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OREGON STATE UNIVERSITY

PROGRESS REPORT

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

Norman Cutshall
Principal Investigator

U. S. Atomic Energy Commission
Contract AT (45-1) 2227 Task Agreement 12
RLO-2227-T12-30

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1 July 1971 through 30 June 1972

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

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

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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. 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
Tomio Iwamoto, Ph.D. Research Associate	Co-Investigator Nekton Ecology
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
Robert L. Holton, Ph.D. Research Associate	Co-Investigator Radioecology

TECHNICAL STAFF

Norman Farrow Instrument Technician	Radioecology
I. Lauren Larsen, B.S. Research Associate	Gamma Ray Spectrometry
David L. Stein, B.S. Assistant in Oceanography	Nekton Ecology
Jerome Wagner, B.A. Assistant in Oceanography	Atomic Abosrption Spectrometry
Show Wu, B.S. Assistant in Oceanography	Radiochemistry
Robert Ruff, B.S. Assistant in Oceanography	Benthic Ecology
Katherine Nafe, B.S. Assistant in Oceanography	Bentnic Ecology

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

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Abstracts only

INTRODUCTION

This is an annual report of progress in marine radioecological studies under U.S. Atomic Energy Commission Contract Number AT(45-1) 2227, Task Agreement 12. It includes material from Contract Number AT (45-1) 1750 which preceded the present contract. The report format is essentially the same as last year and includes only brief descriptions of incompleted research in progress. Completed research papers which have been submitted for publication or which have been published during the period 1 July 1971 to 30 June 1972 are included.

This year's report includes seventeen completed papers in reprint or preprint form. In addition we are reproducing abstracts of chapters contributed by OSU to "The Columbia River Estuary and Adjacent Ocean Waters" (edited by A.T. Pruter and D.L. Alverson). Because the fifteen chapters (315 pages) would exceed space limitations herein the full texts will not be included. One Ph.D. and four master's theses have been completed during the past year and their abstracts are in Section III.

Our research task force this year has included Dr. Cutshall (radiochemistry), Dr. Pearcy (nekton ecology) and Drs. Carey and McCauley (benthic ecology). Dr. Renfro (radiobiology) began a leave of absence in September 1971. He will spend two years with the IAEA Marine Radioactivity Laboratory in Monaco. Dr. Holton (radioecology) joined our group in September 1971.

The initiation of ^{55}Fe studies by Dr. David Jennings at Oregon College of Education in Monmouth during the past year is welcome. Through cooperative sampling and analysis, we expect both his and our programs to benefit.

Our research program continues to emphasize direct analysis of environmental radionuclides in the context of a broad, ecological program. Our analytical capability is strongest in gamma-ray spectrometry and atomic absorbtion spectrophotometry. We also use neutron activation analysis (in the OSU Triga reactor) and are presently setting up a liquid scintillation system and an electrochemical system.

RADIOANALYSIS

Ingvar L. Larsen

The analysis of samples for radioactivity is generally accomplished by counting the prepared samples in one of two 5x5 inch NaI(Tl) well detectors, each coupled to a 512 multichannel analyzer. A 3x3 inch NaI(Tl) solid detector coupled to a third 512 multichannel analyzer allows counting of larger environmental samples such as whole clams, mussels and water samples. Depending upon the level of activity present, environmental samples are counted between 100 to 800 minutes. Spiked Laboratory samples are counted for shorter durations, usually 40 minutes or less. After completion of the count, the appropriate fraction of a 1000 minute background count is subtracted from the sample count and the net data read out from the analyzer via Tally paper punch tape, electric typewriter, and an X-Y recorder. Conversion of the counted data to units of radioactivity is accomplished by comparing the sample data to that of liquid standards of similar geometry. For simple spectra having isolated photopeaks the areas underneath the photopeaks and the respective counting time is compared to a standard and the amount of radioactivity determined. Complex spectra, those with overlapping photopeaks, are resolved by using a non-linear least squares program in conjunction with a CDC 3300 computer on campus. All sample radioactivity is decay corrected back to the date of collection.

The two well-type detectors are in use approximately 22 hours/day, 7 days/week, and the 3x3 inch detector is used intermittingly on demand. Our counting laboratory is participating in the IAEA (Monaco) low-level intercalibration program.

STABLE ELEMENT ANALYSES

Ingvar L. Larsen and J. Wagner

Stable element measurements are made by atomic absorption spectrophotometry, utilizing a Perkin-Elmer model 303 instrument. At present we have 23 elements which can be measured. During the 12-month period from July 1971 to June 1972 approximately 10,959 samples of organisms, sediment, and water samples were analyzed for various trace elements. Thirteen people made use of the instrument during this period. Four standards were analyzed for Zn, Cd, Cu, Pb, and Hg. The inter-lab standards were Orchard Leaves (NBS No. 1571), Bovine Liver (NBS) Tuna flesh (NBS) and Hake (Battelle-Northwest).

Our atomic absorption laboratory will be expanded considerably during the summer, 1972. Funds provided by the National Science Foundation (GA-34103) will be used to purchase a new system including a graphite atomizer assembly. This system will not only increase the number of samples we can analyze but also will provide dramatically increased sensitivity for several elements.

II. STUDENT PARTICIPATION

Students contribute substantially to our research program. During the past year one student has completed his doctorate and four have completed the master's. Abstracts of their thesis are printed in section III. In each case where financial support has been provided to students, the source of funds is identified. Thesis advisors are named in parentheses.

DEGREES COMPLETED

DOCTOR OF PHILOSOPHY

John Bolen — FWQA Fellowship

Dr. Bolen completed requirements for the Ph.D. in General Science. His thesis is titled "Seasonal Concentration, Turnover and Mode of Accumulation of ^{32}P by the Juvenile Starry Flounder *Platichthys stellatus* (Pallas) in the Columbia River Estuary." Dr. Bolen is presently with the U. S. Atomic Energy Commission in Bethesda, Maryland. (Lyford, Renfro)

MASTER OF SCIENCE

Jay Gile — Teaching Assistant

Mr. Gile received his degree in General Science with a thesis on "Zinc, Copper and Manganese in the Razor Clam, *Siliqua patula*." He is working for the Environmental Protection Agency in Rockville, Maryland. (Cutshall)

William M. Lenaers — FWQA Trainee

Mr. Lenaers completed the M. S. degree in Oceanography. His thesis research dealt with "Photochemical Degradation of Sediment Organic Matter: Effect on ^{65}Zn Release." Mr. Lenaers is now on duty as a 2nd Lieutenant with the U. S. Army. (Cutshall)

Lynn Tucker McCrow

Mrs. McCrow received the M. S. degree in Oceanography. Her thesis title is "The Ghost Shrimp, *Callianassa californiensis*, Dana, 1854 in Yaquina Bay, Oregon." She is now at South Dakota State University, McCauley)

Douglas Squire

Mr. Squire has completed his M. S. thesis, "The Japanese Oyster Drill, *Oceanebra japonica*, in Netarts Bay, Oregon" and is employed at the OSU Marine Science Center. (Carey)

Ph.D. CANDIDATES

Vernon G. Johnson — AEC Graduate Assistant

Mr. Johnson holds an M. S. degree in Oceanography from OSU. He spent four years at the National Reactor Testing Station in Arco Idaho and then returned to OSU to work toward the doctorate. His thesis research, which deals with radionuclide transport in the Columbia River following reactor shutdown, is nearing completion. (Cutshall)

Janakiram R. Naidu — AEC Graduate Assistant

Mr. Naidu received the M. S. from the University of Washington and then worked for six years with the India Atomic Energy Commission. His thesis research involves comparison of ^{65}Zn, Zn, Cd and Hg in hake collected along the West Coast of the U. S. (Cutshall)

Walter Pearson — JPPC Graduate Assistant

Mr. Pearson received his M. S. degree from the University of Alaska in 1969. He has recently completed a tour of duty in the U. S. Army, joining us in the fall of 1971. His thesis research will be developed around studies of the effects of various pollutants on the behavior of marine invertebrates. (Holton)

Henry Vanderploeg — AEC Graduate Assistant

Mr. Vanderploeg has an M. S. degree from the University of Wisconsin. His thesis will involve modeling ^{65}Zn turnover in benthic fishes. He will join the Ecology Division, Oak Ridge National Laboratory in the Fall of 1972. (Pearcy)

MASTER OF SCIENCE CANDIDATES

David Evans — Teaching Assistant

Mr. Evans holds a B. S. in chemistry from UCLA. His thesis will deal with the effects of ocean water upon the soluble/suspended distribution of radionuclides in the Columbia River Estuary. He will spend the summer of 1972 at Richland, Washington on a NORCUS Fellowship. His adviser there will be R. W. Perkins. (Cutshall)

Priscilla Harney — Teaching Assistant

Miss Harney is a graduate of the University of California. Her thesis research deals with turnover of ^{65}Zn and ^{54}Mn in the freshwater mollusc *Anodonta*. (Holton)

Harold Longaker — Teaching Assistant

Mr. Longaker is a graduate of the U. S. Naval Academy. Following his navy tour he worked as an electronics engineer. His thesis research involves uptake of Co by Coccolithus huxleyi. (Holton)

Ronald C. Scheidt — NSF-IDOE Assistant

Mr. Scheidt holds an A. B. in chemistry from Fresno State College. He worked for ten years as a radiochemist at the U. S. Naval Radiological Defense Laboratory. His thesis research will involve studies of ^{228}Ra and ^{228}Th in coastal and shelf biota and sediments. (Cutshall)

Linda Smith — JPPC Graduate Assitant

Miss Smith received her B. A. degree in zoology from the University of Wyoming in 1972. She plans to begin studies on zooplankton populations in the nearshore zone. (Holton)

Stanley V. Gregory — Fisheries and Wildlife Department

Mr. Gregory received his B. S. in zoology from the University of Tennessee in June 1971. His thesis research is concerned with the biogenic enrichment of streams by salmon carcasses. (Donaldson)

Jose R. Cañon — Chilean National Scholar

Mr. Cañon is here on a fellowship from the government of Chile. He is using data from the Chilean Fisheries Development Institute to do a thesis on the behavior of the anchoveta Engraulis ringens off the coast of Chile. (McCauley)

Bruce L. Boese

Mr. Boese received his B. S. from Southern Oregon College of Education. He is employed part time at the National Environmental Research Center, Corvallis, and plans to do thesis work on some phase of coastal pollution. (McCauley)

Robert A. Parr

Mr. Parr received a B. S. from Bowling Green University. He is working on the effects of dredging in an estuary. (McCauley)

III. THESES

SEASONAL CONCENTRATION, TURNOVER AND MODE OF ACCUMULATION OF ^{32}P BY THE JUVENILE STARRY FLOUNDER *PLATICHTHYS STELLATUS* (PALLAS) IN THE COLUMBIA RIVER ESTUARY*

by John Joseph Bolen

Abstract of Ph.D. Thesis

The seasonal concentration, turnover and mode of accumulation of ^{32}P by the juvenile starry flounder in Alder Slough, a small ecosystem in the Columbia River Estuary, was examined during 1969 and 1970. Levels of ^{32}P and concentrations of total P were measured to permit computation of specific activities (nCi ^{32}P/g total P).

Seasonal fluctuations of ^{32}P in flounder collected from Alder Slough were characterized by spring and summer highs and fall and winter lows with the difference between the least and most radioactive fish being approximately 500 pCi/g. The seasonality of ^{32}P in flounder can be attributed to low-high temperature effects on rates of metabolism and food intake. Concentrations of ^{32}P in fall and winter were primarily regulated by the temperature regime while the higher levels during spring and summer were modified by the annual spring freshet and subsequent oceanic influence on estuarine temperature and salinity structure.

Uptake studies conducted in Alder Slough with caged fish and the use of an exponential model failed to produce a meaningful ^{32}P biological half-life for starry flounder. Failure of the model to describe ^{32}P accumulation is believed to be due to the assumptions inherent in its use. Retention experiments with flounder held in a sea water tank at Newport, Oregon and caged flounder in the Yaquina River yielded effective half-lives equal to or greater than the radionuclide's physical half-life. Large differences between the ^{32}P content of individual fish resulted in biological half-lives with large error terms and prevented drawing definite conclusions from these studies.

The main pathway of ^{32}P accumulation by the juvenile flounder was determined by maintaining fish in Columbia River water and feeding radioactive and non-radioactive amphipod-isopod mixtures in the presence and absence of active sediment. Flounder populations fed active food, and active food with active sediment present accumulated 3.3 and 3.7 times the activity of flounder receiving ^{32}P from water alone. Radioactive sediment did not appear to contribute to the ^{32}P body burden of the fish. Phosphorus-32 uptake from water averaged 24% of that from food plus water. Flounder fed the radioactive amphipod-isopod mixtures assimilated an average of 16% of the ingested ^{32}P.

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* Dr. John H. Lyford, major professor

ZINC, COPPER AND MANGANESE IN THE RAZOR CLAM, *Siliqua patula**

by Jay Dean Gile

Abstract of M.S. Thesis

Zinc, copper and manganese concentrations were measured by atomic absorption spectroscopy in *Siliqua patula* collected during May, 1970 through May, 1971. Individual clams were analysed to determine the degree of variation among individuals. Statistical analysis proved the variation to be highly significant. Monthly composite samples of 18 clams were collected from three sites along the Washington-Oregon coast. The samples were analysed to examine differences in concentration among two general groups of tissue, collection sites and monthly concentrations within a site.

Significant differences were found between the tissue groups, with copper and manganese being consistently higher in portion B (gills, liver, digestive system and reporductive tissue). Zinc was generally found in higher concentration in portion A(foot, neck, mantle, adductor muscle and reproductive tissue).

A statistically significant difference was also noted between the three sites, however no pattern in the concentration was apparent. These results may indicate that the variation between sites reflects only the high degree of variability among individuals.

Statistically significant differences were also noted between the months examined within each site. There appeared to be a general trend of increasing concentration in Spring and Summer for all three elements. Prior investigations indicate that the razor clam undergoes most of its growth activity in early Spring and most of its reproductive activity in late Spring and early Summer. It is possible that the increased concentration in Spring and Summer is responding to increased requirements due to changes in metabolic rate brought about by increased growth and the reproductive activity. However it is equally important to recognize that the monthly variation could be reflecting the variation among individuals.

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* Dr. Norman H. Cutshall, major professor

PHOTOCHEMICAL DEGRADATION OF SEDIMENT ORGANIC MATTER: EFFECT ON Zn-65 RELEASE*

by William Michael Lenaers

Abstract of M.S. Thesis

Columbia River sediment was irradiated with ultraviolet light to determine if organic material could be removed without altering the sorptive properties of the hydrous oxides of iron and maganese.

A laboratory preparation of Zn-65 spiked hydrous ferric oxide was subjected to ultraviolet irradiation in order to assess the photochemical effect upon Zn-65 release. The photochemically induced release of Mn-54 present on the Columbia River sediment was used to assess the effect on the hydrous oxides of manganese.

The ultraviolet irradiation proved effective in removing up to 68% of the sedimentary organic material in 17 hours without causing release of Zn-65 or Sc-46.

While the ultraviolet irradiation had no effect upon Zn-65 release from laboratory preparations of hydrous ferric oxides and Zn-65 spiked montmorillonite, a significant release of Mn-54 resulted from the photolysis treatment. The removal of Mn-54 was not accompanied by the release of sorbed Zn-65 or Sc-46 (nuclides expected to be sorbed by hydrous oxides), nor did there appear to be any permanent change in the nature of the Mn-54 on the sediment. Although it is possible that the hydrous oxides of manganese are affected by the ultraviolet treatment, it is likely that another species, such as the carbonate, is the species involved.

Photo-oxidation appears to provide a method of obtaining sediments with substantially reduced organic content without affecting the sorptive properties of hydrous oxides or clay minerals. This result should allow the use of uptake studies to determine the importance of organic material in trace metal sorption by sediments.

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* Norman H. Cutshall, major professor

THE GHOST SHRIMP, *CALLIANASSA CALIFORNIENSIS* DANA, 1854, IN YAQUINA BAY, OREGON*

by Lynne Tucker McCrow

Abstract of M.S. Thesis

The life cycle of *Callianassa californiensis* Dana, 1854, was studied in the tidal estuary , Yaquina Bay, Oregon. At this latitude it is largely restricted to intertidal sandy mudflats under predominately 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. Largescale breeding generally begins in the spring, and ovigerous females may be plentiful in the cooler layers of 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 off shore 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 a bay.

THE JAPANESE OYSTER DRILL, *OCENEBRA JAPONICA*, IN NETARTS BAY, OREGON**

by Douglas Richard Squire

Abstract of M.S. Thesis

It has been shown that a large localized population of *Ocenebra japonica* exists on a sandy low tide island in the tail of Netarts Bay. Introduced with *Crassostrea gigas* planted in the 1930's, the Japanese drill lives in association with relict oysters left behind by the defunct industry. Data from spat-baited traps furnished an index of distribution, and indicated the drills may move outward and downward in the summer, returning to the relicts for protection from winter weather when temperatures fall.

Snails fed mono-specific diets of *C. gigas*, cockles (*Clinocardium nuttalli*), and *Olivella biplicata* were tested to determine prey preference. Naive (field) and starved specimens were also tested, and statistical comparison of these results demonstrated prey preference. could be dietetically altered, and confirmed that *C. nuttalli* was the chief prey item in the field.

A single spring spawning was noted, but few juvenile drills (< 18 mm) were recorded. The presence of numerous small prey--some of which had been drilled--and of a population distribution similar to literature reports indicate the population is viable.

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* James E. McCauley, major professor
** Andrew G. Carey, major professor

Fifty-three juveniles grew an average of 8.76 mm in 85 days of unrestricted feeding. Local control measures for this potentially serious pest are discussed.

IV. PAPERS PRESENTED AND MEETINGS ATTENDED

ANDREW G. CAREY, JR.

Oregon State University, Faculty Seminar, October 1971, "Ecology of the Sea Floor."

Oregon State University, Triad Club Seminar, January 6, 1972, "Cruise to the end of the earth."

Oregon State University Chapter, American Institute of Industrial Engineers, February 15, 1972, "Arctic Marine Ecology".

Long Beach Navy Yard, U. S. Coast Guard Oceanographic Group, Western Beaufort Tea Ecological Cruise - 1972, Planning Conference, Feb. 29 - Mar. 2, 1972.

