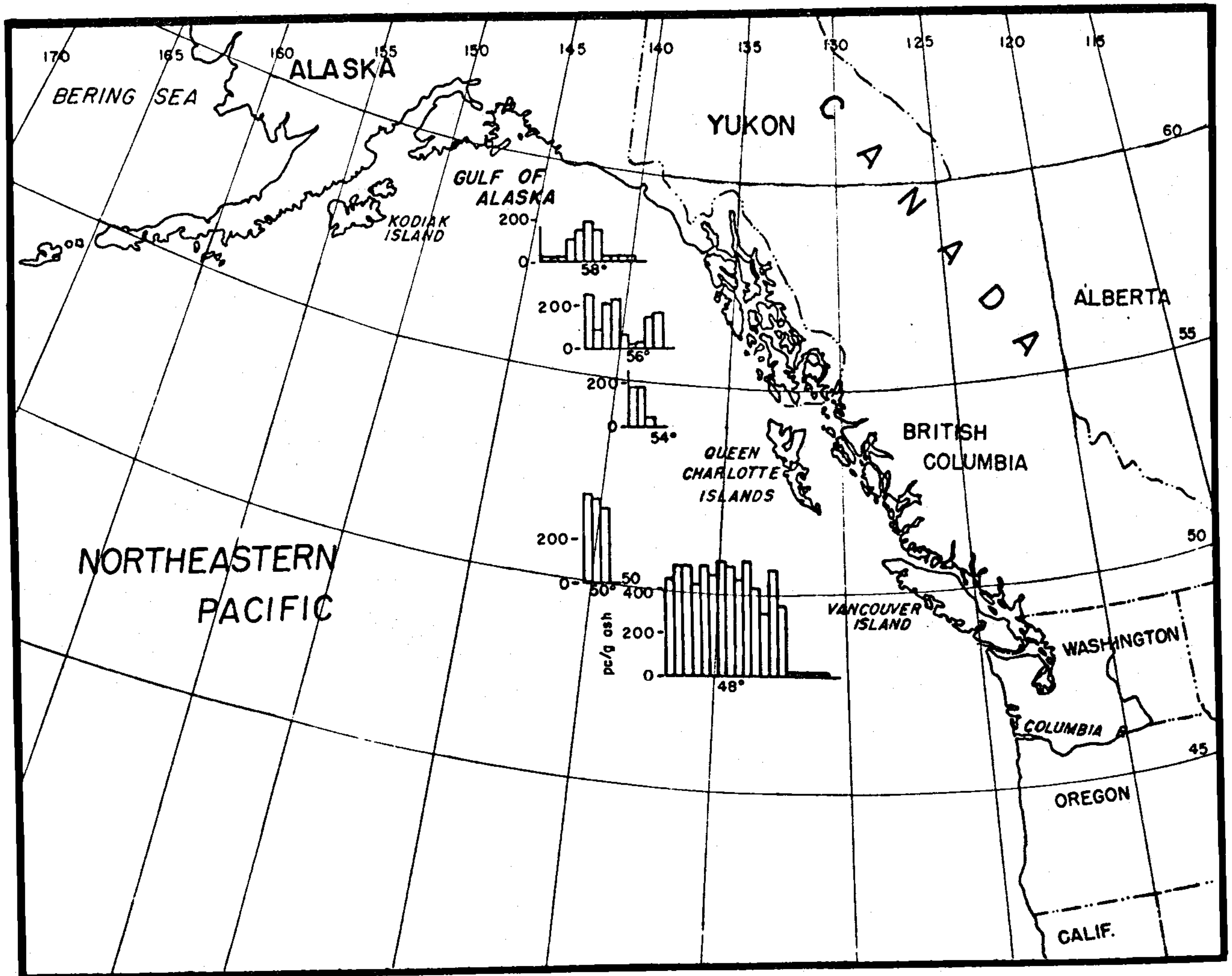


Figure 3. General collection latitude and Zinc-65 activity levels observed for juvenile coho from the Northeast Pacific, 1967.