Battelle Northwest, Richland, Washington, Environmental Sciences Division, April 14, 1972, "Ecology of the Deep-Sea Floor."

University of Washington, Seattle, IAEA Symposium - The Interaction of Radioactive contaminants with the constituents of the Marine Environment, June 10 - 14, 1972.

ANDREW G. CAREY, JR. and N. CUTSHALL

Zinc-65 Specific Activities from Oregon and Washington (U.S.A.) Continental Shelf Sediments and Benthic Invertebrate Fauna

Abstract: The relationships between the benthic fauna and sediments on the continental shelf of Oregon and Washington have been investigated by determining specific activities of ^{65}Zn, a radionuclide present in the Northeast Pacific Ocean. Zinc-65, induced by neutron activation in Columbia River water used to cool plutonium production reactors at Richland, Washington, was carried down the river and into the marine environment.

Sediment from the Columbia River moves northward. Zinc-65 specific activities in sediment and benthic invertebrates decrease northward with distance from the river and westward with both distance and depth. Many organisms to the south of the river mouth and westward with depth have higher ^{65}Zn specific activities than the sediments in, or on, which they live. Other sources of ^{65}Zn via the food web are suspected as the cause for the differential in specific activity between the sediment and benthic fauna. Long-term declines in ^{65}Zn specific activities have been noted. A wide range of ecological and systematic forms have been included in the study.

Norman Cutshall

Workshop on Marine Environmental Quality, Durham, New Hampshire. August 9-13, 1971. NAS-NRC Ocean Affairs Board.

Environmental Quality Baselines Workshop, Brookhaven National Laboratory, May 24-26, 1972. NSF-IDOE.

American Society of Limnology and Oceanography - Pacific Section (joint with AAAS-Pacific Section) Eugene, Oregon. June 12-15, 1972.

Symposium on Interaction of Radioactive Contaminants with the Consituents of the Marine Environment. Seattle, Washington. July 10-14, 1972. IAEA.

Robert L. Holton

Workshop on Marine Environmental Quality, Durham, New Hampshire. August 9-13, 1971. NAS-NRC Ocean Affairs Board.

Great Lakes Environment and Impact of Power Plants. January 12-13, 1972. Argonne National Laboratory, Argonne, Illinois.

Environmental Quality Baselines Workshop, Brookhaven National Laboratory, May 24-26, 1972. NSF-IDOE.

American Society of Limnology and Oceanography - Pacific Section (joint with AAAS - Pacific Section) Eugene, Oregon, June 12-15, 1972.

INGVAR LARSEN, ROBERT HOLTON, NORMAN CUTSHALL, AND JERRY WAGNER

The Decline of ^{65}Zn Specific Activity in Mussels from a Marine Environment Following Reactor Shutdown.

Abstract: The decline of ^{65}Zn specific activity in mussels from a marine environment was observed following final Hanford reactor shutdown. Observed values of ^{65}Zn specific activity remained fairly constant for several months indicating a fairly long lag time for ^{65}Zn to travel through the Columbia River system. Following the "lag period" ^{65}Zn specific activity values declined exponentially. The decline began approximately 185 days after the reactor shutdown (28 January 71) and had a slope of -0.00158 log SA/d. An ecological half-life on 191 days was obtained from the slope of this decline.

Individual specific activity studies were more uniform than either ^{65}Zn concentration factors or stable zinc concentrations.

A significant difference in specific activity was found between two arbitrarily designated size groups for specimens collected in September 1971 but not in samples collected in February 1972. Whether this is a seasonal phenomenon or not is being further investigated.

Symposium on the Interaction of Radioactive Contaminants with the Constituents of the Marine Environment, Seattle, Washington, July 10-14, 1972. IAEA.

William G. Pearcy

Governor's Conference on Marine Fisheries. Portland, December 1971.

University National Oceanographic Laboratory System. College Station, Texas, May 1972.

American Society of Limnology and Oceanography - Pacific Section (joint with AAAS - Pacific Section) Eugene, Oregon, June 12-15, 1972.

W. G. PEARCY

Albacore Oceanography off Oregon 1970.

Abstract: Symposium on the Interaction of Radioactive Contaminants with Consitutents of the Marine Environment, Seattle Washington, July 10-14, 1972. IAEA.

During July 1970, albacore boats trolling surface jigs (jig boats) had record catches in an area off the mouth of the Columbia River. The jig fishery collapsed suddenly in late July and was poor thoroughout the remainder of the summer. No obvious oceanographic changes could be correlated with these drastic changes of fishing success. Favorable water temperatures extended through August, traditionally the month of largest albacore landings in Oregon.

Bait boats, which chum with live bait, had good fishing off Oregon from mid-August to October, indicating that the poor success of jig boats during this time was caused by the behavior of albacore relative to surfacetrolled fishing gear. It is postulated that albacore descended into subsurface water in response to a change in availability of their preferred prey, the saury; here they were less accessible to jigboats than bait boats. Saury were common in the stomachs of albacore during periods of good jig fishing and were the dominant food where high albacore catches were made by our research vessel.

The first albacore catches of the season were probably from an area of warm temperature and low salinity representing Columbia River plume water. The subsequent migration to the north appeared to be along the oceanic edge of the plume. In general, high catches by boats were not within the core of the plume but in 15.5°C water, especially in areas where a horizontal thermal gradient was apparent.

Priscilla Harney
American Society of Limnology and Oceanography - Pacific Section (joint with AAAS - Pacific Section) Eugene, Oregon June 12-15, 1972.

PRISCILLA HARNEY, ROBERT HOLTON, and NORMAN CUTSHALL

^{65}Zn and ^{54}Mn in Freshwater Molluscs *Anodonta*

Abstract: Permanent shutdown of plutonium production reactors at Hanford, Washington, in January, 1971 afforded an opportunity to conduct unique studies on the decline of radioactivity in organisms. The freshwater mollusc, *Anodonta*, is an excellent biological indicator for Zn-65 and Mn-54, two radionuclides produced in reactor coolant water.

A field determination was made of the biological and ecological half-lives of Zn-65 and Mn-54 in *Anodonta*. The biological half-life describes the rate at which the organism expels an element. The ecological half-life incorporates the effects of other declining radioactive components of the ecosystem with simple biological turnover. It can be used to predict the length of time needed for organisms in a contaminated environment to rid themselves of radioactivity.

In addition the following participated in the Symposium on the Interaction of Radioactive Contaminants with the Constituents of the Marine Environment. Seattle, Washington, July 10-14, 1972. IAEA.

Ronald Scheidt
Jerome Wagner
Henry Vanderploeg
David Evans

V. RESEARCH IN PROGRESS

RADIOECOLOGICAL KINETICS

Several research problems involving mathematical representation of radionuclide turnover in organisms are under study. The goals of these studies are to test the adequacy of existing kinetic models and to directly determine the kinetic parameters governing radionuclide turnover in specific organism/nuclide combinations. Both laboratory and field experiments are under way.

CADMIUM TURNOVER IN FRESHWATER MOLLUSCS

Norman Cutshall, Peter Mellinger, David Willis

Dr. Mellinger recently completed a Ph.D. research problem(in General Science) on the turnover of Cd and Hg in Margaritifera margaratifera. Uptake and loss were determined under controlled laboratory conditions using radioisotopic tracers. The data for cadmium are now being analyzed using a multicompartment model.

^{65}Zn TURNOVER IN PACIFIC OYSTERS

Norman Cutshall

Accumulation and loss of ^{65}Zn by Pacific oysters (Crassostrea gigas) are being treated using first-order, isotope exchange kinetic equations. We are attempting to relate the uptake phase, steady-state conditions, and loss phase of ^{65}Zn turnover with a single set of parameters. Because of their relatively long life and slow growth, adult oysters appear ideal subjects for this exercise. Data from the University of Washington, College of Fisheries (Dr. Allyn Seymour) are being treated with the equations developed. Initial results appear quite promising that the models used are adequate for description of long-term turnover. A manuscript on this subject is nearing completion.

^{65}Zn AND ^{54}Mn LOSS IN FRESHWATER MOLLUSCS

Priscilla Harney

The rate of decline of whole-body content of ^{65}Zn and ^{54}Mn in Anodonta wahlamatensis is being followed for populations in the Columbia River estuary and for populations transferred from the estuary and from McNary reservoir into the Willamette river at Corvallis. Specific activities of these nuclides are being periodically measured in different body tissues.

It appears that the rate of decline of ^{65}Zn is greater than that of ^{54}Mn. Early results suggest a more rapid decline in clams held in the Willamette than in those remaining in the Columbia. Radionuclides derived from Columbia River sediments may be available to organisms.

DETERMINATION OF ^{65}Zn SPECIFIC ACTIVITY IN MUSSELS AND BARNACLES FROM THE OREGON COAST

Ingvar L. Larsen and Jerry Wagner

With the phase-out of the last single-pass plutonium production reactor at Hanford, Washington in January 1971, artificial radionuclides introduced into the Columbia River from this source has been terminated. Due to the distribution pattern of the Columbia River and the adjacent ocean current system, ^{65}Zn has been prevalent in marine organisms along the Oregon-Washington Coasts. With the cessation of the radionuclide input, opportunities to measure changes in an environmental system arose and a sampling program was initiated to collect mussels (*Mytilus californianus*) and Goose-neck barnacles (*Mitella polymerus*) from the Oregon Coast. A determination of the ^{65}Zn ecological half-life in these organisms was anticipated as well as effects, if any, of the Columbia River Spring freshet and its relationship to changes in ^{65}Zn specific activity.

^{65}Zn AND ^{55}Fe TURNOVER IN ORGANS OF FISHES

Norman Cutshall, C. David Jennings (Oregon College of Education, Monmouth)

We are continuing our study of the turnover rates of ^{65}Zn in carp (*Cyprinus carpio*) collected at McNary Dam. The residence time for ^{65}Zn in various organs has been estimated from specific activity measurements in blood and organs. Samples collected during the past year to directly determine residence times and the results will be compared to those predicted by the specific activity model.

This project has been expanded to include study of ^{55}Fe turnover by Dr. Jennings. By sharing the tasks of sample collection and preparation we can process more samples, more efficiently.

RADIONUCLIDE TRANSPORT AND DISPERSION

Processes which transport and disperse radionuclides in the environment are important in lowering the availability of radionuclides to individual organisms. At the same time the number of individuals involved increases. In cases where changes in physical or chemical form of the radionuclides occur, these changes may become equally important in determining what populations accumulate radionuclides.

POST SHUTDOWN RADIONUCLIDE TRANSPORT STUDY

Vernon G. Johnson

An investigation of the behavior and transport/dispersal of the residual Hanford-produced radioactivity in bed sediments of the Columbia River System was initiated on February 17, 1971. Both fluvial and estuarine portions of the System are under study. Objectives and experimental plan were described in the previous progress report.

Primary effort during the past year involved sample collection and processing. With the exception of the monthly composite water sample station at Prescott, sample collections will be terminated following the 1972 spring freshet. Full-time effort will then be devoted to final data reduction and analysis.

MOVEMENT OF COLUMBIA RIVER SEDIMENT ON THE CONTINENTAL SHELF

Norman Cutshall

We are attempting to treat the shelf sediment radioactivity data reported last year with a particle-settling/advective transport model. Initial fits of averaged data to a two dimensional model are moderately good. We are proceeding with a three-dimensional model and point-by-point fitting. If successful the fitting should allow estimation of effective particle transport velocities and settling rates over the continental shelf.

ISOTOPE DILUTION OF ^{65}Zn IN OREGON COASTAL WATERS

Norman Cutshall, Ingvar Larsen, Jerry Wagner

Several observers have noted cases where ^{65}Zn specific activities in coastal organisms have exceeded specific activities in concurrently taken water samples. It has been suggested that this anomaly may be caused by physico-chemical differentation of Zn and ^{65}Zn in the complex coastal system or by temporal fluctuations in specific activities in the water. If the latter were true, then organisms might reflect some average of water values. We are attempting to model the isotope dilution of ^{65}Zn

from the Columbia River with ocean water zinc along the coast. Mean annual salinities at Oregon coastal stations and ^{65}Zn specific activities in coastal organisms are being compared. A manuscript is in preparation.

EFFECTS OF SEAWATER ON RADIONUCLIDE FORM

David Evans

Mixing of river water and its suspended load with seawater alters the chemical environment of radionuclides and establishes new equilibrium conditions. Mr. Evans' M.S. thesis and the completed paper included in section VI of this report involve analysis of data from the Columbia River estuary to search for changes in the distribution of radionuclides between dissolved and sorbed phases.

SPATIAL PATTERNS OF ^{65}Zn SPECIFIC ACTIVITY IN PELAGIC AND BENTHIC FOOD WEBS ON OREGON'S CONTINENTAL SHELF, JULY 1970

H. A. Vanderploeg and W. G. Pearcy

During July 1970 extensive collections of pelagic orgaisms, benthic fishes and their stomach contents from a number of stations on Oregon's continental shelf were analyzed for ^{65}Zn specific activity (SA). Also, analyzed for ^{65}Zn SA were water and phytoplankton from a station within the Columbia River plume.

^{65}Zn is conveyed to benthic fishes through detrital and pelagic food webs. Our analyses indicate that the relative importance of these pathways changes with distance from the Columbia River mouth. Furthermore, when these spatial patterns of SA in the food webs are coupled with ^{65}Zn SA data for shelf sediments (Cutshall, et al., 1971), water and phytoplankton, they will provide insight into the process responsible for the introduction of ^{65}Zn into and its subsequent dispersal by benthic fishes and their food webs.

REFERENCE

Cutshall, N., Renfro, W., Evans, D., and V. Johnson. 1971. Zinc-65 in Oregon-Washington continental shelf sediments. Third Radioecology Symposium, Oakridge, Tennessee.

BENTHOS

BENTHIC ECOLOGY AND RADIOECOLOGY

by A.G. Carey, Jr.

(1) Specific activities for ^{65}Zn on the Oregon and Washington continental shelf.

Benthic fauna are being collected on six east-west transects across the continental shelf for a continuing study of the ^{65}Zn specific activities during the period of decline of ^{65}Zn caused by radioactive decay. Integrated cruises with radiochemistry are undertaken seasonally to define changes with time and season in the organisms and their sedimentary environment. It is anticipated that the sedimentary studies by radiochemistry will help define the source of ^{65}Zn for the benthic organisms. A station at the edge of the continental shelf off Newport at 200 m depth and a deep station at 2370 m 65 miles west of Tillamook Head are included in the project to add information to the long-term decline of ^{65}Zn in benthic fauna.

(2) Summary and analysis of benthic radioecological data.

All data on radioisotopes and stable elements collected since June 1962 in the Northeast Pacific by our group are being summarized and analyzed. A major effort has been placed in undertaking quality control of the data, coding, and storing on magnetic tape at the OSU Computer Center. About 90% of the data are presently on file and ready for statistical analysis. We will look at the effect of station, depth, distance from the river, taxa, feeding type, year and season on: 1) the presence or absence of all radionuclides detected in the fauna and 2) ^{65}Zn specific activities and concentrations in the fauna.

(3) Ecology of Cascadia Plain.

Sampling was completed at the grid of thirteen stations on central Cascadia Abyssal Plain. The quantitative beam trawl samples have been identified, counted and weighed. Final analysis of the data is underway. The major objectives of this project are: (1) to determine the effects of proximity to the continental margin on the structure of abyssal benthic communities and (2) to determine the effects of north-south gradients of depth and sediment characteristics on the abundance and distribution of the large epibenthic fauna. Sediment and bottom water samples have been analyzed to provide environmental data.

On Cruise Y 7206-D we sampled epibenthic organisms, sediments, and bottom water at two stations at the base of the continental slope west of Heceta Bank. The objective of the project is to determine if seasonal run-off of turbid layers along topographic lows is a source of food for the slope-base fauna. Sites were chosen for study based on topography and geological data on seasonal bottom turbidity and bottom currents.

OTHER RADIOECOLOGICAL STUDIES

BIOGENIC ENRICHMENT OF STREAMS BY SALMON CARCASSES

Stanley V. Gregory (Dept. of Fisheries and Wildlife)

The contribution of nutrients to streams by salmon carcasses was examined by preliminary laboratory stream studies. ^{131}I was injected into rainbow trout which were held in an aquarium for three days to allow the radioactive iodine to be incorporated into their tissues. Two trout were killed, and their tissues were dissected out to determine the relative distribution of the ^{131}I. Two trout were homogenized to determine whole body activity. The remaining trout was killed and placed in the stream to decay. Algae, moss, sediment, caddisflies, mayflies, stoneflies, snails, crayfish and trout were periodically removed, monitored for activity and returned to the stream. Activity in the organisms was expressed as picoCuries/gram wet weight and micrograms ^{131}I/gram wet weight. Water samples were taken hourly to form daily composites. 500 milliliters of the daily composite were filtered, and iodine was chemically separated from the filtered water. Both the filter and precipitate were counted for activity to determine ^{131}I in the particulate and soluble fractions.

Field studies will be conducted at Berry Creek Experimental Station, Benton County, Oregon. Experiments will be conducted with ^{32}P, ^{131}I and possibly ^{99}Mo and ^{45}Ca. Adult salmon will be tagged with these radionuclides, killed and placed in the stream to decay. Stations will be set at the carcasses, 0.5 m., 1.0 m., 5 m., 10 m., 50 m., 100 m., 300m., and 500 m. from the carcasses. At each station samples of the stream organisms, water, sediment, terrestrial surface and subsurface soil samples and terrestrial vegetation will be taken. Concentration factors will be determined for all samples to examine major pathways of nutrient transfer through the stream ecosystem. Possible increase in food organisms for young salmon due to enrichment of the stream by salmon carcasses will be considered. (NSF-IBP-9039)

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-2napthol 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.

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 through 1970. 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.

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.

MERCURY, ZINC AND CADMIUM IN PACIFIC HAKE

J. Naidu

Pacific Hake, collected synoptically from the Columbia River plume and from along the West Coast of the U. S., have been analyzed for ^{65}Zn specific activity. The same samples are being analyzed for Hg and Cd. By using ^{65}Zn specific activity as an index of exposure to Columbia River water, it should be possible to determine whether or not the river has been a significant source of these metals.