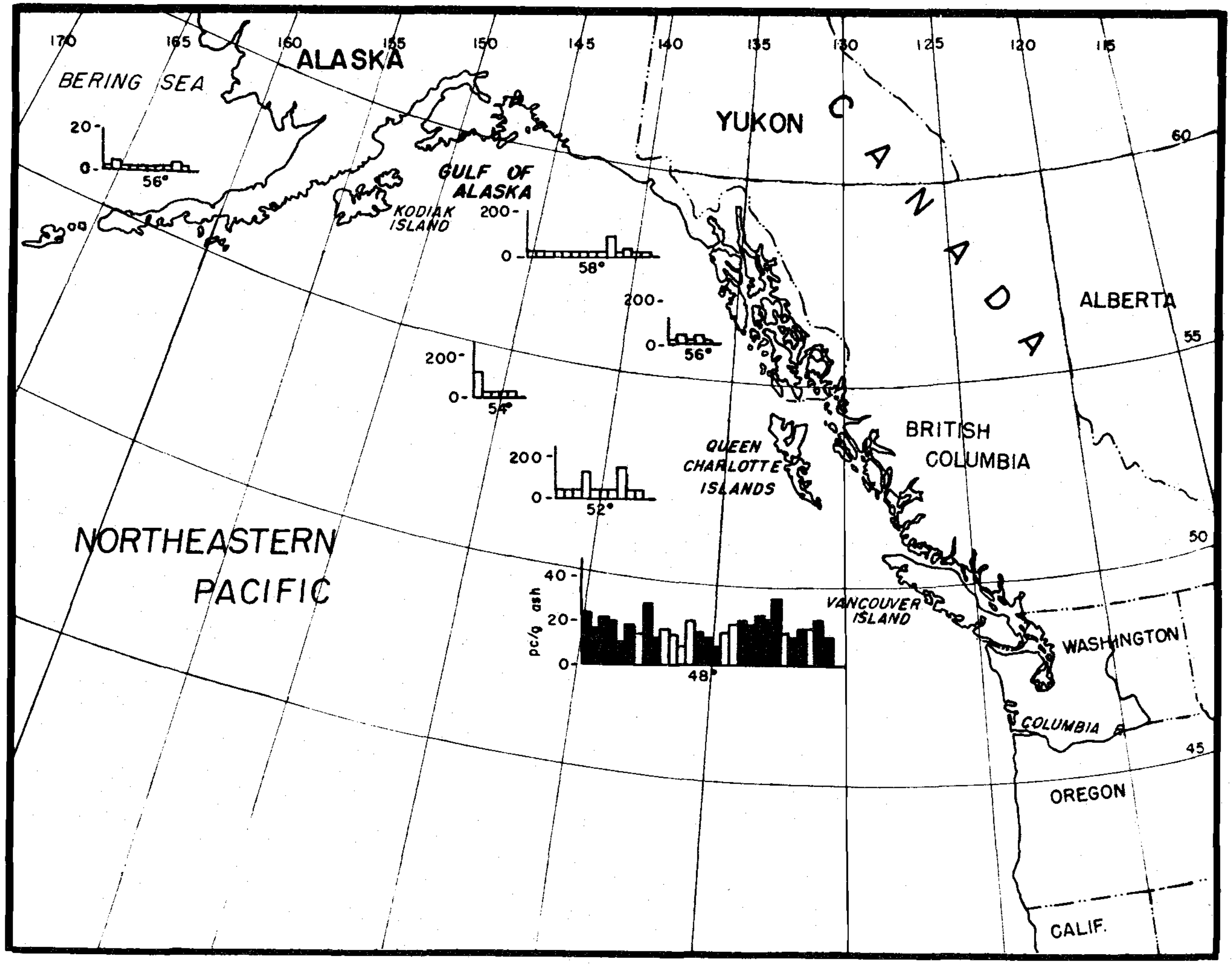


Figure 4. General collection latitude and Zinc-65 activity levels observed for juvenile coho from the Northeast Pacific, 1968.
(Shaded bars indicate fin-marked fish)

Discussion

Since Hanford debris is not the only source of radioactive contamination in the ocean, it is possible for coho living beyond the Columbia River plume influence to obtain ^{65}Zn. The amount of activity coho accumulate from non-Hanford sources, which we are calling "background" activity, must be estimated before the usefulness of ^{65}Zn in identifying Oregon-Washington coho can be stated.

As mentioned, the 1967 collection contained several fish with comparatively low levels of activity (7 to about 40 pCi/g ash). Because of the marked difference in activity between these coho and the remainder of the samples, and because this difference was observed primarily in the northern groups, it appears that the coho involved originated north of the influence of the Columbia plume. As such they should provide a measure of background ^{65}Zn activity. However, the Bering Sea samples obtained in 1968 had activity levels of 0.8 to 3.4 pCi/g ash which is considerably lower than those just discussed (Figure 4). Because of the remoteness of this collection area relative to the Columbia River plume, and because the demand for zinc by the fish in this group as indicated by ^{64}Zn levels was similar to that of fish from the northern Gulf of Alaska, these values are a better indication of background activity than that provided by the coho taken in the Gulf of Alaska. Accordingly, the Gulf-caught coho with low activity values, even though far removed from the measured flow of the Columbia plume, must be acquiring Hanford produced ^{65}Zn. Data presented by Kujala (1966, M.S. thesis) on adult chum (*O. keta*) and pink salmon (*O. gorbuscha*) show a similar relationship between ^{65}Zn activity in fish taken in the Chukchi Sea and the Gulf of Alaska. From this information, background levels of ^{65}Zn in coho appear to be less than 4 pCi/g ash and to exist only in the Bering Sea stocks of North American coho, making them separable from the Gulf of Alaska fish.

The five coho included in the 1967 48° group with ^{65}Zn activity levels, averaging about 1/20th as high as the rest of the group, merit comment. The great difference suggests that they are spurious, but this could not be substantiated. Another explanation is that they may represent Puget Sound-Strait of Georgia fish that remained in inside waters until well after the Columbia plume turned south. The 1968 data included values for 29 coho captured in August within a few miles of the collection site of the five coho in question. Twenty-two of these coho carried fin marks showing that they came from Puget Sound. Zinc-65 activity was about the same for marked and unmarked fish and equal to that observed in the five 1967 coho. Thus, it seems likely that the fish collected at the west end of Juan de Fuca Strait in both 1967 and 1968 that had values of about 30 pCi/g ash or less were fish originating in the Puget Sound-Strait of Georgia area. The capture of these fish in August and September is compatible with the suspected outmigration timing of part. of the semi-resident Puget Sound coho.

The absence of fin marked fish from the northern collecting areas was both surprising and disappointing. The large number of 1965- and 1966-brood Oregon and Washington coho that were marked was a prime justification for conducting this study during the 1967 and 1968 field seasons. Failure to obtain valid fin marked fish cost us the opportunity to work with fish of known origin when assigning activity levels to Oregon-Washington coho.

With consideration of the foregoing, the following interpretation of the data is offered. Samples collected in 1967 at 48° latitude show high levels of ^{65}Zn activity, and variation in activity within the samples is small compared to the 54° to 58° groups. These fish probably originated from areas south of the Fraser River, i.e., Oregon and Washington. Much greater variation is evident in the 54° to 58° groups. As mentioned, the lower values are thought to represent fish of northern origin. The remainder of the coho in these groups with their higher activity levels must have been in the plume and are probably of southern origin. The observed decrease in activity levels by latitude could be compared against a closely calculated decrease from a base of about 400 pCi/g ash if migration rate and time of ocean entry were better understood. From what is known, 1 to 4 months is needed for coho to move from the southern to the northern sampling areas. If these times for migration are related to the "effective half-life" for ^{65}Zn in coho, which may be similar to that for rainbow trout—4.5 months—(Nakatani, 1966), a decrease in activity of 10% to 40% would be expected. The observed decrease in activity from the 48° sample to the 56° and 58° samples is about 65%.

The 1968 data while having a different time-area distribution than those for 1967 are in general agreement with them. Thirty-five coho were analyzed from the 52° to 58° groups and, like 1967, activity values fell into two groups pointing to the presence of fish from two different origins. Unlike 1967, the lower values, interpreted to be coho of northern origin, were the most abundant in 1968. Samples were not obtained in June at 48° and 50° to compare with the high values observed in 1967. The absence of these samples to serve as a base for comparison prevents an evaluation of the higher activity values in the 52° to 58° samples, as was possible with the 1967 data.