Primary effort during the past year has been devoted to completing the Hg analyses using the flameless atomic absorption (FAA) method. IDOE orchard leaves and NBS bovine liver were used as biological reference standards. In addition, water samples from the Columbia River were analyzed for total Hg using a modified EPA oxidation-reduction/closed-cycle FAA method. EPA standards for Hg in water were used to validate the method.

Both atomic absorption and radiochemical activation analysis are being used to determine Cd. Initial results for IDOE and NBS biological standards are encouraging.

CONCENTRATION OF RADIUM-228 BY CALCAREOUS BENTHIC ORGANISMS

by R. C. Scheidt

The distribution and transport of natural radioactive ^{228}Ra within the ecosystem and its concentration by benthic marine organisms is being investigated. The present hypothesis is that calcium carbonate secreting organisms incorporate ^{228}Ra into their shells or tests by subsititution for calcium.

Continental shelf sediments are suspected to contain placer deposits, high in heavy mineral assemblages. Associated with these dense assemblages are ^{232}Th-containing minerals, which are the source of ^{228}Ra. Hypothetically, ^{228}Ra diffusing from these deposits into overlying waters is incorporated into calcium carbonate shells of benthic organisms.

Radium-228 is being measured in the shells of calcareous organisms and the ^{232}Th daughters are being measured in adjacent sediment in order to determine whether the organisms reflect sediment radioactivity. Quantitative mineralogy of the sediment is also being determined by X-ray diffraction and trace metal concentrations within each mineral fraction are being determined by instrumental and radiochemical neutron activation analysis.

MACROURIDS FROM THE NORTHEAST PACIFIC COAST OF THE UNITED STATES

D. Stein, W. G. Peacy, J. Ambler

Rat-tail fishes (Macrouridae) form the majority of the biomass of benthic and epibenthic fishes on the slope and abyssal plain off Oregon. The taxonomic status of many species is in dispute, and little is known of their ecology.

Examination of speciation, reproduction, growth, and feeding habits is in progress, utilizing collections made between 1961 and the present. To date approximately 2200 individuals of seven different species, including one new species, have been examined, and several synonymies have been discovered. Three aspects of reproduction being investigated are seasonality, size at maturity, and fecundity. Study of feeding habits is difficult due to the inversion of stomachs resulting from swimbladder expansion upon rapid ascent to the surface in the trawl. However, evidence indicates moderately selective feeding upon epi-benthic and bentho-pelagic organisms.

VI. RESEARCH COMPLETED

DORSADENA YAQUINAE, A NEW GENUS AND SPECIES OF MYCTOPHID FISH FROM THE EASTERN NORTH PACIFIC OCEAN

By LEONARD R. COLEMAN[1] AND BASIL G. NAFPAKTITIS[2]

ABSTRACT: A new genus and species of myctophid fish, *Dorsadena yaquinae*, from the eastern north Pacific Ocean is described. Relationship between the new form and *Lampadena* Goode and Bean is suggested by similarities in the structure, size and position of the supra- and infracaudal luminous glands, in the arrangement of the body photophores and in otolith morphology. *Dorsadena yaquinae*, like *Lampadena* and *Taaningichthys*, seems to be one of the deepest dwelling myctophids. Its isolated occurrence off Oregon may be attributed to inadequate sampling of depths exceeding 1500 meters in the central and western north Pacific. On the other hand, the eastern north Pacific specimens may represent an expatriate population.

Recent collections of oceanic fishes by the Department of Oceanography, Oregon State University, have yielded specimens of an undescribed lanternfish. This fish is so distinct from any other myctophid as to preclude its placement in any of the approximately thirty genera of the family.

The new species is represented by five specimens, 58.0–101.5 mm in standard length, collected between latitudes 44°N and 45°N, and longitudes 134°W and about 139°W where subarctic water predominates in at least the upper 300 meters.

Counts and measurements were taken according to Nafpaktitis (1968). Photophore and otolith terminologies follow those of Bolin (1939) and Frizzell and Dante (1965), respectively. The otoliths are deposited in the collections of John E. Fitch of the California Department of Fish and Game.

Dorsadena, new genus

Diagnosis: A large, elongate luminous gland immediately in front of adipose fin. Large, undivided supra- and infracaudal luminous glands. Four to five Prc, in three groups: first two close together and about at level of dorsal margin of infracaudal luminous gland. third at midlateral line, fourth posterior to, and about at level of ventral margin of. supracaudal luminous gland; often a fifth Prc develops close to. and at level of. fourth Prc. Numerous minute secondary photophores on head, trunk and base of caudal fin.

The name *Dorsadena* [dorsal and adena, from the Greek $\alpha\delta\eta\nu$ (aden) = gland] refers to the unique preadipose gland. Type species:

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[2]Department of Biological Sciences. University of Southern California, Los Angeles, Calif. 90007; and Research Associate in Ichthyology. Natural History Museum of Los Angeles County, Los Angeles, Calif. 90007.

***Dorsadena yaquinae*, new species**
Figures 1–4

Holotype: Los Angeles County Museum of Natural History (LACM) 30841-1; 77.0 mm, R/V YAQUINA, haul MT-866, between 45°05′N, 138°33′W and 44°44′N, 138°32′W, 0453-1205 hrs, 25 July 1966; 10′ Isaacs-Kidd Midwater Trawl, depth of haul 0-2700 m, 8000 m of wire out; bottom depth approximately 4207 m.

Paratypes: Oregon State University Department of Oceanography (OSUDO) 1226, 101.5 mm, and 1227, 58.0 mm. Collection data for both are the same as for the holotype. U.S. National Museum (USNM) 204869; 87.0 mm, R/V YAQUINA, station NH-450, haul OTB-163, between 44°39′N, 134°34′W and 44°45′N, 134°46′W, 1835-0400 hrs, 1-2 March 1967; 22′ shrimp-type otter trawl, depth of haul 0-3860 m, 6000 m of wire out. Museum of Comparative Zoology (MCZ) 46681; 62.0 mm, R/V YAQUINA, station NH-450, haul MT-1040, between 44°45′N, 134°46′W and 44°43′N, 134°42′W, 0223-0305 hrs, 2 March 1967; 6′ Isaacs-Kidd Midwater Trawl, depth of haul 0-180 m, 800 m of wire out; bottom depth approximately 3800 m.

Diagnosis: As for genus.

Description: D. 14-15; A. 12-14; P. 15-16; V. 8 (9 on one side of one specimen); gill rakers (4)5+1+11, plus 1-3 rudiments on the upper limb and 3-4 rudiments on the lower limb of the first (right) gill arch; PO 6-8; VO 3-5; SAO 3; AO 5-7+3-5, total 9-11; Prc 2+1+1-2.

A moderately large myctophid fish. Head large, about 3.3 in standard length (SL). Eye large, 12.3 (11.6-13.5) in SL, 3.8 (3.7-4.1) in length of head and 2.5 (2.3-2.8) in length of upper jaw. Mouth large, terminal, somewhat oblique; length of upper jaw about 5 in SL, 1.5 in length of head, extending 1.0 to 1.3 times the diameter of eye behind vertical through posterior margin of orbit. Length of snout 1.4 (1.2-1.5) in diameter of eye. Posterior opercular margin forming a blunt point somewhat above base of pectoral fin. Pterotic spine well developed. Caudal peduncle 10.0 (9.0-11.0) in SL.

Origin of dorsal fin over base of ventral fin. Origin of anal fin on, or slightly in advance of, vertical through end of base of dorsal fin. Pectoral fin short, its delicate, fragile rays about as long as diameter of eye. Ventral fins extending to anus. Base of adipose fin over end of base of anal fin.

Dn absent. A very small, poorly developed Vn immediately above, or in contact with, dorsal margin of CO1 (lacrimal) bone. Op_1 poorly defined, about at level of angle of mouth and close behind preopercular margin. Op_2 twice as large as general body photophores, at least twice its own diameter above and behind Op_1.

Body photophores generally small and ill defined, at least in preserved specimens. PLO slightly in advance of vertical through upper end of base of pectoral fin and about its own diameter below lateral line. PVO_1 under, or slightly in advance of, PVO_2, which is located about its own diameter in front

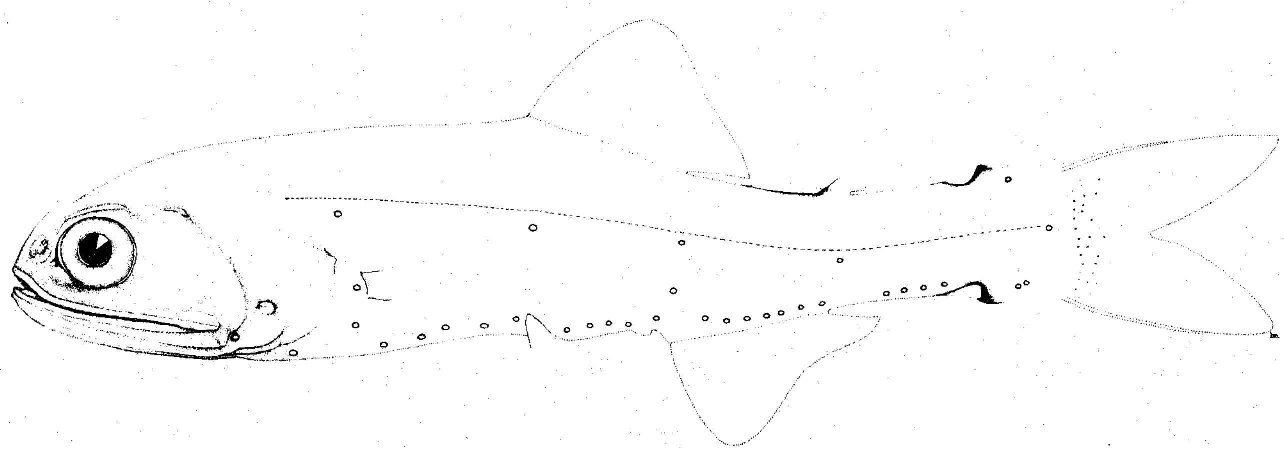

FIGURE 1. *Dorsadena yaquinae;* holotype, 77.0 mm in SL; LACM 30841-1.

TABLE 1. Measurements of *Dorsadena yaquinae*

Character	OSUDO 1226 101.5 mm	MCZ 46681 62.0 mm	OSUDO 1227 58.0 mm	LACM 30841-1* 77.0 mm	USNM 204869 87.0 mm	Mean
	Measurements in percent of standard length					
Diameter of eye	7.4	8.4	8.6	8.2	8.0	8.1
Length of upper jaw	20.7	19.8	19.8	20.6	19.5	20.1
Length of head	30.5	30.6	31.6	31.2	30.5	30.9
Depth of caudal peduncle	11.0	11.3	9.7	10.4	9.2	10.3
From tip of snout to base of pectoral fin	33.5	33.1	33.6	33.0	32.2	33.1
From tip of snout to base of ventral fin	48.3	48.4	46.9	50.6	47.7	48.4
From tip of snout to origin of dorsal fin	48.3	48.4	46.6	50.6	48.3	48.4
From tip of snout to origin of anal fin	63.1	64.5	63.8	63.6	64.4	63.9
From tip of snout to base of adipose fin	77.8	79.0	75.0	77.9	75.6	77.1
Length of caudal glands	5.4	4.8	5.2	4.2	4.6	4.8
Length of preadipose gland	8.4	8.1	6.2	7.8	7.8	7.7
Character	*Measurements in percent of head length*					*Mean*
Length of upper jaw	67.7	64.7	62.8	66.3	64.2	65.1
Diameter of eye	24.2	27.4	27.3	26.3	26.4	26.3
Length of snout	21.0	18.4	19.1	18.8	18.9	19.2

*Holotype

of middle of base of pectoral fin. Six to eight PO, variably spaced on a wavy line. VLO about 1.5 times its own diameter below lateral line. Three to five, usually four, VO, level. SAO forming an obtuse angle; SAO_1 over anus and slightly raised above level of last VO; distance between SAO_2 and SAO_3 1.5 to 2.0 times as large as that between SAO_1 and SAO_2; SAO_3 somewhat in advance of, or behind, vertical through center of SAO_2 and about its own diameter below lateral line. First and last AOa interspaces sometimes distinctly enlarged; first AOa, or last, or both slightly raised. Pol behind last AOa, under base of adipose fin and about its own diameter below lateral line. AOp evenly spaced, level; last AOp over anterior portion of infracaudal luminous gland. Prc_1-Prc_2 interspace less than one photophore diameter; Prc_2 slightly higher than Prc_1; Prc_3 well behind Prc_2 and at level of lateral line; one or two additional Prc organs posterior to supracaudal luminous gland and under dorsal procurrent caudal rays.

Supra- and infracaudal luminous glands undivided, of equal size, their length 1.6-2.0 times in diameter of eye, directly apposed to each other, and framed by darkly pigmented tissue; most luminous tissue found within a darkly pigmented "hood" at posterior part of each organ.

An undivided luminous gland, about as long as eye diameter, extending from anterior end of base of adipose fin to about midway between end of base of dorsal fin and adipose fin; gland outlined by black pigment, with luminous tissue bulging dorsally.

Large numbers of minute secondary photophores present on head, trunk and proximal part of caudal fin. Along the lateral line, they appear to be arranged in a rather regular pattern (Fig. 2).

Jaws with needlelike teeth, inner ones longer than outer; 5 to 8 broad-based, hook-like, forward-inclined teeth on posterior part of dentary; a long, narrow band of slender teeth on each palatine; mesopterygoids with minute, widely scattered teeth and enlarged, widely spaced ones along periphery and posterior part of each mesopterygoid; vomer toothless.

The gonads of all five specimens are either poorly developed or regressed.

Circumorbital bones

The circumorbital bones (Fig. 3) show some interesting features. In the following discussion the terminology is that used by Paxton (in press).

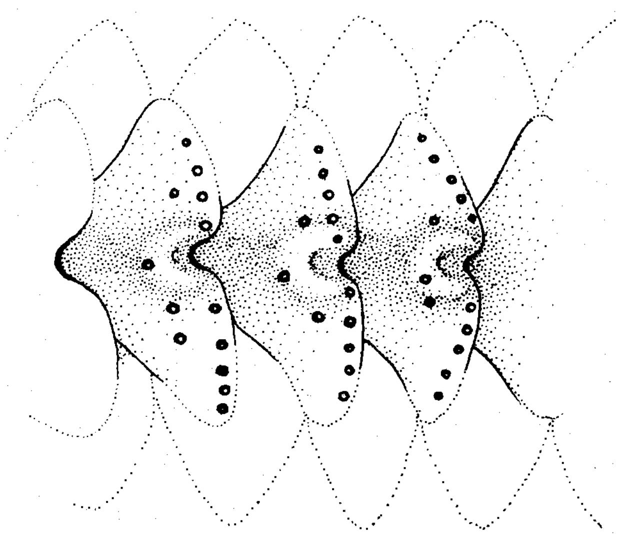

FIGURE 2. *Dorsadena yaquinae;* distribution of secondary photophores on lateral line scales.

The anterodorsal part of the first circumorbital, CO1 (lacrimal of some authors), is folded over to form a large, lateral flap anteroventrad to the eye. This flap is clearly visible on intact specimens. Paxton (in press) found that in myctophids "The anterodorsal margin is folded ventrally, so that the anterior end of the CO1 approaches a closed tube in some forms. In a number of species, the Vn orbital organ lies on top of the folded edge of the CO1." However, with the exception of those members of the genus *Diaphus* with a well developed Vn (ventronasal) and those of the genus *Gymnoscopelus*, e. g., *G.* (*Gymnoscopelus*) *opisthopterus, G.* (*Nasolychnus*) *piabilis*, with extensive luminous tissue along the anterior and anteroventral orbital margin, in no other myctophid form is this flap so extensively developed. It is conceivable that the ancestral stock from which *Dorsadena* evolved had a well-developed Vn. Interestingly, the CO1 lateral flap appears relatively well developed in *Lampadena anomala*, the Vn of which is very small, poorly developed and lies anterodorsad to the CO1.

According to Paxton (op. cit.), the lateral margin of the orbital portion of the third circumorbital, CO3 (jugal of some authors), in lantern fishes, is solid or split. In many forms "A keel or flag of bone projects posteriorly from the lateral margin at the level of the split. . . ." In *Dorsadena yaquinae* the lateral margin of the orbital portion of the CO3 is split. At the level of the split, the two parts contribute to the formation of a large, spine-like, posteroventrally-directed bony process (Fig. 3), also clearly visible on intact specimens. A relatively well-developed similar process is found also in *Lampa-*

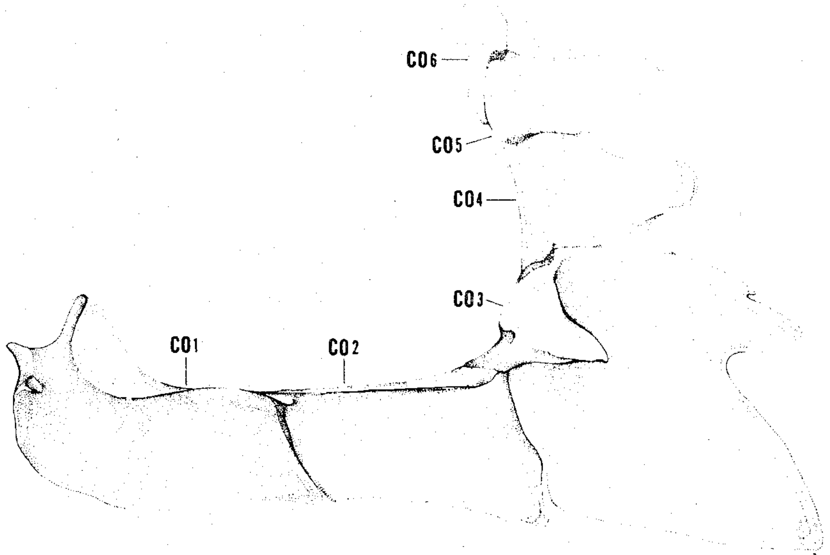

FIGURE 3. *Dorsadena yaquinae;* circumorbital bones.

dena, e.g., *L. urophaos* and *L. anomala*, and in some *Lampanyctus*.
The other circumorbital bones show no marked peculiarities.

Otoliths

Dorsadena yaquinae has a small sagitta (Fig. 4), which is almost as high as it is long—length to height ratio 1.03:1. It is not notched posterodorsally and its ventral margin is smooth. The rostrum is well developed; the antirostrum bluntly rounded but distinct. The collum divides the sulcus into two almost equal sections. The lateral face of the otolith is smooth and somewhat convex.