An original intent of this study was to obtain coho from the "high seas" wintering areas west of Oregon and Washington for ^{65}Zn analysis, but this was not possible. However, we can estimate the levels of activity that could be expected there based on observed values from coho collected earlier inshore. Doing so would pose no problem if the physical decay rate of ^{65}Zn were the only consideration, but biological elimination also reduces activity. Nakatani (1966) studied the combined effect of both factors on the activity levels in rainbow trout and concluded that the effective half-life of ^{65}Zn in rainbow was 19 weeks or 4.5 months. By applying this rate, in the absence of similar data for coho, to the 1967 and 1968 data with a time lag of 6 months, estimates of March-April levels can be obtained.

The lowest values observed in Gulf of Alaska fish were between 5 and 10 pCi/g ash. Using 7 as a median value, a 6-month "decay" would reduce activity by 1.33 half-lives or to about 2.5 pCi/g ash, which is essentially the same as expected background levels. However, many of the coho that were considered to be of northern origin had activity values of 10 to 40 pCi/g ash, which is, at this rate of decay, sufficiently high to permit separation 6 months later from background level activity of 1-3 pCi/g ash. This being the case, coho with much higher activity levels that originated from the Oregon-Washington area would certainly be identifiable.

The observations of Kujala (1966, M.S. thesis) noted previously on pink and chum salmon, and the general similarity in feeding and migrating habits between these species and coho, suggests that levels of ^{65}Zn activity might be used to separate stocks of chums and pinks. Since these data point to a transport of Columbia River ^{65}Zn into the Northwestern Gulf of Alaska, even stocks of salmon originating there might be discernible on the high seas by their ^{65}Zn content from fish originating farther west where less influence of the Columbia River should be felt.

Conclusions

1. Background levels of ^{65}Zn activity for coho are low, probably about 1 to 3 pCi/g ash.
2. Coho using the coastal waters from Cook Inlet, Alaska, to Oregon currently have sufficient intake of Hanford produced ^{65}Zn to develop activity levels at least several times higher than background levels.

3. Further study of the change in amount of ^{65}Zn in coho with time and space should demonstrate that (1) different groups of North American coho can be identified by their ^{65}Zn content and (2) that most coho originating in northeastern Pacific streams can be separated from Bering Sea fish using levels of ^{65}Zn activity as the identifying mechanism even when captured on the high seas.
4. The possibility exists that species of salmon from Alaska and British Columbia streams, other than coho, accumulate sufficient ^{65}Zn to separate them from Western Pacific and Bering Sea stocks.
5. This work was not conclusive regarding migratory patterns of coho but did support the concept of a northerly migration of juvenile coho from Oregon and Washington.

Acknowledgments

As indicated, this study was undertaken because three research entities were sufficiently interested to give time and materials to it. While the agencies have been recognized, individuals have not. Those who contributed greatly to the program's success include: Messrs. Allan Hartt and Michael Dell of the Fisheries Research Institute, University of Washington, who provided the samples under a program funded by the U. S. Bureau of Commercial Fisheries, used in the study; Dr. Charles Osterberg and Mr. Norman Kujala of the Department of Oceanography, Oregon State University, who provided for the ^{65}Zn analysis and gave counsel on program design; and Mr. Robert McQueen of the Fish Commission of Oregon, who prepared the samples for analysis.

Literature Cited

Anonymous. 1966. Will Korea Fish Salmon in 1967? Pac. Fish. 64(10):12 Oct. 1966.

Carey, A. G., W. G. Pearcy and C. L. Osterberg. 1966. Artificial Radionuclides in Marine Organisms in the Northeast Pacific Ocean. Symposium on Disposal of Radioactive Wastes in the Seas, Oceans and Surface Waters. Int. At. Ener. Agcy., Vienna 1966:303-319.

Fisheries Research Board of Canada. 1967. Progress in 1965 in Canadian Research on problems Raised by the Protocol. Ann Rep. Int. No. Pac. Fish. Comm. 1965.

Hartt, Allan C. 1966. Migrations of Salmon in the North Pacific Ocean and Bering Sea as Determined by Seining and Tagging. Bull. Int. No. Pac. Fish. Comm. (19):79-81.

Hartt, A. C., L. S. Smith, M. B. Dell and R. V. Kilambi. 1967. Tagging and Sampling; *In* Report on the Investigations by the United States for the International North Pacific Fisheries Commission—1966. Ann. Rep. Int. No. Pac. Fish. Comm. 1966.

Kujala, Norman F. 1966. Artificial Radionuclides in Pacific Salmon. Dept. of Oceanography. Unpublished M.S. thesis. Oregon State University, Corvallis.

Nakatani, R. E. 1966. Biological Response of Rainbow Trout (Salmo gairdneri) ingesting Zinc-65. Symposium on Disposal of Radioactive Wastes in the Seas, Oceans and Surface Waters. Int. At. Ener. Agcy., Vienna 1966:809-823.

Osterberg, C. L., N. Cutshall and J. Cronin. 1965. Chrome-51 as a Radioactive Tracer of Columbia River Water at Sea. Science 150 (3703):1585-1587. Dec. 1965.

Royce, William F., Lynwood S. Smith and Allan C. Hartt. 1968. Models of Oceanic Migrations of Pacific Salmon and Comments on Guidance Mechanisms. U. S. Bur. Comm. Fish., Fish. Bull. 66(3):441-462.

The following publications have been derived from Atomic Energy Commission contract AT(45-1)1750 or its successor AT(45-1)2227 Task Agreement 12.

Research Articles

Beasley, T. M., and C. L. Osterberg. 1969. Spontaneous deposition of lead on silver and nickel from organic and inorganic digests. Analytical Chem. 41:541-543. (RLO-1750-72)

Brownell, C. A. and J. E. McCauley. 1971. Two new gregarine parasites from the spatangoid urchin Brisaster latifrons. Zool. Anz. 186:191-197. (RLO-1750-59)

Carey, A. G., Jr. 1965. Preliminary studies on animal-sediment interrelationships of the Central Oregon Coast. In Trans. of the Symposium on Ocean Science and Engineering 1:100-110. (RLO-1750-2)

Carey, A. G., Jr. 1966. Studies on the ecology of benthic invertebrate fauna in the Northeast Pacific Ocean off Oregon, U.S.A., p. 36. In Abstracts of Papers, Proc. 11th Pac. Sci. Congr., (Tokyo), Vol. II, Sci. Counc. Japan, Tokyo.