Nafpaktitis and Paxton (1968) have briefly discussed the trends in otolith morphology within the genus *Lampadena*. The sagittae of all the species of this genus, with the exception of *L. anomala*, are relatively large and clearly longer than they are high. Their ventral margins and, in at least two cases, dorsal margins as well, are scalloped. The rostra are little to moderately developed and the antirostra are in some cases indistinct. *L. anomala* has a relatively small otolith with a length to height ratio of 1.2:1, a smooth ventral margin and a greatly developed rostrum.

The otoliths of *L. anomala* and *D. yaquinae* are markedly similar. Figure 4 shows the otoliths of the two forms and also that of *Taaningichthys* sp., a genus closely related to *Lampadena*.

Relationships

Until thorough osteological studies are made on cleared and stained specimens of *Dorsadena*, interpretations regarding relationships of the new genus are of necessity based almost solely on external morphology.

There are several morphological similarities between *Dorsadena* and *Lampadena*. The most striking similarity is found in the structure, size and position of the supra- and infracaudal luminous glands. The body photophores in both genera are rather poorly developed and similarly arranged. With very

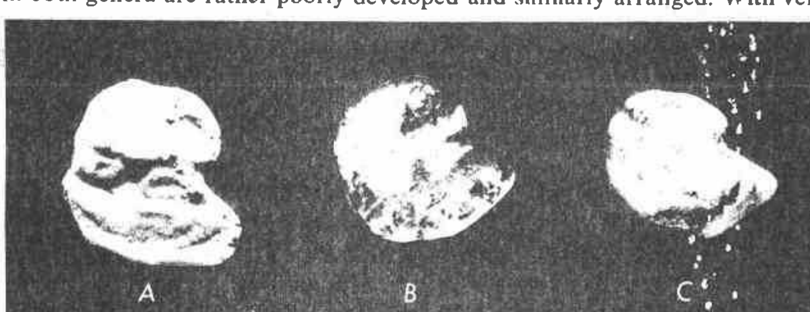

FIGURE 4. Medial views of left otoliths, anterior end to the right: (A) *Dorsadena yaquinae*, otolith 2.40 mm long, specimen 101.5 mm in SL; (B) *Taaningichthys* sp., otolith 1.90 mm long, specimen about 50 mm in SL; (C) *Lampadena anomala*, otolith 1.95 mm long, specimen about 48 mm in SL.

few exceptions, the PO and VO series are, in terms of numbers, remarkably constant within the Myctophidae. In *Dorsadena,* as in *Lampadena* and the closely related *Taaningichthys*, even the PO and VO vary in numbers. Limited osteological observations (circumorbital bones) also revealed close similarities.

Nafpaktitis and Paxton (1968) pointed out the marked differences in otolith morphology between *L. anomala* and all the rest of the species of *Lampadena*. In fact, the otolith of *L. anomala* may, in some important respects, be considered as intermediate between the long, scalloped otoliths of the rest of the species of *Lampadena* and the almost round, smooth-edged otolith of *Taaningichthys* sp. (Fig. 4). In the same manner, the otolith of *Dorsadena yaquinae* has features which may be considered intermediate between *L. anomala* and *Taaningichthys* sp., perhaps somewhat closer to the former than to the latter.

Most species of *Lampadena* appear to be among the deepest dwelling of myctophids. The very few known captures of *L. anomala* with open nets have been made below 750 meters. Shallow captures of large specimens during the night, indicative of extensive vertical migration, are known for *L. luminosa* and *L. urophaos.* Young (20-35 mm) specimens of *L. speculigera, L. dea* and *L. chavesi* have been taken during the night in the upper 200 meters.

If we assume that the body photophores of *Lampadena*, which are poorly developed (especially in *L. anomala*) and variable in numbers, reflect deep mesopelagic, or bathypelagic, existence with limited or nonexisting migratory habits, then the correlation is stronger in *Taaningichthys.* The two known species of this genus show marked degeneration of body photophores and lateral line. The photophores are small, highly superficial and their numbers as well as their arrangement vary considerably. A third species (Davy, in press) appears to have completely lost its body photophores. The lateral line components are extremely reduced. The eye, in contrast, is very large and well developed. Members of the genus *Taaningichthys* are seldom taken above 800 meters and they do not seem to undertake diel vertical migrations.

With the exception of a single specimen (MCZ 46681) taken with a 6′ Isaacs-Kidd Midwater Trawl between the surface and about 200 m, the specimens of *Dorsadena yaquinae* were captured with larger gear and at depths exceeding 2000 meters. The possibility does exist that the animals may have been caught anywhere between the surface and the maximum depth of each trawl, since the collecting gear used remained open throughout the operation. However, with the exception mentioned above, *Dorsadena* has not been taken in shallower hauls, which greatly outnumber the deep tows. In addition to capture data, several features of the body photophores suggest that *Dorsadena* occurs at depths similar to those occupied by *Lampadena* and *Taaningichthys.* If this is the case, then evolutionary convergence could account for the state of development of body photophores in the three genera. On the other hand, a detailed osteological study may support our conclusion that *Dorsadena* is closely related to *Lampadena.*

Following is a synoptic list of external characters that both relate and distinguish the three genera, *Lampadena*, *Dorsadena* and *Taaningichthys*, as they are understood at this time.

Lampadena Goode and Bean, 1896

1. Body moderately robust.
2. Ventral fins inserted under origin of dorsal fin.
3. Teeth on vomer present (absent in *L. dea*?).
4. Lateral line well developed.
5. Preadipose luminous gland absent.
6. Crescent of white tissue on dorsal half of iris present in only one species, *L. chavesi*.
7. PO 5-6; VO 3-6; SAO 3; AOa 3-8; AOp 2-5; Prc 2+1.
8. Secondary photophores absent or, if present, restricted to head.

Dorsadena, new genus

1. Body moderately robust.
2. Ventral fins inserted under origin of dorsal fin.
3. Teeth on vomer absent.
4. Lateral line well developed.
5. Preadipose luminous gland present.
6. Crescent of white tissue on iris absent.
7. PO 6-8; VO 3-5; SAO 3; AOa 5-7; AOp 3-5; Prc 2+1+1-2.
8. Secondary photophores present on head, trunk and proximal part of caudal fin.

Taaningichthys Bolin, 1959

1. Body slender.
2. Ventral fins inserted in advance of origin of dorsal fin.
3. Teeth on vomer absent.
4. Lateral line absent or very poorly developed.
5. Preadipose luminous gland absent.
6. Crescent of white tissue present on posterior half of iris.
7. PO 5-6; VO 2-10; SAO 1; AOa 1-8; AOp 1-5; Prc 2+1; or photophores absent.
8. Secondary photophores, if present, restricted to head and interradial membrane of caudal fin.

DISCUSSION

Most lanternfishes perform diel vertical migrations of several hundred meters. During their vertical migrations, these animals cross a wide range of temperature and salinity. It is therefore difficult to understand how a given set of physico-chemical factors at a particular depth could limit the horizontal distribution of these organisms. The answer, or answers, to the puzzle probably lie in the reproductive physiology on the one hand, and in the tolerance limits of the early, epipelagic stages on the other. While a large portion of the epipelagic larvae remain within the ecologically optimum area where they grow, sink and subsequently metamorphose, many may be transported by currents to waters of different physico-chemical properties. In this alien environment, some young will perish, others will survive, sink and metamorphose. However, these expatriates are usually unable to reproduce. As Bolin (1959b) points out: "While straggling adults may exist for long periods in waters far beyond the normal range of the species, permanent populations are restricted to the proximity of the areas where spawning can be successful." It is therefore necessary to exercise extreme caution in discussing ranges and distributional patterns, especially when we are dealing with oceanic, midwater organisms with epipelagic larval stages, such as myctophids, because the area in which a species can exist may be much larger than the area in which it can spawn. For instance, are the subarctic waters off Oregon within the "normal" range of *Dorsadena yaquinae*? Does this fish spawn there? The poorly developed and, in the larger specimens, regressed gonads do not seem to indicate that spawning takes place in that area. If it does, then the absence of larvae and young in the California Current System may perhaps be accounted for by the change in the physico-chemical properties of the subarctic water along the course of the California Current.

On the basis of the available data, however, it seems more likely that here we are dealing with an expatriate population originating in deep, seldom sampled waters either of the Subtropic Region or of the central and western Subarctic Region.

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Geographic Distribution and Relative Abundance of Salpidae off the Oregon Coast

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HUBBARD, L. T., JR., AND W. G. PEARCY. 1971. Geographic distribution and relative abundance of Salpidae off the Oregon coast. J. Fish. Res. Bd. Canada 28: 1831–1836.

Six species of salps were identified from 437 midwater trawl and 202 plankton net collections off Oregon from 1961 to 1964: *Helicosalpa virgula*, *Iasis zonaria*, *Salpa fusiformis*, *Pegea confoederata*, *Thalia democratica*, and *Thetys vagina*. Relative abundance of the species varied in time and space and few distributional patterns were evident. *Salpa fusiformis* and *I. zonaria*, the most common species, were found during all seasons of the year, the highest numbers usually during the summer, the upwelling season. *Thalia democratica*, *H. virgula*, and *T. vagina* were found only during 1963, and *P. confoederata* was most common during 1963. This was an abnormally warm year and the presence of these species off Oregon may have been related to advection from the south or west and the lack of upwelling.

HUBBARD, L. T., JR., AND W. G. PEARCY. 1971. Geographic distribution and relative abundance of Salpidae off the Oregon coast. J. Fish. Res. Bd. Canada 28: 1831–1836.

Nous avons identifié six espèces de salpes provenant de 437 traits de chalut pélagique et 202 traits de filet à plancton effectués au large des côtes de l'Orégon de 1961 à 1964: *Helicosalpa virgula*, *Iasis zonaria*, *Salpa fusiformis*, *Pegea confoederata*, *Thalia democratica* et *Thetys vagina*. L'abondance relative des espèces varie dans le temps et dans l'espace et les schémas de répartition sont à peu près nuls. *Salpa fusiformis* et *I. zonaria*, les espèces les plus communes, se rencontrent en toutes saisons avec maximum en été, saison de la remontée d'eaux profondes. *Thalia democratica*, *H. virgula* et *T. vagina* n'ont été capturés qu'en 1963, année où *P. confoederata* fut le plus commun. Cette année-là fut exceptionnellement chaude et la présence de ces espèces au large des côtes de l'Orégon peut être attribuable à l'advection en provenance du sud ou de l'ouest et à l'absence de remontée d'eaux profondes.

Received May 20, 1971

MOST species of salps are cosmopolitan warmwater plankters, and their incursions into colder zones may indicate the intrusion of warm water into cold-water zones (Thompson 1948; Yount 1958; Fraser 1962). Species that occur in temperate waters often show sporadic and enormous fluctuations in numbers that are possibly related to hydrographic conditions (Braconnot 1963; Sewell 1953). Dense patches or swarms, which may result from direct transport of swarms or reproduction en route, may drastically affect phytoplankton and zooplankton populations. Fraser (1949, 1962), for example, noted that standing stocks of copepods were scarce when salps were abundant.

The ocean off Oregon is generally cool. The water mass is modified Pacific subarctic water. During summer, prevailing winds create upwelling of cold water near the coast that counteracts the seasonal warming processes (Smith et al. 1966; Pattullo et al. 1969). The ocean environment off Oregon may therefore represent a northern boundary and not a salubrious environment for many species of salps. The purpose of this study was to determine the occurrence of salps off Oregon seasonally and geographically, to relate their occurrence to environmental conditions, and to learn if some species may be indicators of warmwater advection.

Methods

Collections of pelagic animals including salps were made from July 1961 through June 1963 at stations located along transect lines at right angles to the Oregon coast off the mouth of the Columbia River, Coos Bay,

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and Brookings (Fig. 1). The lines extended from 5 to 165 nautical miles offshore, with stations at intervals of 10–20 miles. The Coos Bay, Newport, and Columbia River stations were usually sampled monthly and Brookings stations usually every 2 months from June 1962 through April 1964. A line to 145 miles off the Siuslaw River was sampled in November 1963. Salps were also collected on a cruise to the southwest of Oregon to 34°23′N, 140°46′W.

Collections were made with a 6-ft Isaacs-Kidd midwater trawl and 1-m diam plankton nets. From July 1961 to July 1962 the front half of the midwater trawl net consisted of 38-mm mesh (square measure) and the after half was lined with 13-mm mesh netting. After July 1962 the trawl was lined throughout with 5-mm knotless nylon mesh netting. The 1-m nets were made of nylon with mesh apertures of .571 mm. A flow meter in the mouth of the meter nets and a depth-distance recorder in the mouth of the midwater trawl provided estimates of the amount of water filtered during each tow. Both midwater trawl and meter net tows were made to 200 m, depth permitting, between dusk and dawn.

Meter net sampling in conjunction with the midwater trawling was begun May 1963. At first, the meter net was attached above the midwater trawl and both were towed simultaneously. These oblique tows were abandoned in favor of separate vertical tows in December 1963.

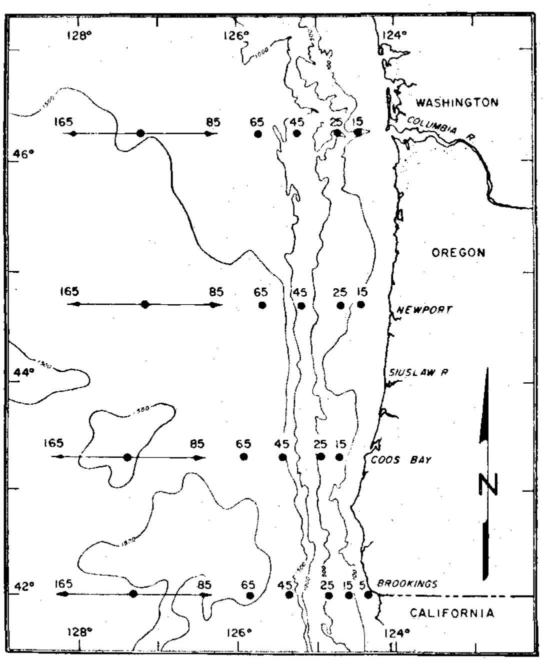

FIG. 1. Stations where collections of salps were made off the Oregon coast. Numbers indicate distances offshore in nautical miles. Stations at 20-mile intervals between 85 and 165 miles offshore were sampled less frequently than inshore stations and are not individually designated. (Bottom contours are in fathoms.)

Midwater trawl collections contained most of the salps used in this study. Meter net collections usually did not filter enough water to effectively sample the generally sparse salp populations.

Two collection methods provided information on depth distribution of the salps within the upper 1000 m. A total of 116 samples from multiple opening–closing meter nets, operated by piston cutters (Yentsch et al. 1962), and 103 midwater trawl samples, taken with a Multiple Plankton Sampler attached to the codend of the trawl (Pearcy and Hubbard 1964), were examined for salps.

In all, 434 midwater trawl and 200 1-m net samples were examined for salps. Samples were preserved in 5% formalin at sea and sorted ashore. When there were fewer than 100 salps per sample, the entire sample was sorted for salps. If the sample contained many salps, a Folsom Plankton splitter (McEwen et al. 1954) was utilized to produce a subsample of at least 100 salps. Oozooids and blastozooids were counted separately but are treated together in the paper.

Species Composition

Six species of salps were collected during the study: *Helicosalpa virgula, Iasis zonaria, Salpa fusiformis, Pegea confoederata, Thalia democratica*, and *Thetys vagina* (Table 1 and Fig. 2). The frequency of occurrence of each species was low. *Salpa fusiformis*, the most common salp, was found in less than 20% of all collections.

SALPA FUSIFORMIS CUVIER 1804

Salpa fusiformis, a common species of salp along the west coast of North America (Ritter 1905; Thompson 1948; Berner MS 1957), was the most abundant species collected. The frequency of occurrence and the average number per tow were lowest along the northern stations (Table 1).

The irregular occurrence of salps off Oregon is illustrated in Table 2, which shows the catches of *S. fusiformis* off Newport. This species was absent from most of the collections but, where it was present, numbers were often high. Patchiness in time and space is emphasized by the fact that when catches were made at one station during a month, it was often absent in adjoining stations for that month, or from the same station for preceding or succeeding months. Patches or swarms of this and other species of salps have been reported by Hardy (1936), Hardy and Gunther (1935), Fraser (1949), and Foxton (1966).

Salpa fusiformis occurred each month of the year at some time during the study, except October (Fig. 2). Thus its occurrence was not limited to any one season. Off Newport, there was a seasonal

TABLE 1. Frequencies of occurrence in percent and (in parentheses) average catches per midwater trawl of salps in 316 tows along four station lines 15–165 miles off Oregon, July 1961–June 1964. The average volume of water filtered by 309 tows was 13.5 × 10^3 m^3 (SD 3.7 × 10^3 m^3).

	Columbia River (56 tows)	Newport (123 tows)	Coos Bay (52 tows)	Brookings (85 tows)	Avg
Salpa fusiformis	9(12)	15(37)	33(38)	22(22)	19
Iasis zonaria	0(0)	4(0.4)	11(1.4)	33(1.9)	12
Pegea confoederata	2(<0.1)	2(0.3)	2(5.3)	2(0.2)	2.0
Thetys vagina	0(0)	2(0.6)	4(1.9)	1(0.6)	1.6
Thalia democratica	0(0)	4(1,190)	0(0)	1(0.6)	1.9
Helicosalpa virgula	0(0)	0(0)	2(<0.1)	0(0)	0.3

TABLE 2. Midwater trawl catches of *Salpa fusiformis* (number per 1000 m^3) at various stations off Newport, August 1961–May 1964 (0 = tows made but no salps caught; – no tows made).

Months	Nautical miles offshore 15	25	45	65	65+
1961					
Aug.	0	0	0	–	–
Nov.	0	0	0	1.51	–
Dec.	0	0	0	0	0
1962					
Jan.	0	0	0	0	0
Feb.	0	0	0	0	0
Apr.	–	0	–	–	0
May	0	0	0	0	135
June	–	–	1.01	518	77.3
July	0	0.42	0	2.09	–
Aug.	0.22	0.44	0.29	2.07	–
Sept.	0	0	0	1.82	0
Oct.	0	0	–	–	–
Nov.	0	0	0	0	–
Dec.	0	0	0	1.26	0
1963					
Jan.	0	0	0	0	–
Feb.	0	0	0	0	0
May	–	0	0.24	0	0
June	–	0	0	4.50	–
July	–	–	0	0	0
Aug.	–	0	0	0	–
Sept.	0	–	–	–	0
Oct.	0	0	0	–	–
Nov.	0	0	4.47	0	–
Dec.	0	0.08	0	0	–
1964					
Feb.	0	0	0.05	1.63	0
Mar.	0	0	0	0	–
Apr.	0	0	0	1.10	–
May	–	0	0	0	–

"bloom" from May through September 1962 when catches were high and it was the most numerous species (Table 2). However, it was not particularly common during the summers of 1961 and 1963 off Newport.

IASIS ZONARIA (PALLAS) 1774

Iasis zonaria, one of the most common salps in temperate waters (Thompson 1948), was second only to *S. fusiformis* in its occurrence and abundance. *Iasis zonaria* showed a very definite pattern in its latitudinal distribution. Both frequency of occurrence and catch per tow decreased from south to north (Table 1). It appeared most commonly off Brookings, where it occurred at all stations 15–165 miles offshore, and not at all off the Columbia River. This trend suggests a southerly center of abundance. Such a conclusion was supported by high catches of this species on a cruise south and west of Oregon between 43°10′N, 132°20′W and 36°34′N, 141°11′W, February–March 1965.

Iasis zonaria occurred most months of the year (Fig. 2), but highest catches were made in the spring and summer.

PEGEA CONFOEDERATA (FORSKÅL) 1775

Occurrence of *P. confoederata* off Oregon represents a significant extension of its known range. It is a truly warmwater species and is abundant in all warm and temperate oceans as far north as southern California (Thompson 1948).

The species occurred in only 2% of the collections during the study (Table 1). It was captured at least once on every station line. An interesting latitudinal change in the distance we found it offshore was apparent. The farther north we found this species, the closer to shore it occurred. It was collected 105–145 miles off Brookings, 65 miles off Coos Bay, 14–65 miles off Newport, and 15 miles offshore of the Columbia River.

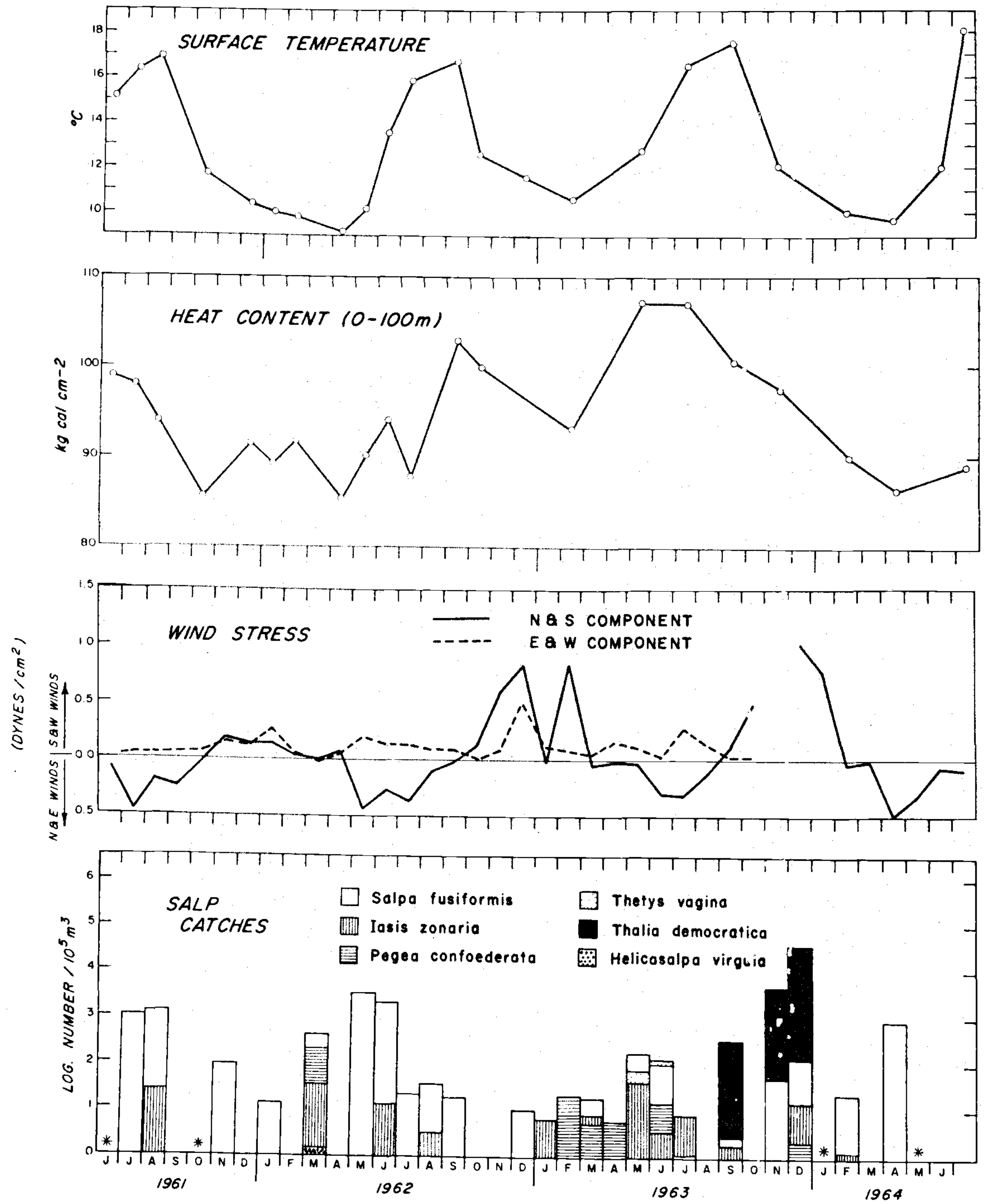

FIG. 2. Monthly variations of some ocean features and salp catches, 1961–64. Surface temperature is that at the station 65 miles off Newport. Heat content is that at the station 65 miles off Newport (data from Pattullo et al. 1969 except for 1961). The points for heat content on June 1961 and November 1963 and those for surface temperature on June 1961 and 1964 are from the station 45 miles off Newport. Wind Stress is calculated from monthly mean sea-level atmospheric pressure at 45°N, 125°W (data in part from Smith 1964). Salp catches are from midwater trawls. The logarithm of the catch of each species is plotted from the abscissa. Asterisks (*) denote months when no tows were made. Months are blank when tows were made but no salps were caught.

Pegea confoederata appeared irregularly throughout the winter and spring (December–June) (Fig. 2). It was collected off southern Oregon in March and June of 1962 and off central and northern Oregon in February, April, and June of 1963. Its frequency of occurrence was higher in 1963 than any other year.

THETYS VAGINA TILESIUS 1802

This cosmopolitan species was captured only five times, all in May and June of 1963. It was collected on every station line except the northern line, occurring between 25 and 5 miles offshore.

THALIA DEMOCRATICA (FORSKÅL) 1775

The occurrence of this form off Oregon represents a northern extension of its known range in the eastern Pacific. It is the most abundant species of salp south of 35° in the northeastern Pacific (Ritter 1905; Thompson 1948; Berner MS 1957).

Thalia democratica was collected only 12 times. All occurrences were in September, November, and December of 1963 (Fig. 2). When present, it was very numerous, and densities were much higher than found for any other salp. Maximum catches were 80 per m^3 in midwater trawls and 150 per m^3 in plankton nets.

HELICOSALPA VIRGULA (VOGT) 1854

Helicosalpa virgula, which usually has been collected in warm oceanic regions (Thompson 1948; Yount 1958), has not previously been reported in the northeastern Pacific Ocean. Two specimens were caught 45 miles off Coos Bay in March 1963.

Depth Distribution

In the over 200 samples made with opening-closing nets in the upper 1000 m, no salps were collected below 150 m. This indicates that salps off Oregon are generally epipelagic in their vertical distribution and are found where wind-driven ocean circulation is most pronounced.

Salps and Ocean Conditions

1963 was an unusual year during this study and provides evidence for intrusion of warmwater salps into Oregon waters. *Thalia democratica*, *Thetys vagina*, and *Helicosalpa virgula* were collected only during this year (Fig. 2). *Pegea confoederata* occurred more frequently during 1963 than in any other year. All these species are thought to be warmwater forms (Ritter 1905; Thompson 1948; Berner MS 1957; Yount 1958). Berner, for example, states that *T. democratica* is a warmwater form, often abundant south of 35°N off California in the northeastern Pacific.

Data on heat content in the upper 100 m (from Pattullo et al. 1969), but not surface temperature, shows that 1963 was an unusually warm year off Oregon (Fig. 2). Dodimead and Pickard (1967) also found that 1963 was a warm year: temperatures at the top of the halocline were generally warmer than average over a large region of the eastern subarctic Pacific. Wickett (1967, and unpublished data) calculated that Ekman transport to the south between 45° and 50°N in the northeastern Pacific was lower in 1963 than other years during our study. This resulted in a weakened California Current System and a greater possibility of transport of surface waters from central regions into Oregon waters. These annual differences suggest that the warmwater salps present in 1963 may be indicators of advection of water from the south or southwest.

Seasonal variations in wind direction from 1961 to 1964 (Fig. 2) were obvious. Northerly winds predominated in the summer, resulting in coastal upwelling (Smith et al. 1969); southerly winds predominated in the winter, resulting in a northerly and inshore movement of surface waters (Burt and Wyatt 1964). Highest catches of salps, mainly *S. fusiformis*, occurred during the summers of most years, when northerly winds prevailed. *Iasis zonaria* also occurred most frequently during the summer. The very high catches of *T. democratica* in the fall of 1963 coincided with a period of southerly wind stress. Likewise, *P. confoederata* usually occurred during the winter or just after periods of southerly winds and currents.

Although advection from warmer regions may explain the occurrence of some salp species off Oregon, it is not an equally tenable explanation for all species of salps. *Salpa fusiformis* and *I. zonaria* were found in Oregon waters all seasons of the year. High catches of these species were made during the summers, when northerly winds and upwelling prevailed, and in years other than 1963. Both of these species have wide latitudinal ranges that extend into temperate waters (Thompson 1948). They are perhaps the most likely species to have year-round resident populations off Oregon.

Salpa fusiformis is known to be a eurythermal species (Thompson 1948; Berner MS 1957). Off Scotland, *S. fusiformis* is common and the only salp that normally reproduces at these latitudes (Fraser 1949, 1962). Off Oregon *S. fusiformis* was found at surface temperatures ranging from 8 to 14 C and surface salinities from 30.5 to 33.5‰.

The variety of sizes, the occurrence of sexual as well as asexual stages, and stolon proliferation found in *S. fusiformis* and *I. zonaria* off Oregon are evidence for local reproduction and in situ changes in population number. Reproduction may be rapid and affect population fluctuations and patchiness. Braconnot (1963) obtained complete development of oozoids and liberation of chains of blastozoids in only 8–12 days in laboratory experiments with *T. democratica*. The fact that highest numbers of *S. fusiformis* and *I. zonaria* were found during the summer, especially in oceanic water, may be related to the pronounced heating of offshore surface waters during this season (Pattullo et al. 1969). Upwelling and the Columbia River plume influence phytoplankton production off Oregon during the summer (Anderson 1964; L. E. Small et al. unpublished data) and may also influence the reproduction and abundance of these species of salps.

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SCATTERING LAYERS AND VERTICAL DISTRIBUTION OF OCEANIC ANIMALS OFF OREGON*

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ABSTRACT

This paper reviews some of the distributional features of vertically migrating micronekton off Oregon; describes a new, conducting-cable, midwater-trawl system using an eight-net, opening-closing cod-end unit; and gives some preliminary results on trawl catches relative to sound-scattering layers.

A variable complex of organisms, including euphausiids, a sergestid shrimp, and mesopelagic fishes, was often common in 12- and 38.5-kHz scattering layers. The depth range of many species was broad, and sometimes the largest catches were made at depths above or below scattering layers. Variability was large among nets that fished either horizontally or vertically during single tows.

DISTRIBUTION OF MESOPELAGIC ORGANISMS OFF OREGON

Only a few species of oceanic micronekton predominate our nighttime-midwater trawl collections in epipelagic waters off Oregon. The lanternfishes *Stenobrachius leucopsarus, Diaphus theta,* and *Tarletonbeania crenularis;* the melanostomiatid *Tactostoma macropus;* the sergestid shrimp *Sergestes similis;* and the euphausiid *Euphausia pacifica* are all abundant. All these species (except *T. macropus*) have been correlated with biological sound scattering in other areas (Barham, 1956 and 1963; Kampa and Boden, 1954; Taylor, 1968; Tucker, 1951).

Of the fishes, *Stenobrachius leucopsarus* juveniles (less than 30-mm standard length) have a gas-filled bladder, but the swimbladder of adults is regressed and surrounded by fatty tissue (Capen, 1967; Butler, 1970). We have found gas in the swimbladders or body cavities of some *Diaphus theta* and *Tarletonbeania crenularis;* gas usually occurred in small individuals but was found in individuals larger than 30 mm. All *Hierops (Protomyctophum) crockeri* and *thompsoni* examined at sea had gas-filled swimbladders (Butler, 1970).

Studies with an opening-closing cod-end unit on a 6-foot Isaacs-Kidd midwater trawl (IKMT) provide good evidence for vertical migration of the four common mesopelagic fishes and *Sergestes similis* between broad depth intervals off Oregon. In the upper 150 m, nighttime catches exceeded daytime catches; between 150 and 500 m, daytime exceeded nighttime catches (Pearcy and Forss, 1966; Pearcy and Laurs, 1966). Catches of these species between 500 and 1,000 m were low, and no diel differences were evident. The ratios of night to day catches per m^2 in the water column to 1,000 m for all species were greater than 1.0, indicating avoidance of

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the trawl during the daytime. Although only slightly more *Diaphus theta* were collected per m^2 at night, over four times as many *Tarletonbeania crenularis* were caught at night than during the day.

The average size of mesopelagic fishes also varied with depth; individual weight was lower in 0- to 150-m collections than in 150- to 500-m and 500- to 1,000-m collections (Pearcy and Laurs, 1966). These studies also show broad depth ranges for mesopelagic species. During the night, for example, lanternfishes and shrimps were caught at all depths within the upper 1,000 m and were not concentrated solely near the surface. Vertical migrations and distributional patterns *within* these broad depths undoubtedly occur. Pearcy (1964) found that the three common lanternfishes sometimes have different distributions within the upper 100 m at night.

In any quantitative study of pelagic animals, distributional patterns and catch variability are important considerations. Repeated tows during night or day periods suggest patchy or clumped distributions of mesopelagic fishes (Pearcy, 1964; Pearcy and Laurs, 1966). Ebeling, Ibara, Lavenberg, and Rohlf (1970) reported that most mesopelagic fishes off southern California were more clumped at middepths during the day than near the surface during the night. Donaldson (1968) found that the thickness of 38.5-kHz scattering layers was less during the day than at night off Oregon, a trend that suggests that the density of organisms within layers may be higher by day (Taylor, 1968).

The number of scattering-layer organisms may vary seasonally and annually. Significant differences in the number and biomass of midwater animals have been reported off Oregon (Laurs, 1967; Pearcy, 1964, 1965; Pearcy and Forss, 1966; Pearcy and Laurs, 1966; Pearcy and Osterberg, 1967). In oceanic waters over and beyond the continental slope, the highest biomass of small nektonic fishes, squids, and shrimps generally occurred in the summer; the lowest biomass occurred in the winter. Over the outer edge of the shelf, however, the reverse was true. Usually higher catches were made in winter than in summer.

These inshore-offshore and seasonal changes also may be related to changes in size structures of populations. The decrease in biomass in winter offshore catches was correlated with an increased recruitment of small *Stenobrachius leucopsarus*. Small lanternfishes of this species have gas-filled swimbladders, but large individuals do not. The sound-scattering potential offshore, therefore, may be higher during winter than during summer, even though the total micronekton biomass may be lower in winter.

MIDWATER TRAWL SYSTEM

A conducting cable system using a 6-foot IKMT with an eight-bar multiple plankton sampler (MPS) (Bé, 1962; Pearcy and Hubbard, 1964) as an opening-closing cod-end device sampled oceanic animals to 1,000 meters (Fig. 1). Pressure (depth), temperature, flow (revolutions), and net opening were scanned sequentially and transmitted as frequency-modulated (FM) signals from transducers on the IKMT-MPS to recording units on deck.

The electrical system is illustrated in Figure 2 as a block diagram. One hundred fifty milliamperes at 50 volts direct-current is transmitted down the 4,600 m of 11-mm coaxial cable (U.S. Steel Corp.) into the pressure housing on the MPS. This housing contains the net actuator, transducer, and scanning and signal transmission electronics. When a net release button is pushed on shipboard, a polarity reversal of the voltage to the MPS takes place. When the net release button is returned to its normal position, the motor circuit actuates a 2-rpm gear motor for one shaft revolution that opens one net and closes another. Cams located on top of the MPS are coupled directly with the motor shaft in the electronics package. During one motor-shaft revolution, one cam turns 360°, releasing one lever bar that holds the net bar in a cocked position.