Carey, A. G., Jr. 1968. Zinc-65 in echinoderms and sediments in the marine environment off Oregon. Proc. Second Nat. Radioecol. Symp. Conf. 6705-03, p. 380-388. (RLO-1750-20)

Carey, A. G., Jr. (in press) Zinc-65 in benthic invertebrates of the Oregon Coast. In Bioenvironmental Studies of the Columbia River Estuary and Adjacent Ocean Region. A. T. Pruter and D. L. Alverson, Eds. Seattle, University of Washington Press. (RLO-1750-55)

Carey, A. G., Jr. (in press) Ecological observations on the benthic invertebrates from the central Oregon continental shelf. In Bioenvironmental Studies of the Columbia River Estuary and Adjacent Ocean Region, A. T. Pruter, and D. L. Alverson, eds. Seattle, University of Washington Press. (RLO-1750-57)

Carey, A. G., Jr. (in manuscript) A comparison of benthic infaunal abundance on two abyssal plains in the northeast Pacific Ocean. (RLO-1750-67)

Carey, A. G., Jr. (in manuscript) Food sources of sublittoral, bathyal, and abyssal asteroids in the northeast Pacific Ocean off Oregon (RLO-2227-T12-13)

Carey, A. G., Jr. and D. R. Hancock. 1965. An anchor-box dredge for deep sea sampling. Deep Sea Res. 12(6):983-984.

Carey, A. G., Jr. and H. Heyomoto (in press) Techniques and equipment for sampling benthic organisms. In Bioenvironmental Studies of the Columbia River Estuary and Adjacent Ocean Region, A. T. Pruter and D. L. Alverson, eds. Seattle, University of Washington Press (RLO-1750-58)

Carey, A. G., Jr., W. C. Pearcy, and C. L. Osterberg. 1966. Artifical radionuclides in marine organisms in the northeast Pacific ocean off Oregon. Disposal of radioactive wastes into seas, oceans, and surface waters. International Atomic Energy Agency, (Vienna), p. 303-319. (RLO-1750-3)

Carey, A. G., Jr., R. R. Paul. 1968. A modification of the Smith-McIntyre grab for simultaneous collection of sediment and bottom water. Limnol. Oceanogr. 13(3):545-549. (RLO-1750-24)

Cross, F. A., J. M. Dean, C. L. Osterberg. 1969. The effect of temperature, sediment, and feeding upon the behavior of four radionuclides in a marine benthic amphipod. Proc. Sec. Nat. Symp. Radioecol. Conf. 6705-03, p. 450-461. (RLO-1750-18)

Cross, F. A., S. W. Fowler, J. M. Dean, L. F. Small and C. L. Osterberg. 1968. The distribution of ^{65}Zn in tissues of two small marine crustaceans determined by autoradiography. J. Fish. Res. Bd. Canada 25(11): 2461-2466. (RLO-1750-71)

Cross, F. A. and L. F. Small. 1967. Copepod indicators of surface water movements off the Oregon Coast. Limn. and Ocean. 12:60-72.

Curl, H. J., N. Cutshall, and C. Osterberg. 1965. Uptake of chromium (III) by particles in seawater. Nature 205(4968):275-276.

Cutshall, N., V. Johnson, and C. Osterberg. 1966. Chromium-51 in seawater: chemistry. Science 152:202-203. (RLO-1750-5)

Cutshall, N., and C. Osterberg. 1964. Radioactive particle in sediment from the Columbia River. Science. 144(3618):536-537.

Cutshall, N., W. C. Renfro, D. W. Evans, and V. G. Johnson. 1971. Zinc-65 in Oregon-Washington continental shelf sediments. Third Symposium on Radioecology. Oak Ridge, Tennessee. 10-12 May 1971 (in press) (RLO-2227-T12-4)

Donaldson, H. A. and W. G. Pearcy. (in press) Sound scattering layers off the Oregon Coast. Deep Sea Research. (RLO-1750-62)

Eagle, R. J. 1969. First records from the northeastern Pacific of the deep-sea ophidioid fish Parabassogigas grandis. J. Fish. Res. Bd. Canada 26:1680-1685. (RLO-1750-38)

Forster, W. O. (in press) Radionuclide distribution in the Columbia River and adjacent Pacific shelf sediments. In Bioenvironmental Studies of the Columbia River Estuary and Adjacent Ocean Region. A. T. Pruter and D. L. Alverson, eds. Seattle, University of Washington Press. (RLO-1750-49).

Forster, W. O. (in press) Radioactivity and stable nuclides in the Columbia River and adjacent northeast Pacific Ocean. In Bioenvironmental Studies of the Columbia River Estuary and Adjacent Ocean Region. A. T. Pruter and D. L. Alverson, eds. Seattle, University of Washington Press. (RLO-1750-60)

Griggs, G. B., A. G. Carey, Jr., and L. D. Kulm. 1969. Deep-sea sedimentation and sediment fauna interaction in Cascadia Channel and on Cascadia Abyssal Plain. Deep-Sea Research. 16:157-170. (RLO-1750-26)

Gross, M. G., A. Carey, G. Fowler, and L. D. Kulm. (in press) Distribution of organic carbon in surface sediments, Northeast Pacific Ocean. In Bioenvironmental Studies of the Columbia River Estuary and Adjacent Ocean Region. A. T. Pruter and D. L. Alverson, eds. Seattle, University of Washington Press. (RLO-1750-27)

Haertel, L., and C. Osterberg. 1967. Ecology of zooplankton, benthos, and fishes in the Columbia River estuary. Ecology 48(3):459-472. (RLO-1750-6)

Haertel, L. S., C. L. Osterberg, H. Curl, Jr. and P. K. Park. 1969. Nutrient and Plankton ecology of the Columbia River estuary. Ecology 50: 962-978. (RLO-1750-77)

Hansen, P. J. and W. O. Forster. 1969. Measurement of Columbia River flow time from Hanford's reactors to Astoria, Oregon---Summer 1966. Water Resources Research 5:1129-1131. (RLO-1750-47)

Holton, R., W. O. Forster, and C. L. Osterberg. 1971. The effect of gamma irradiation on the reproductive performance of Artemia as determined by individual pair matings. Proc. Third Symposium on Radioecology, Oak Ridge Tennesee. 10-12 May 1971. (in press) (RLO-1750-88)

Holton, R., W. O. Forster, and C. L. Osterberg. 1971. The effects of gamma irradiation on the maintenance of population size in the brine shrimp Artemia. Proc. Third Symposium on Radioecology. Oak Ridge, Tennessee. 10-12 May 1971 (in press) (RLO-1750-89)

Hubbard, L. T. and W. G. Pearcy. (in press) Geographic distribution and relative abundance of the Salpidae off the Oregon Coast. Limnology and Oceanography. (RLO-1750-64)

Jennings, D., N. Cutshall, and C. Osterberg. 1965. Detection of gamma-ray emission in sediments in situ. Science 148(3672):948-950.