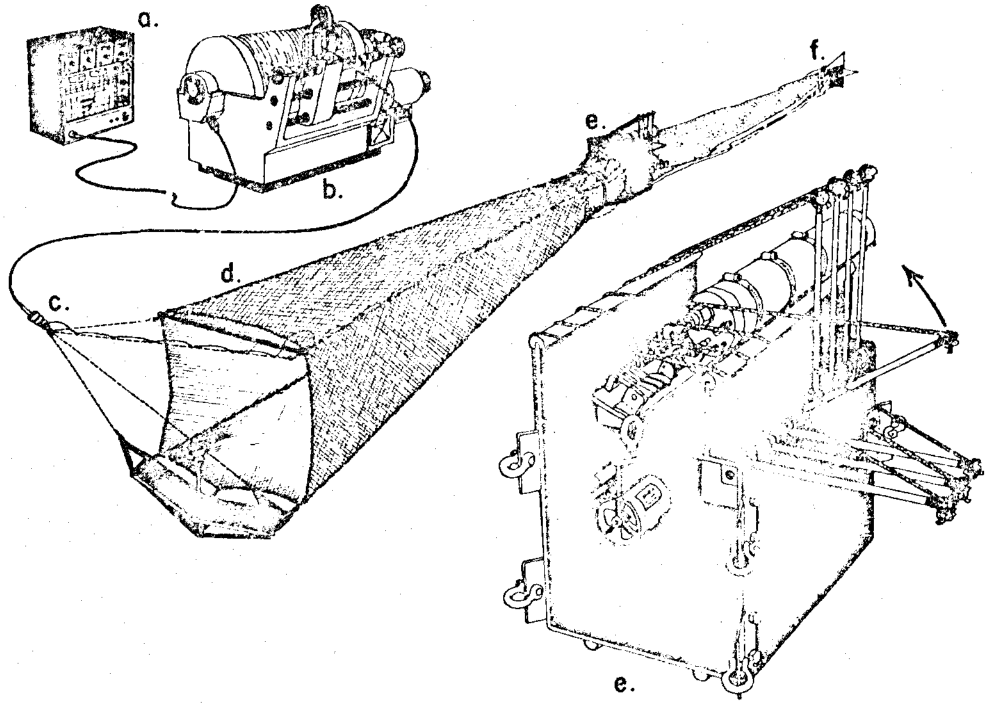

Figure 1. A conceptual drawing of the components of a conducting-cable, midwater-trawl MPS system with the following parts: (a) deck readout recorders, (b) deck winch with slip rings and conducting cable, (c) electric swivel, (d) 6-foot IKMT, (e) eight-bar MPS, and (f) eight sample nets.

This operation is repeated eight times for release of eight nets. During the motor operating period, an FM signal that identifies which net is opened is transmitted to the surface.

Actuation of the net release motor interrupts the automatic scan sequence of the transducer outputs. Between net actuations, the electronic scanner sequentially connects the transducer outputs for discrete periods of time to a voltage-controlled oscillator (VCO) generating FM signals. The VCO output is coupled through an electronic driver stage to the coaxial cable. Signals are displayed aboard ship in two ways: on an analog strip-chart recorder, and on a digital counter. The recorder offers a quick observation of a tow pattern of the trawl. The digital readouts, which are periodically written on the strip-chart record, give the greatest resolution. The maximum resolving capability in the monitoring system is one part in one thousand of transducer output signal.

Depth was monitored with a potentionmetric type Servonic model H-172-5 pressure transducer. The transducer was calibrated in the lab with a temperature-corrected Heise pressure gage. The depth resolution was ± 1 m and was transducer limited.

Water temperature was sensed by a 10-kΩ thermistor (Yellow Springs Instrument Corp.) at 25°C. It was calibrated to ±0.02°C in an ice bath with a Hewlett-Packard quartz thermometer and referenced by a platinum thermometer and Mueller bridge. The thermistor time constant was 1.3 min.

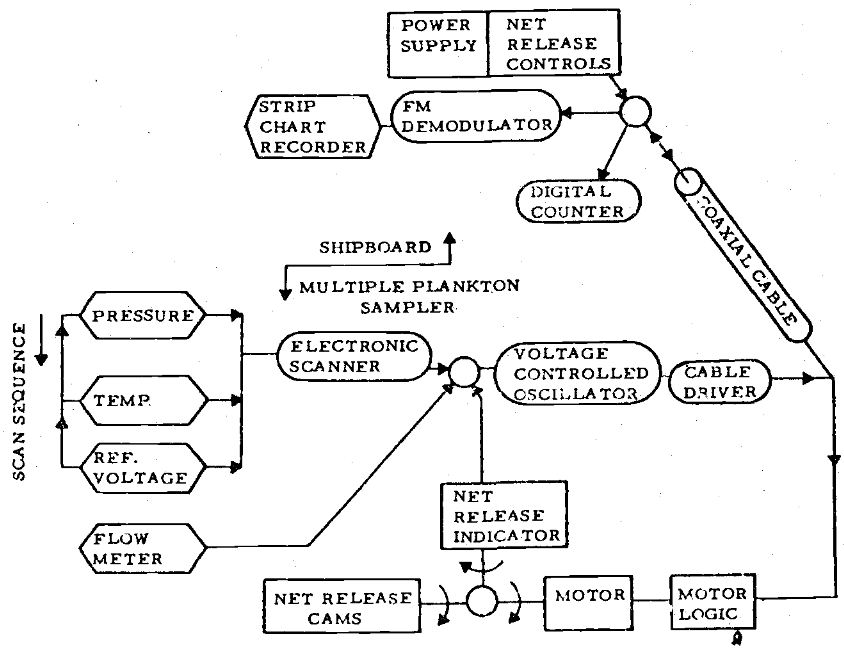

Figure 2. Block diagram of the electronic modules inside the MPS electronics case

A voltage reference was used to excite the pressure and temperature transducers and to act as a figure of merit. This reference is monitored each scan cycle along with the transducer signals. If our reference has changed during a tow, it indicates not only an error in data but an electrical malfunction in the transmitting electronics.

The electronics scanner was set to sense pressure for 20 sec and temperature and reference for 10 sec each. As indicated in Figure 2, however, the flowmeter has a priority to interrupt the scanner at any time. This is because the flowmeter is a revolution counter, recording a signal every 1,000 revolutions of an impellor by causing the VCO input to go to zero. On the strip-chart recorder, the flowmeter signals appear as event marks that interrupt the regular analog records of pressure and temperature.

The MPS box (40 X 40 X 51 cm) is made of 7-mm aluminum and weighs 30 kg complete with the electronic package on top. The MPS nets, 3 m long, are of 0.571-mm Nitex. The liner of the IKMT is 5-mm mesh.

The electrical IKMT-MPS system was used successfully on a cruise from 12 to 18 November 1969. Twenty-six separate tows were made; opening-closing malfunctions occurred on five tows, usually because of human error in resetting the equipment. The flowmeter, mounted inside the MPS box, worked on only eight tows because of a short in the magnetic switch. The flow through the MPS on these eight tows was fairly uniform throughout an entire tow. There was no evidence for closure of the MPS mouth caused by twisting of the net. However, in one case, an interruption in the flow was caused by a squid caught in the impeller.

Catches were calculated on the basis of grams (wet weight) collected per minute. Tow speeds were fairly constant within a single tow and ranged from 3.4 to 4.6 knots among tows. At this speed, a 6-foot IKMT (mouth area of 2.9 m^2) with a filtration efficiency of 85% (Pearcy and

Laurs, 1966) filters about 260 to 350 m^3/min. All tows were beyond the continental slope off central Oregon between latitudes 44°12′ and 44°55′ N and longitudes 125°25′ and 126°05′ W).

When the trawl descended to the maximum tow depth, the first MPS net fished obliquely over a large depth range. Because of this, and the fact that flow rate was usually lower in this net, the first net often was not included in the catch results of all tows.

Two echo sounders were used during this cruise: (1) a 12-kHz Edo model 248 transceiver with a pulse power of 1,400 watts and an Edo 333B recorder and (2) a 38.5-kHz Simrad 510-S echo sounder with a pulse power of 450 watts. Gain was reduced in surface waters of both recorders to accentuate subsurface scattering layers; hence, surface scattering layers in the upper 36 m usually were not recorded.

SCATTERING LAYER VARIATIONS

The depth and thickness of 12-kHz scattering layers for two diel periods during the cruise are replotted in Figure 3. Variability is pronounced. Layers were recorded within the upper 100 m during both day and night periods. Sometimes these surface layers deepened or shoaled within day or night periods. Migration of layers occurred during twilight periods (sunrise was about 0600 hours; sunset, 1730 hours, local mean time). The descent on 18 November was to greater depths than on 14 November. Ascent toward the surface occurred during midafternoon on both days. Note that a layer descended from the main ascending migratory layer at about 1800 hours on 18 November; it migrated downward to about 400 m, but then ascended to rejoin the main layer at 2400 hours. This descent of a secondary layer from a main ascending layer was observed on another day; but in this second instance, it remained at 400 m and did not ascend to join the main layer. Echo groups or "tent fish" were recorded near the surface after descent of the mi-

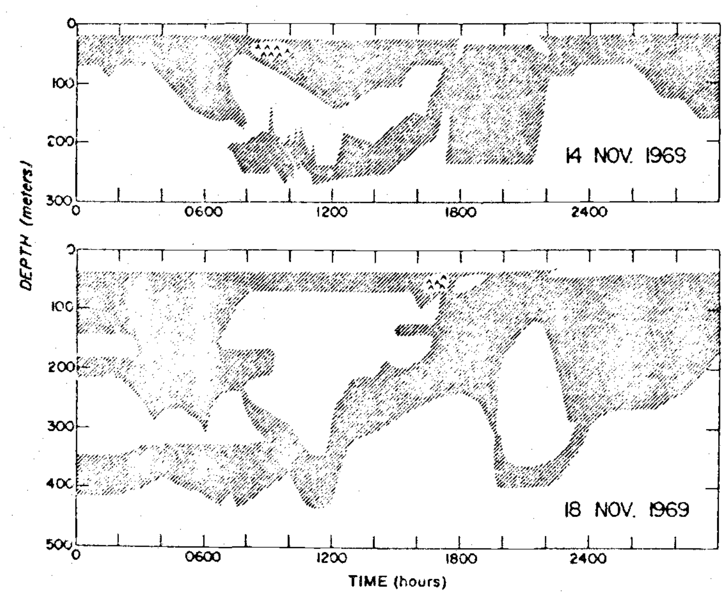

Figure 3. Depth distribution of 12-kHz sound-scattering layers over two diel periods of the November cruise. ^^ indicates echo groups.

gratory scattering layers on 14 November and before ascent of the migratory layer on 18 November (see also Fig. 4).

MIDWATER TRAWL CATCHES AND SCATTERING LAYERS

The catches of midwater animals relative to sonic-scattering layers are summarized for six of our IKMT-MPS tows in Tables 1 through 6 and Figures 4 through 9. These tows indicate some of the spatial and temporal variations of the catches.

Variability within Depths

Repeated collections were made at 40 m within a scattering layer after it ascended into surface waters (Fig. 4 and Table 1). Each net in this series sampled for 20 min, filtering approxi-

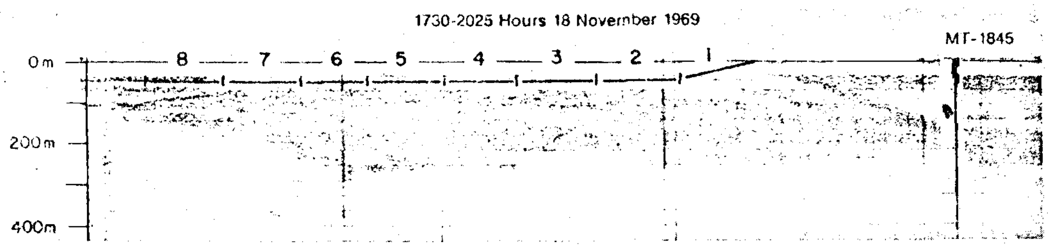

Figure 4. A 12-kHz echogram taken from 1730 to 2025 hours on 18 November 1969. In Figures 4 through 9, the echogram is superimposed on the trajectory of the trawl and numbers of the MPS nets. The times given apply to the duration of the tow, time increasing from right to left.

Table 1. Catches of Midwater Animals from 1730 to 2025 Hours on 18 November 1969

Depth range of sound-scattering layer (m)		Depth of each net fished		Biomass[a] (grams wet weight/minute)				Number of *S. leucopsarus*
38.5 kHz	12 kHz	Net	Depth (m)	F	S	E	P	
10-60	36-250	2	40	0.11	0	3.20	0.54	6
		3	40	0.30	T	2.25	0.40	0
		4	40	T	T	4.80	0.26	8
		5	40	T	T	5.32	0.61	2
		6	40	T	T	1.05	0.70	1
		7	40	0.06	0.05	4.36	0.38	3
		8	40	0	0	4.80	0.30	0

[a]Catches are represented as follows: F = Fishes, S = shrimps, E = euphausiids, and P = plankton. Large catches are underlined. T indicates trace, less than 0.01 g/min. S or L refers to the numbers of small (less than 30-mm standard length) or large (greater than 30-mm standard length) *Stenobrachius*. Genera in parentheses were common but did not predominate the catch.

mately 5,000 m^3 at 3.4 knots. Variations in the biomass (grams wet weight per minute) of fishes and shrimps were large among samples. Catches of euphausiids and plankton, however, were less variable. The numbers of the common lanternfish *Stenobrachius leucopsarus* also indicated a clumped or patchy distribution.

The tow depicted in Figure 5 and Table 2 shows both horizontal and vertical variability of catches. The largest catches of fishes, shrimps, euphausiids, and plankton were made in the first net at 0 to 35 m. Although the 12-kHz scattering layer started 18 m from the surface and the 38.5-kHz layers started 10 m from the surface, the layers probably continued to the surface through the gated-out portion of the echograms. Two of the three samples at 35 to 38 m had large fish biomasses; only one of the three samples below the scattering layer at 77 m had a large *Sergestes* biomass. The biomass of *Euphausia pacifica*, on the other hand, was uniformly large between 35 and 77 m and small below 77 m. Thus, large catches were made within the scattering layer, and smaller catches were made below the scattering layer. Variability within horizontal strata was again large, and variability was larger for fishes and shrimps than for euphausiids.

Table 2. Catches of Midwater Animals from 2040 to 0010 Hours on 14 November 1969

Depth Range of sound-scattering layer (m)		Depth of each net fished		Biomass[a] (grams wet weight/minute)				Abundant genera	
38.5 kHz	12 kHz	Net	Depth (m)	F	S	E	P		
10-50	18-70	1	0-35	5.56	1.95	20.56	24.01	*Stenobrachius* (S > L)	Medusae
		2	35	2.46	0.30	3.00	0.71	*Tactostoma*	*Euphausia*
		3	35-38	2.38	0.58	5.40	0.13	*Diaphus*	*Sergestes*
		4	38	0.79	0.06	3.99	0.04	*Tarletonbeania*	
		5	38-77	2.11	0.43	3.18	0.76	*Tactostoma*	
		6	77	0.13	0.46	0.18	0.15		
		7	77	0	0.08	0.09	0.06		
		8	77	0.67	1.17	0.20	0.28	*Sergestes*	

[a]See Table 1.

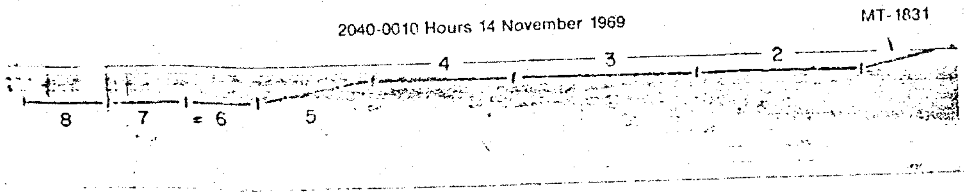

Figure 5. A 12-kHz echogram taken from 2040 to 0010 hours on 14 November 1969

Variability Among Depths

Two tows sampled similar depths and fished through and below a scattering layer during one night (Figs. 6 and 7 and Tables 3 and 4). The layer, which first shoaled and then deepened, was from 18 to 90 m on the 12-kHz Edo. Two layers within this depth range appeared on the 38.5-kHz Simrad echogram. In the first tow *Sergestes similis* biomass peaked between 10 and 45 m; the *Euphausia pacifica* biomass was largest at 45 m (within both the 38.5- and 12-kHz layers); and the fish biomass (mainly *Tactostoma macropus*) was largest between 96 and 144 m, near the lower edge of the thick portion of the layer (Table 3).

Table 3. Catches of Midwater Animals from 2048 to 2351 Hours on 13 November 1969

Depth range of sound-scattering layer (m)		Depth of each net fished		Biomass[a] (grams wet weight/minute)				Abundant genera
38.5 kHz	12 kHz	Net	Depth (m)	F	S	E	P	
10–25		7	10-45	5.54	3.09	0.13	0.34	*Sergestes* (*Stenobrachius*)
40–50	18–70							
		6	45	0.74	0.52	0.21	1.09	*Euphausia* { *Stenobrachius*, *Tactostoma*, *Euclio* }
		5	45-91	0.68	1.10	0.10	0.14	
		4	91-96	0.49	0.70	0.02	0.10	
		3	96-144	1.20	0.29	0.01	0.18	*Tactostoma*
		2	141-145	0.41	0.17	0	0.35	

[a]See Table 1.

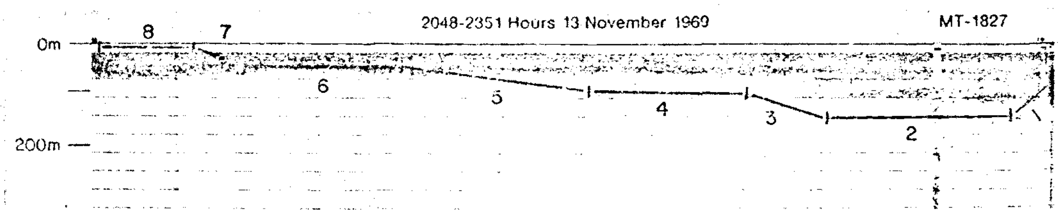

Figure 6. A 12-kHz echogram taken from 2048 to 2351 hours on 13 November 1969

The second tow (Table 4, Fig. 7) which started about 2 hours after the end of the first one, had the largest catches of fishes, shrimps, and euphausiids in the 97-145 m net, below or in the lower edge of the scattering layer. Most of the fish biomass caught at the depth of the scattering layer was from *Tactostoma macropus*. These changes in vertical distributions may be caused by horizontal patchiness or the descent of *Sergestes* and *Euphausia* within the scattering layer during the sampling period.

Table 4. Catches of Midwater Animals from 0200 to 0535 Hours on 14 November 1969

Depth range of sound-scattering layer (m)		Depth of each net fished		Biomass[a] (grams wet weight/minute)				Abundant genera
38.5 kHz	12 kHz	Net	Depth (m)	F	S	E	P	
15-25		1	0-10	0.08	0.25	0.06	0.58	
40-50	18-90	2	10-50	0.76	0.04	0	0.15	(*Tactostoma*)
		3	50	0.62	0.04	0.08	0.30	
		4	50	0.41	0.06	0.23	0.25	
		5	50-97	0.15	0.28	0.14	0.21	
		6	97	0.05	0.46	0.26	0.20	
		7	97-145	<u>1.17</u>	<u>0.86</u>	<u>0.49</u>	0.39	*Stenobrachius*(S) *Tactostoma* *Sergestes* *Euphausia*

[a]See Table 1

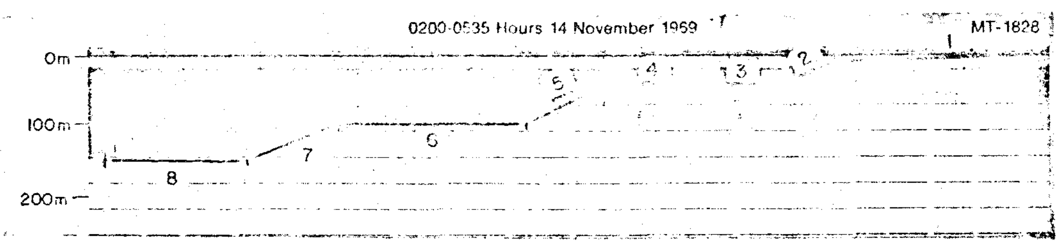

Figure 7. A 12-kHz echogram taken from 0200 to 0535 hours on 14 November 1969

Deep Scattering Layers

Sometimes during the day, and less commonly at night, a deep scattering layer (DSL) was apparent on 12-kHz echograms at 350 to 420 m (Figs. 8 and 9). Tables 5 and 6 show the catches above and within such a deep layer on two consecutive tows.

During the daytime tow (Figure 8 and Table 5), catches of fishes and shrimps were larger in samples in the DSL than above the DSL. (Nets 1 and 2 fished in the surface scattering layer but caught almost nothing.) Euphausiids were most numerous in and just above the DSL (324 to 410 m). The large plankton biomass in net 4 resulted from *Lensia*, a nonphysonect siphonophore. The most numerous fish in the DSL was small *Stenobrachius leucopsarus* (less than 30 mm).

The DSL started to rise toward the surface at 1400 hours on 17 November (Fig. 8). The migration of this layer continued toward the surface and is apparent between 200 and 300 m in Figure 9. A portion of this migratory layer appeared to split off at 1650 hours (just below start of net 2 in Fig. 9) and descend to 360 to 420 m, the original day depth of the layer in Figure 8. A second layer also appeared to descend from the main layer at 1730 hours (end of net 3) to form an intermediate layer at about 200 m.

The IKMT-MPS was towed horizontally at 173 to 180 m while the main layer migrated upward (Fig. 9 and Table 6). Catches in net 2, which appeared to fish in the densest part of the layer, were low. Many euphausiids were caught in net 3 after the main layer migrated above the tow depth and when the net fished in the vicinity of the intermediate layer. *Sergestes* also was caught at 175 m, but mainly in net 4. The largest fish biomass was caught in the two nets that fished the DSL, which was located between 360 and 420 m.

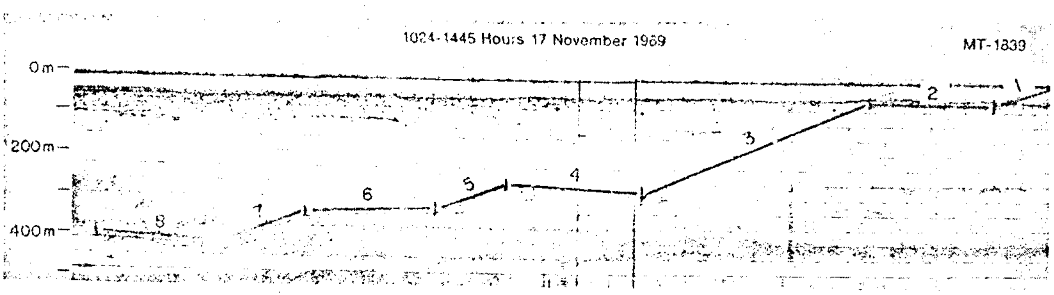

Figure 8. A 12-kHz echogram taken from 1024 to 1445 hours on 17 November 1969

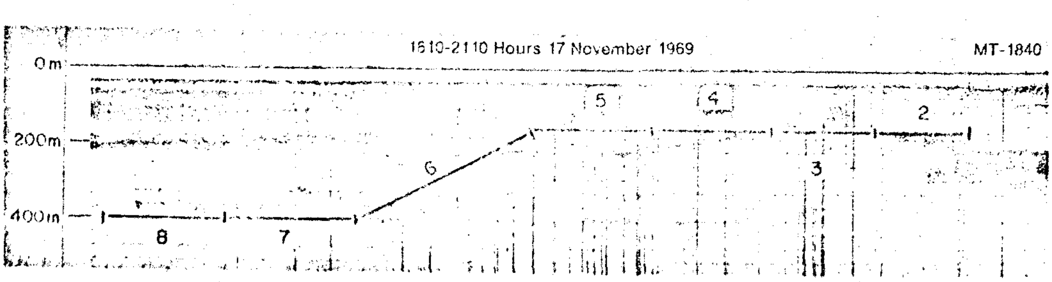

Figure 9. A 12-kHz echogram taken from 1610 to 2110 hours on 17 November 1969

Table 5. Catches of Midwater Animals from 1024 to 1445 Hours on 17 November 1969

Depth range of sound-scattering layer (m)	Depth of each net fished		Biomass[a] (grams wet weight/minute)				Abundant genera
12 kHz	Net	Depth (m)	F	S	E	P	
37–70	2	53–48	0	0	T	0.14	
	3	48–277	T	T	0.01	0.23	
	4	277–256	0	0	0.04	5.16	*Lensia*
	5	256–324	T	T	0.01	0.48	*Euclio*
	5	324–330	0.03	0	0.16	0.53	
350–420	7	330–405	0.12	0.12	0.16	0.27	*Diaphus* *Sergestes* *Stenobrachius* (S) *Euphausia*
	8	405–410	0.42	0.11	0.17	1.09	

[a]See Table 1.

Table 6. Catches of Midwater Animals from 1610 to 2100 Hours 17 November 1969

Depth range of sound-scattering layer (m)		Depth of each net fished		Biomass[a] (grams wet weight/minute)				Abundant genera
38.5 kHz	12 kHz	Net	Depth (m)	F	S	E	P	
down to 175	down to 175	2	173–180	0	T	0.32	0.23	
		3	173–175	0.33	0.32	1.08	0.35	*Euphausia*
		4	175	0.17	0.89	0.12	1.64	*Sergestes*, siphonophore
		5	175	0.11	0.43	0.10	0.21	
	360–420	6	175–400	0.66	0.57	0.15	0.89	*Stenobrachius* (S > L), siphonophore *Tactostoma*
		7	400–410	0.58	0.12	0.06	0.57	*Stenobrachius* (S > L) *Hierops* *Chauliodus*

[a]See Table 1.

Small *Stenobrachius leucopsarus* were numerous in the DSL (350 to 420 m) during both the daytime and nighttime tows (Tables 5 and 6). These fish have gas-filled swimbladders (Capen, 1967) and may be principal contributors to this 12-kHz sound-scattering layer off Oregon. *Sergestes* and *Euphausia*, on the other hand, were common within depths of the DSL during the day but were most common above the deep layer at night. Small *S. leucopsarus* of the same age group also were caught in large numbers near the surface at night. They were common in a scattering layer in the upper 50 m later during the night of 17-18 November, the same night they were captured in deep water (Table 6). This suggests two centers of abundance or migratory and nonmigratory individuals of this age group within the population.

Summary of Occurrences Relative to Scattering Layers

Table 7 shows how frequently common groups of animals had peak abundance in, above and below scattering layers. These data are only from tows that sampled through layers.

Table 7. Occurrence of Maximum Catches of Various Midwater Animals

		Euphausids	Sergestids	Siphonophores	Pteropods	*Stenobrachius*	*Lampanyctus*	*Diaphus*	*Tarletonbeania*	*Hierops*	*Tactostoma*	*Chauliodus*
0–100 m Night	12 kHz (9 tows)	AA IIIII BB	AAA III BB	B	AA II	A IIIII* BBB		III B	II		III BBBB	
	38.5 kHz (8 tows)	IIIIII B	IIIII BB		III	A IIIII*I* BB		A III B	I		II BBBB	
Day	12 kHz (4 tows)	I BB	B	B	I B	BB	B	B	B			
	38.5 kHz (4 tows)	I BB	B	B	I B	BB	B	B	B			
100–275 m Day/night	12 kHz (4 tows)	A II B	II B	II		I BBB*		II B	B	B	B	BB
Day/night	38.5 kHz (3 tows)	A I B	BB	A B	A	A B		A	BB	B		B
350–420 m Day/night	12 kHz (4 tows)	A III	AA I	AAAA		IIII B*		I		II		I

*This table shows how often the maximum catches of various common midwater animals occurred in (I), above (A), and below (B) the sound-scattering layer sampled. Night and day tows were tabulated separately when four or more tows could be included. An asterisk indicates a preponderance of *Stenobrachius* larger than 30 mm.

Within the upper 100 m at night, euphausiids, *Sergestes*, and *Stenobrachius* peaked at scattering-layer depths more frequently than other animals. Euphausiids, for example, were common at scattering-layer depths in seven out of eight tows through 38.5-kHz layers. The higher occurrence of peaks in 38.5- than in 12-kHz scattering layers was influenced by the greater portion of the 12-kHz echograms that were gated out near the surface.

During the day, catches of most groups of animals were largest below both the 38.5- and 12-kHz layers. Only euphausiids and pteropods peaked at scattering depths, and then only infrequently.

Poor correlations also were found between abundances and scattering between 100 to 275 m during day and night periods, but the total number of tows was low. Small *Stenobrachius leucopsarus* were common in all four tows in 12-kHz layers between 350 and 420 m. Euphausiids were also more abundant in this DSL than above it in three of the four tows.

CONCLUSIONS

1. The depth and migratory pattern of scattering layers observed on echograms was variable among diel periods.
2. Replicate samples at discrete depths indicated patchy distributions of fishes and *Sergestes similis*. Catches of *Euphausia pacifica* were less variable.
3. Sampling during single nocturnal periods suggested that the depth distribution of species and species groups may change within surface scattering layers.
4. Although catches of species often varied among depths, many species were caught over wide depth ranges and were not completely aggregated into high-density, thin layers.
5. Catches of fishes, shrimps, and euphausiids were sometimes largest at scattering-layer depths. Sometimes catches of animals were low at scattering-layer depths, however, and sometimes large catches were made where no dense scattering layer was recorded.
6. *Euphausia pacifica*, *Sergestes similis*, and *Stenobrachius leucopsarus* were the animals that were caught most often in largest numbers in scattering layers, especially in the upper 100 m at night.
7. Small *Stenobrachius leucopsarus* (with gas-filled swimbladders) were caught in all tows that sampled the DSL (350 to 420 m) during day or night periods.

ACKNOWLEDGMENTS

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A NEW SPECIES OF *HYMENODORA* (DECAPODA, OPLOPHORIDAE) FROM THE NORTHEASTERN PACIFIC

BY

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INTRODUCTION

On 18 March 1970, two specimens of a new species of the oplophorid shrimp genus *Hymenodora* G. O. Sars, 1877, which possess several characters previously thought to be diagnostic of the oplophorid genus *Systellaspis* Bate, 1888, were collected from off Oregon, U.S.A. It is the purpose of this paper to describe this new species of *Hymenodora*.

The shrimps were taken in a beam trawl (BMT-189) which was towed at depth with 5400 m of cable out for 120 minutes during R/V "Yaquina" cruise Y7003B by the Department of Oceanography, Oregon State University. The depth of the bottom was 2560 m but the trawl failed to reach bottom. The approximate location was off the mouth of the Columbia River from 45°18.0'N 125°43.2'W to 45°17.2'N 125°48.3'W. Also present in the sample were specimens of the typically mesopelagic shrimps *Sergestes similis*, *Petalidium suspiriosum*, *Hymenodora frontalis* Rathbun, *H. glacialis* (Buchholz) and undescribed species of *Acanthephyra* and *Bentheogennema*.

I wish to thank Dr. James E. McCauley and Dr. William G. Pearcy of the Department of Oceanography, and Dr. Ivan Pratt of the Department of Zoology, for help and suggestions in reviewing the manuscript. This research was supported in part by grant AT (45-1) 1750 from the U.S. Atomic Energy Commission, and has been assigned manuscript number RLO-1750-85.

Hymenodora acanthitelsonis n. sp.

Types. — U.S. National Museum, Washington, D.C., Catalog Nos. 137500 and 137501. Holotype: male, carapace length 13 mm. Taken at 45°18.0'N 125°43.2'W to 45°17.2'N 125°48.3'W, R/V "Yaquina" cruise Y7003B, BMT-189, 18 March 1970, 0200 to 0830 PST, sample depth not known, bottom depth 2560 m. Allotype: female, carapace length 12 mm.

Diagnosis. — Telson ending in elongate, rounded end-piece with lateral spines. Anterior margin of first abdominal pleuron with distinct lobe or tooth overlapping hind margin of carapace. Eyes small, lightly pigmented, with median ocular tubercle. Two inner distal lobes of second maxilla broad, not projecting beyond basal lobe. Endopod of first maxilliped composed of two segments. Abdominal

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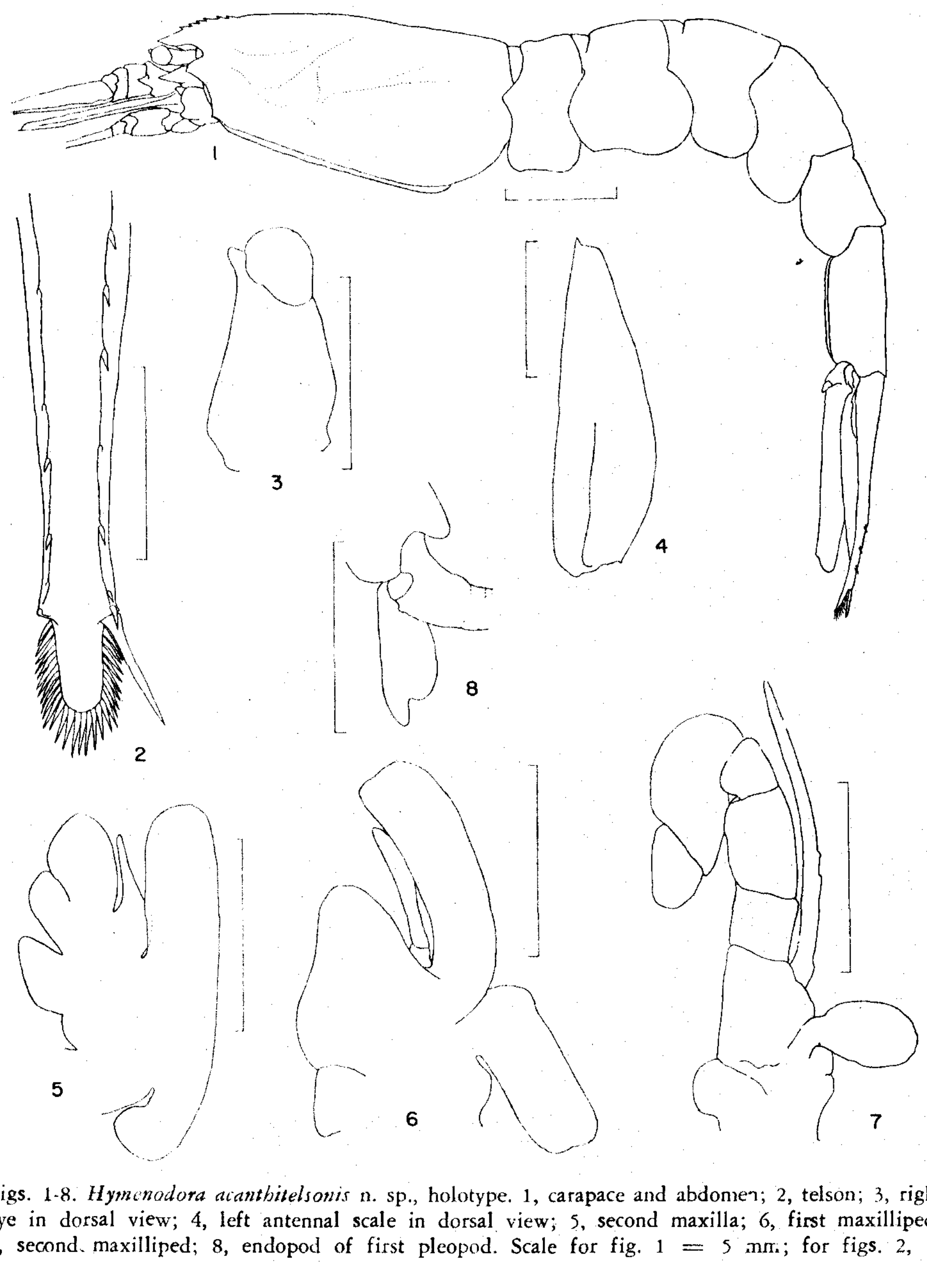
somites not dorsally carinate. Exopods of third maxillipeds and pereiopods neither foliaceous nor rigid.

Description. — Integument thin, rather firm. Carapace (fig. 1) carinate anteriorly on dorsum, carina extending onto rostrum. Dorsal carina with six teeth, three of which behind orbital margin. Rostrum reaching about as far as tips of



Figs. 1-8. *Hymenodora acanthitelsonis* n. sp., holotype. 1, carapace and abdomen; 2, telson; 3, right eye in dorsal view; 4, left antennal scale in dorsal view; 5, second maxilla; 6, first maxilliped; 7, second maxilliped; 8, endopod of first pleopod. Scale for fig. 1 = 5 mm; for figs. 2, 3, 5-8 = 2 mm; for fig. 4 = 3 mm.

eyes, dorsal surface convex. Small pterygostomial spine present. Cervical groove weakly defined laterally, continuous ventrally with obliquely directed sub-hepatic groove. Weakly defined groove directed obliquely upwards towards cervical groove from anterior end of supra-branchial groove. Short groove extending obliquely upward and backward from middle of supra-branchial groove.

Abdominal somites not dorsally carinate. Anterior margin of first abdominal pleuron with distinct lobe or tooth overlapping hind margin of carapace. Sixth abdominal somite about 1.8 times as long as fifth.