Jennings, C. D., and C. L. Osterberg. 1969. Sediment radioactivity in the Columbia River Estuary. Proc. Sec. Nat. Radioecol. Symp. Conf. 6705-03, p. 300-306. (RLO-1750-21)

Jennings, C. D. and C. L. Osterberg. 1971. Specific activity of ^{55}Fe in Pacific salmon. Third Symposium on Radioecology, Oak Ridge, Tennesee. 10-12 May 1971. (in press) (RLO-1750-86)

Johnson, V., N. H. Cutshall, and C. L. Osterberg. 1967. Retention of zinc-65 by Columbia River water. Water Resources Res. 3(1):99-102. (RLO-1750-7)

Kujala, N. F., I. L. Larson, and C. L. Osterberg. 1969. Radioisotope measurements in Pacific Salmon. Proc. Sec. Nat. Symp. Radioecol. Conf. 6705-03. p. 440-449. (RLO-1750-14)

Kyte, M. A. (in manuscript) Recent Ophiuroidea occurring off Oregon, U.S.A. (RLO-2227-T12-12)

Kyte, M. A. (in manuscript) A redescription of *Ophiacantha rhachophora* Clark and a description of [redacted] sp. n. (Echinodermata: Ophiuroidea) (RLO-2227-T12-11)

Larsen, I. L., W. C. Renfro and N. Cutshall. 1971. Zinc-65 specific activity in *Mytilus californianus* tissues. Proc. Third Symposium on Radioecology, Oak Ridge, Tennessee. 10-12 May 1971 (in press) (RLO-2227-T12-5)

Laurs, R. M. and J. E. McCauley. 1964. A new acanthocephalan from the Pacific Saury. J. Parasitol. 50: 569-571.

Loeffel, R. E. and W. O. Forster. 1970. Determination of movement and identity of stocks of Coho salmon in the ocean using the radionuclide zinc-65. Research Reports of the Fish Commission of Oregon 2:1-13. (RLO-1750-87)

McCauley, J. E., 1967. Status of the Heart Urchin, *Brisaster latifrons*. J. Fish. Res. Bd. Canada. 24: 1377-1384. (RLO-1750-11)

McCauley, J. E. (in press) A preliminary checklist of selected groups of invertebrates from otter trawl collections off Oregon. In. Bio-environmental Studies of the Columbia River Estuary and Adjacent Ocean Regions. A. T. Pruter and D. L. Alverson, eds. Seattle, University of Washington Press. (RLO-1750-39).

McCauley, J. E. and A. G. Carey, Jr. 1967. Echinoidea of Oregon. J. Fish. Res. Bd. Canada. 24(6):1385-1401. (RLO-1750-12)

McCauley, J. E., M. A. Kyte, D. L. Stein and A. G. Carey, Jr. (in manuscript) Biological fouling on TOTEM-1, a deep-sea spar buoy. (submitted for publication to Fish. Res. Bd. of Canada) (RLO-2227-T12-8)

McCormick, J. M. 1965. Some aspects of the ecology of hydroids off the Oregon Coast. Northwest Science 39:139-147.

Neal, V. T. (in press) Physical aspects of the Columbia River estuary. In Bioenvironmental Studies of the Columbia River Estuary and Adjacent Ocean Region. A. T. Pruter and D. L. Alverson, eds. Seattle, University of Washington Press. (RLO-1750-40)

Osterberg, C. 1962. Fallout radionuclides in euphausiids. Science, 138 (3539):529-530.

Osterberg, C. 1962. Zinc-65 in slaps and euphausiids, Limnol. Oceanog., 7:478.

Osterberg, C. 1963. The effluent of the Columbia River as a source of radioactivity (abstract). Trans. Am. Geophys. Union 44:212-123.

Osterberg, C. 1968. Radioactivity from the Columbia River. Oc. Sci, and Oc. Engr. Symposium, 2:968-979. (RLO-1750-1)

Osterberg, C., A. G. Carey, Jr., and H. Curl, Jr. 1963. Acceleration of sinking rates of radionuclides in the ocean. Nature (200):1276-1277.

Osterberg, C. L., A. G. Carey, Jr., and W. G. Pearcy. 1966. Artificial radionuclides in marine organisms in the Northeast Pacific Ocean off Oregon, U.S.A. In Abstracts of Papers, No. 320, Symp. IV. Second International Oceanographic Congress, Moscow, USSR. p. 275-276.

Osterberg, C., N. Cutshall, and J. Cronin. 1965. Chromium-51 as a radioactive tracer of Columbia River at sea. Science 150 (3703):1585-1587.

Osterberg, C. L., N. Cutshall, V. Johnson, J. Cronin, D. Jennings, and L. Frederick. 1966. Some non-biological aspects of Columbia River radioactivity. Disposal of Radioactivity Wastes into Seas, Oceans and Surface Waters. International Atomic Energy Agency (Vienna). p. 321-335. (RLO-1750-4)

Osterberg, C., L. D. Kulm, and J.V. Byrne: 1963. Gamma emitters in marine sediments near the Columbia River. Science. 139: 916-917.

Osterberg, C., J. Pattullo and W. Pearcy. 1964. Zinc-65 in euphausiids as related to Columbia River water off the Oregon coast. Limnology and Oceanography. 9(2):249-257.

Osterberg, C., W. G. Pearcy, and H. Curl, Jr. 1964. Radioactivity and its relationship to the oceanic food chains. J. Mar. Res. 22(1):1-12.

Osterberg, C. L., W. G. Pearcy and N. Kujala. 1964. Gamma emitters in a fin whale. Nature. 204:1006-1007.

Osterberg, C. L. and R. Perkins. (in press) Methods for the measurement of Hanford-induced radioactivity in the ocean. In Bioenvironmental Studies of the Columbia River Estuary and Adjacent Ocean Region. A. T. Pruter and D. L. Alverson, eds. Seattle, University of Washington Press. (RLO-1750-70)

Osterberg, C., L. Small, and L. Hubbard. 1963. Radioactivity in large marine plankton as a function of surface area. Nature 197(4870):883-884.

Park, K. 1964. Electrolytic conductance of seawater: effect of calcium carbonate dissolution. Science. 146(3640):56-57.

Park, K. 1966. Columbia River plume identification by specific alkalinity. Limnol. and Oceanogr. 11(1): 180-120.

Park, K. 1966. Deep-sea pH. Science 154(3756):1540-1542.

Park, K. 1966. Surface pH of the northeastern Pacific Ocean. Korean Oceanol. Soc. 1:260-265.

Park, K. 1967. Nutrient regeneration and preformed nutrients off Oregon, Limnol. and Oceanogr. 12:353-357.

Park, K. and H. C. Curl, Jr. 1965. Effect of photosynthesis and respiration on the electrical conductance of seawater. Nature. 205:274-275.

Park, K., M. George, Y. Miyake, K. Saruhasi, Y. Katsauragi, and T. Kanazawa. 1965. Strontium-90 and Cesium-137 in Columbia River Plume, July, 1965. Nature 208 (5015):1084-1085.

Park, P. K., C. L. Osterberg, and W. O. Forster. (in press) Chemical budget of the Columbia River. In Bioenvironmental Studies of the Columbia River Estuary and adjacent Ocean Region. A. T. Pruter and D. L. Alverson, eds. Seattle, University of Washington Press (RLO-1750-41)

Pearcy, W. G. 1962. Egg masses and early developmental stages of the scorpaenid fish, Sebastolobus. J. Fish. Res. Bd. Canada, 19:1169-1173.

Pearcy, W. G. 1964. Some distributional features of mesopelagic fishes off Oregon. J. Mar. Res. 22:83-102

Pearcy, W. G. 1965. Distribution of oceanic cephalopods off Oregon, U.S.A. Proc. XVI Int. Congress Zoology 1:69.

Pearcy. W. G. 1965. Species composition and disttibution of pelagic cephalopods from the Pacific Ocean off Oregon. Pacific Science. 19: 261-266.

Pearcy, W. G. 1970. Vertical migration of the oceanic shrimp Pandalas jordani, a feeding and dispersal mechanism. California Fish and Game 56:125-129. (RLO-1750-52)

Pearcy, W. G. (in press) Distribution and ecology of oceanic animals off Oregon. In Bioenvironmental Studies of the Columbia River Estuary and Adjacent Ocean Region. A. T. Pruter and D. L. Alverson, eds. Seattle, University of Washington Press. (RLO-1750-45)

Pearcy, W. G., and C. A. Forss. 1966. Depth distribution of oceanic shrimps (Decapoda; Natantia) off Oregon. J. Fish. Res. Bd. Canada 23(8):1135-1143. (RLO-1750-16)

Pearcy, W. G., and C. A. Forss. 1969. The oceanic shrimp Sergestes similis off the Oregon coast. Limnol. and Oceanogr. 14:755-765. (RLO-1750-48).

Pearcy, W. G., and L. Hubbard. 1964. A modification of the Isaacs-Kidd midwater trawl for sampling at different depth intervals. Deep-Sea Res. 11:263-264.

Pearcy, W. G. and R. M. Laurs. 1966. Vertical migration and distribution of mesopelagic fishes off Oregon. Deep-Sea Res. 13:153-165. (RLO-1750-9)

Pearcy, W. G. and R. Mesecar. (in manuscript) Scattering layers and vertical distribution of oceanic animals off Oregon. (RLO-1750-65)

Pearcy, W. G., S. L. Meyer, O. Munk. 1965. A "four-eyed" fish from the deep-sea: Bathylychnops exilis Cohen, 1958. Nature, 207:1260-1262.

Pearcy, W. G. and C. L. Osterberg. 1964. Vertical distribution of radionuclides as measured in oceanic animals. Nature, 204:440-441.

Pearcy, W. G. and C. L. Osterberg. 1967. Depth, diel, seasonal and geographic variations in zinc-65 of mid-water animals off Oregon. Int. J. Oceanol. Limnol. 1(2):103-116. (RLO-1750-15)

Pearcy, W. G., and C. L. Osterberg. 1969. Zinc-65 and manganese-54 in albacore, Thunnus alalunga, from the west coast of North America. Limnol. Oceanogr. 13(3):490-498. (RLO-1750-23)

Pearcy, W. G., G. H. Theilacker, R. Lasker. 1969. Oxygen consumption of Euphausia pacifica: The lack of a diel rhythm or light-dark effect with a comparison of experimental techniques. Limnol. Oceanogr. 14(2):219-223.

Pearcy, W. G., and L. F. Small. 1968. Effects of pressure on the respiration of vertically migrating crustaceans. J. Fish. Res. Bd. Canada. 25(7):1311-1316.

Pearcy, W. G., and G. L. Voss. 1963. A new species of gonatid squid from the Northeastern Pacific. Proc. Biol. Soc. Wash. 76:105-112.

Peregras, W. T., W. G. Pearcy, and F. E. Carvey, Jr. 1969. Sebastodes flavidus, a shelf rockfish feeding on mesopelagic fauna, with considerable of the ecological implications. J. Fish. Res. Bd. Canada 26: 2211-2215. (RLO-1750-44).

Renfro, W. C. 1971. Seasonal radionuclide inventories in Alder Slough, an ecosystem in the Columbia River estuary. Proc. Third Symposium on Radioecology. Oak Ridge, Tennessee. 10-12 May 1971 (in press) (RLO-2227-T12-6).

Renfro, W. C. (in press) Radioecology of ^{65}Zn in Alder Slough, a small arm of the Columbia River Estuary. In Bioenvironmental Studies of the Columbia River Estuary and Adjacent Ocean Region, A. T. Pruter and D. L. Alverson, eds. Seattle, University of Washington Press. (RLO-1750-46)

Renfro, W. C., W. O. Forster, and C. L. Osterberg. (in press) Seasonal and areal distribution of radionuclides in the biota of the Columbia River estuary. In Bioenvironmental Studies of the Columbia River Estuary and Adjacent Ocean Region. A. T. Pruter and D. L. Alverson, eds. Seattle, University of Washington Press. (RLO-1750-61)

Renfro, W. C., and C. L. Osterberg. 1969. Radiozinc decline in starry flounders after temporary shutdown of Hanford reactors. Proc. Sec. Nat. Symp. Radioecol. Conf. 6705-03, p. 372-379. (RLO-1750-19)

Renfro, W. C. and W. G. Pearcy. 1966. Food and feeding apparatus of two pelagic shrimps. J. Fish. Res. Bd. Canada 23(12):1971-1975.

Renfro, W. C., R. V. Phelps, and T. F. Guthrie. 1969. Influence of preservation and storage on radiozinc and total zinc concentrations in fish. Limnol. Oceanogr. 14(1):168-179. (RLO-1750-25)

Renshaw, R. W. 1965. Distribution and morphology of the medusa, *Calycopsis nematophora*, from the North Pacific Ocean. J. Fish. Res. Bd. Canada 22(3):841-847.

Renshaw, R. W. and W. G. Pearcy. 1964. A new swivel cable clamp for towing large nets at different depths. Deep-Sea Res. 11:933-934.

Romberg, G. P. and W. C. Renfro. (in press) ^{32}P specific activity and ^{65}Zn concentrations used to study the movement and feeding behavior of young chinook salmon. J. Amer. Fish. Soc. (RLO-1750-84)

Small, L. F. and F. A. Cross. (in press) Effects of the Columbia River plume on two copepod species. In Bioenvironmental Studies of the Columbia River Estuary and Adjacent Ocean Region. A. T. Pruter and D. L. Alverson, eds. Seattle, University of Washington Press. (RLO-1750-42)

Small, L. F. and H. Curl. (in press) Effects of the Columbia River outfall on primary production and light attenuation in the sea. In Bioenvironmental Studies of the Columbia River Estuary and Adjacent Ocean Region. A. T. Pruter and D. L. Alverson, eds. Seattle, University of Washington Press. (RLO-1750-51)

Smiles, M. C. and W. G. Pearcy. 1971. Size structure and growth rate of Euphausia pacifica off Oregon. Fishery Bull. 69:79-86. (RLO-1750-50)

Smoker, W. W. and W. G. Pearcy. 1970. Growth and reproduction of the lanternfish Stenobrachius lencopsaurus. Jour. Fish. Res. Bd. Canada 27:1265-1275. (RLO-1750-63).

Stein, D. and J. Butler. (in press) A notacanthid Macdonaldia challengeri collected off the Oregon coast. Jour. Fish. Res. Bd. Canada. (RLO-2227-T12-3)

Tennant, D. A. and W. O. Forster. 1969. Seasonal variation and distribution of ^{65}Zn, ^{54}Mn, and ^{51}Ct in tissues of the crab Cancer magister Dana. Health Physics 18:649-657. (RLO-1750-37)

Tomlinson, R. and W. C. Renfro. (in manuscript) Non-biological uptake of Zinc-65 from a marine algal nutrient medium. (Submitted for publication to Env. Sci. Tech.) (RLO-2227-T12-9)

Vanderploeg, H. 1971. The rate of zinc uptake by Dover sole in the northeast Pacific Ocean: Preliminary model and analysis. Proc. Third Symposium on Radioecology. Oak Ridge, Tennessee. 10-12 May 1971. (in press) (RLO-2227-T12-7)

Wasmer, R. N. (in press) A new species of Hymenodora (Decapoda: Ophlophoridae) from the northeastern Pacific. Crustaceana. (RLO-1750-85)

Theses

Bertrand. G. A. 1970. A comparative study of the infauna of the central Oregon continental shelf. Ph.D. Thesis, Oregon State University. 123 numbered leaves.

Beasley, T. M. 1969. Lead-210 in selected marine organisms. Ph.D. Thesis, Oregon State University. 81 numbered leaves. (RLO-1750-73)

Bergeron, D. J. 1967. Uptake and retention of Zinc-65 from food of Euphausia pacifica Hansen. Master's Thesis. Oregon State University 60 numbered leaves.

Brownell, C. L. 1970. The relationship between morphology and ecology in the spatangoid urchin Brisaster latifrons. Master's Thesis. Oregon State University. 98 numbered leaves.

Buffo, L. K. 1967. Extraction of Zinc from Sea Water. Master's Thesis. Oregon State University. 49 numbered leaves.

Butler, J. L. 1971. Swimbladder morphology and buoyancy of northeastern Pacific myctophids. Master's Thesis. Oregon State University. 35 numbered leaves.

Cronin, J. T. II. 1967. Techniques of solvent extraction of organic material from natural waters. Ph.D. Thesis. Oregon State University, 79 numbered leaves.

Cross, F. A. 1967. Behavior of certain radionuclides in a marine benthic amphipod. Ph.D. Thesis. Oregon State University. 64 numbered leaves. (RLO-1750-32)

Cutshall, N. H. 1967. Chromium-51 in the Columbia River and adjacent Pacific Ocean. Ph.D. Thesis. Oregon State University. 64 numbered leaves.

Day, D. S. 1967. Distribution of Benthic fishes on the continental shelf and slope off the Oregon Coast. Master's Thesis. Oregon State University. 69 numbered leaves. (RLO-1750-30)

Donaldson, H. A. 1967. Sound scattering by marine organisms in the northeastern Pacific Ocean. Master's Thesis, Oregon State University. 75 numbered leaves. (RLO-1750-31)

Frederich, L. C. 1967. Dispersion of the Columbia River Plume based on radioactivity measurements. Ph.D. Thesis. Oregon State University. 134 numbered leaves.

Haertel. L. S. 1969. Plankton and nutrient ecology of the Columbia River Estuary. Ph.D. Thesis. Oregon State University. 71 numbered leaves. (RLO-1750-75)

Hancock, D. R. 1969. Bathyal and Abyssal polychaetes (Annelids) from the central coast of Oregon. Master's Thesis. Oregon State University. 121 numbered leaves. (RLO-1750-53)

Hanson, P. J. 1967. Vertical distribution of radioactivity in the Columbia River Esturary. Master's Thesis. Oregon State Univeristy. 77 numbered leaves. (RLO-1750-80)

Hanson, P. J. 1969. Water tracing with soluble metal chelates and neutron activation analysis: a laboratory and field study. Ph.D. Thesis, Oregon State University. 100 numbered leaves. (RLO-1750-81)

Holton, R. L. 1968. Effects of ^{60}Co irradiation on the reproductive performance of the brine shrimp _Artemia salina_. Ph.D. Thesis. Oregon State University. 74 numbered leaves. (RLO-1750-34).

Hubbard, L. T. 1967. Distribution and occurrence of Salpidae off the Oregon Coast. Master's Thesis. Oregon State University. 31 numbered leaves.

Hufford, G. L. 1967. Some aspects of the biology of the deep sea holothuroid _Paelopatides_ sp. Master's Thesis. Oregon State University. 67 numbered leaves. (RLO-1750-29)

Jennings, C. D. 1966. Radioactivity of Sediments in the Columbia River estuary. Master's Thesis. Oregon State Univeristy. 62 numbered leaves.

Jennings, C. D. 1967. Iron-55 in Pacific Ocean organisms. Ph.D. Thesis. Oregon State University. 81 numbered leaves. (RLO-1750-35)

Kujala, N. F. 1966. Artificial radionuclides in Pacific salmon. Master's Thesis, Oregon State University. 62 numbered leaves.

Larsen, I. L. 1970. Determination of ^{65}Zn specific activity in various tissues of the California mussel, _Mytilus californianus_. Master's Thesis. Oregon State University. 58 numbered leaves. (RLO-1750-78)

Laurs, R. M. 1967. coastal upwelling and the ecology of lower trophic levels. Ph.D. Thesis. Oregon State University. 121 numbered leaves.

Lee, W. Y. 1971. The Copepods in a collection from the southern coast of Oregon 1963. Master's Thesis, Oregon State University. 62 numbered leaves.

McCormick, J. M. 1965. Some aspects of marine hydroid ecology off Oregon. Master's thesis, Oregon State University. 88 numbered leaves.

Morrison, G. E. 1966. An investigation of the distribution of *Nephthys caecoides* in Yaquina Bay. Master's thesis. Oregon State University. 35 numbered leaves.

Osterberg, C. L. 1962. Radioactivity in Oceanic Organisms. Ph.D. Thesis. Oregon State University. 125 Numbered leaves.

Pope, S. 1970. Antimony-124 in the lower Columbia River. Master's Thesis. Oregon State University. 57 numbered leaves. (RLO-1750-74)

Renfro, W. C. 1967. Radioecology of ^{65}Zn in an arm of the Columbia River estuary. Ph.D. Thesis. Oregon State University. 88 numbered leaves. (RLO-1750-36)

Romberg, G. P. 1969. Determination and application of ^{32}P specific activity in Columbia River fish. Master's Thesis. Oregon State University. 65 numbered leaves. (RLO-1750-82)

Smiles, M. C. 1969. Size, structure and growth rate of *Euphausia pacifica* off the Oregon Coast. Master's Thesis. Oregon State University. 44 numbered leaves. (RLO-1750-79)

Stanford, H. M. 1971. The concentration and oxidation state of Chromium in seawater. Master's Thesis. Oregon State University. 74 numbered leaves.

Sumich, J. L. 1970. Growth of a sea urchin *Allocentrotus fragilis* at different depths off the Oregon coast. Master's Thesis Oregon State University. 51 numbered leaves. (RLO-1750-68).

Tennant, D. A. 1968. Distribution of ^{65}Zn, ^{54}Mn, and ^{51}Cr in the tissues of the Dungeness crab. *Cancer magister* Master's Thesis. Oregon State University. 76 numbered leaves. (RLO-1750-33)

Tipper, R. C. 1968. Ecological aspects of two wood-boring molluscs from the continental terrace off Oregon. Ph.D. Thesis, Oregon State Univsity. 137 numbered leaves.

Tomlinson, R. 1970. Non-biological uptake of Zinc-65 from a marine algal nutrient medium. Master's Thesis. Oregon State University. 62 numbered leaves. (RLO-1750-83)

Tonjes, S. D. 1971. Zinc-65 uptake by a bacterium isolated from Alder Slough, Columbia River Estuary. Master's Thesis. Oregon State University. 38 numbered leaves.

Van Arsdale, H. A. 1967. The distribution of Hyperiid amphipods off the Oregon coast. Master's Thesis. Oregon State University. 34 numbered leaves.

Progress Reports

Osterberg, C. L. (ed) 1965. Ecological Studies of Radioactivity in the Columbia River Estuary and Adjacent Pacific Ocean. Progress Report to AEC. 1 March 1964 through 1 July 1965.

McCauley, J. E. (ed) 1966. Ecological Studies of Radioactivity in the Columbia River Estuary and Adjacent Pacific Ocean. Progress Report to AEC. 1 July 1965 through 30 June 1966. (RLO-1750-8)

McCauley, J. E. (ed) 1967. Ecological Studies of Radioactivity in the Columbia River Estuary and Adjacent Pacific Ocean. Progress Report to AEC. 1 July 1966 through 30 June 1967. (RLO-1750-22)

McCauley, J. E. (ed) 1968. Ecological Studies of Radioactivity in the Columbia River Estuary and Adjacent Pacific Ocean. Progress Report to AEC. 1 July 1967 through 30 June 1968. (RLO-1750-28)

McCauley, J. E. (ed) 1969. Ecological Studies of Radioactivity in the Columbia River Estuary and Adjacent Pacific Ocean. Progress Report to AEC. 1 July 1968 through 30 June 1969. (RLO-1750-54)

McCauley, J. E. (ed). 1970. Ecological Studies of Radioactivity in the Columbia River Estuary and Adjacent Pacific Ocean. Progress Report to AEC. 1 July 1969 through 30 June 1970. (RLO-1750-66)

McCauley, J. E. (ed) 1971. Ecological Studies of the Columbia River Estuary and Adjacent Pacific Ocean. Progress Report to AEC. 1 July 1970 through 30 June 1971. (RLO-2227-T12-10)