Telson (fig. 2) dorsally sulcate, bearing six or seven pairs of dorso-lateral spines; terminating in an elongate, rounded end-piece with about 29 lateral spines, preceded by pair of long lateral spines. Ciliated part of the external margin of uropodal exopod about one-ninth the length of the margin, separated from unciliated part by small tooth.

Eyes (fig. 3) small, lightly pigmented, with well-developed tubercle at base of cornea on the inner side of the peduncle.

Anterior margin of the second segment of antennal peduncle forming a rounded lobe over antennal scale. Antennal scale (fig. 4) three and one-fifth times longer than wide at its greatest breadth, tapered distally; terminal portion truncate, not reaching beyond outer spine.

Mandible toothed along entire cutting edge. Two inner distal lobes of second maxilla (fig. 5) broad, not projecting beyond basal lobe. Endopod of first maxilliped (fig. 6) composed of very short proximal segment and long distal one. Second maxilliped (fig. 7) bearing epipod but no podobranch.

Exopods of third maxillipeds and pereiopods neither foliaceous nor rigid.

Third maxillipeds reaching slightly beyond distal end of antennal scale. Second pereiopods reaching about one-half length of antennal scale. Third pereiopods reaching beyond antennal scale by length of dactyl. Fourth pereiopods reaching beyond antennal scale by about one-half length of dactyl. Fifth pereiopods reaching about one-half length of antennal scale.

Endopod of first pleopod of male (fig. 8) with elongate tooth-like projection on distal margin. Second to fifth pleopods of male and female with slender appendix interna. Appendix masculina on second pleopod of male as long as appendix interna.

Color in life not known. Faded to white in formalin, spines and setae on thoracic appendages orange in color.

Name. — The specific name *acanthitelsonis* is in reference to the spiny end-piece on the telson.

Remarks. — *Hymenodora acanthitelsonis* shows certain features previously thought to be diagnostic of the genus *Systellaspis*. In *Systellaspis*, the anterior margin of the first abdominal pleuron is armed with a distinct lobe or tooth overlapping the hind margin of the carapace, and the telson terminates in an end-piece laterally armed with spines (Chace, 1936, 1940). *Hymenodora acanthitelsonis* differs from *Systellaspis* in these features only in the shape of the terminal end-piece of the telson, which is apically acute in *Systellaspis* but rounded in *H. acanthitelsonis*. *Hymenodora acanthitelsonis* also differs from *Systellaspis* in the size and pigmentation of the eyes, which are very large and well-pigmented in *Systellaspis* (Chace, 1936, 1940).

Examination of specimens from Oregon material of the three other species of *Hymenodora*, *H. frontalis* Rathbun, 1902, *H. gracilis* Smith, 1886, and *H. glacialis* (Buchholz, 1874) all previously reported from off Oregon (Forss, unpubl.; Pearcy & Forss, 1966), reveals that the anterior margin of the first abdominal pleuron in these is not entire as has been reported for the genus (Chace, 1936, 1940), but is armed with a lobe or tooth. This tooth is not as well developed in these three species as it is in *H. acanthitelsonis* or in *Systellaspis*, and it rarely overlaps the hind margin of the carapace (it does so most often in *H. frontalis*, which has the lobe better developed than either *H. gracilis* or *H. glacialis*).

The form of the second maxilla and the number of segments in the endopod of the first maxilliped of *H. acanthitelsonis* is typical of the genus *Hymenodora*. According to Smith (1886) and Balss (1925), the two inner distal lobes of the second maxilla of *Hymenodora* are broad and do not project beyond the basal lobe, while the endopod of the first maxilliped is composed of only two segments, a very short proximal segment and a long distal segment. In the allied genera of *Acanthephyra*, *Meningodora*, *Notostomus*, *Ephyrina* and *Systellaspis* the two inner distal lobes of the second maxilla are narrow and project beyond the basal lobe, while the endopod of the first maxilliped is composed of three segments.

Hymenodora acanthitelsonis differs from the other three species of the genus in the nature of the terminal end of the telson. In *H. frontalis*, *H. gracilis*, and *H. glacialis*, the telson is distally truncate, not terminating in an end-piece laterally armed with spines as in *H. acanthitelsonis*. Otherwise, *H. acanthitelsonis* differs from *H. frontalis* in lacking the long rostrum extending beyond the level of the eyes to or slightly beyond the distal segment of the antennular peduncle; it differs from *H. gracilis* in lacking a podobranch on the second maxilliped; and by the anterior margin of the second segment of the antennal peduncle forming a rounded lobe, instead of a blunt tooth, over the antennal scale; it differs from *H. glacialis* in possessing a somewhat lower and longer rostrum, a considerably harder and less pliable carapace, and having a more vertical and less concave groove between the cervical and supra-branchial grooves.

Although *Hymenodora acanthitelsonis* possesses characters previously thought to be diagnostic of *Systellaspis*, characters no longer valid for distinguishing between the two genera, the small and weakly pigmented eyes, the form of the second maxilla and the number of segments in the endopod of the first maxilliped in *H. acanthitelsonis* may still be regarded as characters of generic value.

ZUSAMMENFASSUNG

Eine neue Garnele vom nordöstlichen Pazifik, *Hymenodora acanthitelsonis* n. sp. (Familie Oplophoridae), wird beschrieben. Sie unterscheidet sich von den anderen Arten der Gattung

Hymenodora dadurch, dass der Vorderrand des ersten Pleonalsegment einen deutlich ausgeprägten Lappen oder Zahn besitzt, der den hinteren Rand des Carapax überschneidet. Ausserdem besitzt sie ein Telson, dessen Endstück seitlich mit Dornen bewaffnet ist. Diese Merkmale, die man früher nur *Systellaspis* aber nicht *Hymenodora* zugeschrieben hat, können daher nicht mehr als Unterscheidungsmerkmale zwischen diesen zwei Gattungen gelten. *Hymenodora acanthitelsonis* hat die kleinen, wenig pigmentierten Augen und Mundgliedmassen, die für die Gattung *Hymenodora* typisch sind.

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THE EFFECT OF GAMMA IRRADIATION ON THE REPRODUCTIVE PERFORMANCE OF ARTEMIA AS DETERMINED BY INDIVIDUAL PAIR MATINGS*

BY

Robert L. Holton, William O. Forster, Charles L. Osterberg

ABSTRACT

The brine shrimp, Artemia, was used as an experimental organism to study the effects of ^{60}Co gamma on the reproductive performance of an animal species. The total reproductive ability of the brine shrimp was fractionated into various components and the effects of irradiation on each of these components was then determined by studies of reproductive behavior in individual pair matings.

In this study, the components identified were the number of broods produced per pair, the number of nauplii voided per brood, the survival of nauplii to sexual maturity, the number of mature adults produced per brood, and finally the number of mature adults produced per pair.

All component parameters of total reproductive performance were shown to be affected by irradiation with the range of doses used in this experiment. However, the number of broods per pair was shown to be the factor most sensitive to irradiation with effects noted at doses of 900 rads and above.

INTRODUCTION

There is a sizable amount of literature which is concerned with the effects of ionizing radiation on physiological processes as well as with genetic change and the subsequent appearance of mutations in future generations. The recent publication by Grosch (1965) summarizes much of this research. The emphasis in the present study is different. In this case, the irradiation is considered as a ecological factor and its effect on the reproductive performance of a laboratory population is evaluated. Only by successful reproduction can a species maintain its place in the ecosystem.

This study was initiated to add to our understanding of the effects of various doses of gamma irradiation upon the reproductive ability of an animal population. Such knowledge is essential if we are to understand the

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effects of present and future doses of irradiation upon the various populations and hence on the production and evolution of various ecosystems of our modern world. However, in the environment the situation is far from this simple. We must not only know the effects of these various doses of irradiation upon the reproductive ability and physiological functioning of the population, but we must also know the degree to which a particular plant or animal species concentrates the various radionuclides, where they are located in the organism, and what dose these nuclides will deliver to the germinal tissue as well as to important somatic tissues which might affect the physiological functioning of the organism in a competitive situation.

An experiment has been performed to evaluate the effects of acute doses of gamma rays, from a ^{60}Co source, upon the reproductive ability and hence on population maintenance of laboratory populations of the brine shrimp, Artemia. The brine shrimp was chosen as the experimental organism for several reasons. First, it was considered desirable to extend population radiosensitivity studies of crustaceans. Second, the brine shrimp proved to be a very tractable laboratory animal that could easily be reared through many successive generations. The brine shrimp is an especially favorable animal for these studies since it is possible to fractionate the reproductive performance into several components and to study the effect of irradiation on each parameter. Finally, the attention was focused on this animal by the work of Grosch (1962, 1966) in which he studied the effects of the accumulation of the raionuclides ^{65}Zn and ^{32}P upon the reproductive behavior of Artemia. This research allows some comparison between the effects of incorporated radionuclides and the effects of irradiation from an external source.

In particular, this series of experiments was designed to establish dosage levels, in rads, at which the reproductive ability of Artemia was affected and to determine the dose required to reduce the reproductive ability of the population to zero and thus fix the level at which a laboratory population would be unable to reproduce itself and hence go to extinction under laboratory conditions.

METHODS AND MATERIALS

The Organism

The genus Artemia is a member of the Order Anostraca, Subclass Branchiopoda, Class Crustacea of the Phylum Arthoropoda (Barnes, 1963) Each of the members of the Branchiopoda has an epipodite on the thoracic appendages which serves as a gill, hence the name Branchiopoda, meaning "gill feet." The Anostraca are called "fairy shrimp." They have no carapace and the compound eyes are stalked. Other members of the order typically inhabit temporary fresh water ponds, while the genus Artemia is found in both temporary and permanent ponds of high salinity.

Although laboratory experiments show that Artemia survives and reproduces for many generations in sea water, it is never found in this environment in nature. However, it is found widely distributed in more saline waters in many parts of the world. It is apparently able to survive only where members of higher trophic levels are eliminated by the increased ionic concentration of these waters (Carpelan, 1957).

Due to the taxonomic problems cited by Holton (1968) we will refer to the organism used only by the generic name Artemia in this paper. However, the particular organisms used were from the population which inhabits the Great Salt Lake, Utah, in the United States. The particular cysts used were collected in August of 1965 by the Brine Shrimp Sales Company of Hayward, California. All experimental work reported was conducted between September 1966 and June of 1967, hence the cysts were between one and two years of age during the course of this week.

This population is a diploid amphigonic population (Bowen, 1964) which is well known due to its extreme abundance in Great Salt Lake. Cysts are harvested regularly and sold commercially to be hatched as food for aquarium fishes.

The Life Cycle

It will be possible to dicuss the reproductive performance of this organism only after a brief review of the life cycle of Artemia. A more detailed presentation of the life cycle will be found in Holton (1968).

Upon hatching, this genus emerges as a typical nauplius bearing the customary three pairs of appendages. In successive instars we observe the development of the thoracic appendages, modification of the body shape and specialization of the head appendages. In particular at about the 8th instar we can detect a sexual dimorphism manifest in the structure of the second antennae. In the female the second antennae which were used for locomotion in earlier stages are reduced greatly in size. In the male the structure of the second antennae is increased in size and modified in structure to be used to grasp the female during copulation. By the 9th instar the modifications are distinct and the sexes easily distinguishable.

After the male attains sexual maturity, he grasps the female during copulation, with his enormous specialized second antennae. The female violently resists this action, but a successful male secures a position dorsal to and partly behind the female, with his antennae locked around her body just in front of the ovisac. The two animals are firmly united and swim about in this fashion. At intervals the male curls forward the hind part of his body, attempting to insert one of the two male organs into the uterus. The female does not permit this unless she has recently completed a molt, successful copulation being restricted to this period.

The reproductive system of the female consists of two ovaries, two oviducts and ventral uterus. The following sequence of events occurs in the adult female (Bowen, 1962). The female expels from the uterus an egg generation, the process taking two to ten hours. Then she molts in a few seconds and the next egg generation passes from the ovaries to the oviducts in less than two hours. Copulation appears to be effective only while the eggs remain in the oviducts with fertilization occurring as they pass from the oviducts into the uterus. Shortly after the eggs enter the uterus, the shell glands may begin to secrete the dark shell material which surrounds the cysts.

Lochhead (1941) and Bowen (1962) have shown that under ideal conditions, the shells are not formed and the cysts hatch to yield free living nauplii before they are expelled from the uterus. Hence we have a viviparous type of birth. However, in some cases, a thin shell is formed and the cysts which are expelled typically hatch in about one day. These cysts are often called "summer eggs." A third possibility is the formation of the thick shelled "winter eggs," which are capable of surviving for a long time under adverse conditions.

The life cycle is advantageous for studying reproductive performance since it is possible to follow several parameters in a single experiment. Each pair produces several broods during their life time and therefore it is possible to quantitatively determine the effect of irradiation on the number of broods produced per pair, the number of nauplii voided per brood, the number of nauplii voided per pair, the survival of nauplii to sexual maturity, the number of mature adults produced per brood and finally the number of mature adults produced per pair.

Culture Methods

All cultures were maintained under constant illumination in the laboratory. The laboratory used had no outside windows, and it was found that the animals reacted to the sudden turning on of the room lights after being in total darkness by several minutes of very rapid random movement before settling down to a normal swimming pattern typically exhibited in the light. During the course of the experiments, the temperature of the laboratory was maintained within the range of $21.0 \pm 0.7^{o}C$.

Since all experimental work in this study was conducted using Artemia cysts from Great Salt Lake and since in their normal environment, this population is subjected to salt concentrations of several times that of sea water, the question of the proper salt concentration to use in a laboratory study arose. A small experiment was designed to help resolve this question. Several groups of animals were reared in sea water and in sea water with various amounts of sodium chloride added, of from 50 to 150 g per liter. When mature, the shrimp were irradiated at several different doses and their survival was evaluated. The data are graphed in Figure 1.

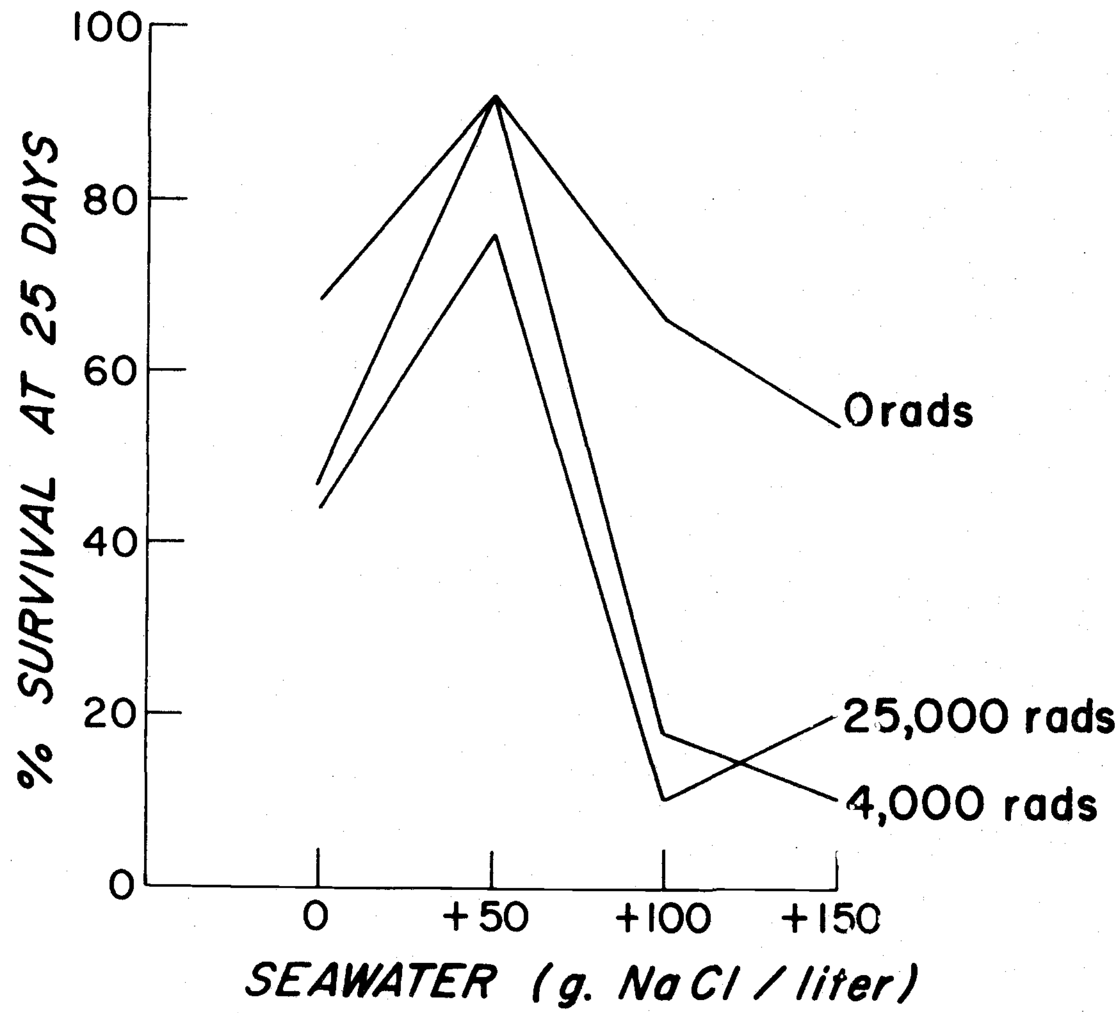

Figure 1. The percent of young adult Artemia surviving for 25 days at various doses or irradiation in four different culture waters.

It should be noted that at all levels of irradiation the survival was best in the sea water with 50 g of added sodium chloride per liter and this water was used as a standard culture water. It would seem likely that this culture water would most nearly approximate the environmental conditions of Great Salt Lake, in which this population evolved, of any of the various waters tested. It is interesting that both Bowen (1962) and Grosch (1966) have also adopted culture water with 50 g of NaCl added to each liter of sea water for their work with Artemia, although they used a different criteria for selection of this culture water.

All cysts were hatched in sea water, with hatching being complete in 48 hours after hydration of the cysts. At 48 hours after hydration, the newly hatched nauplii were transferred with a large pipette to the standard culture water and remained in this water during the course of the experiments.

Individual pair matings were made in approximately 500 ml of culture water (one pint polyethylene freezer cartons). Each pair mating was examined daily and when young were noted, the parents were transferred into a new culture container and the young were raised to maturity in the original container. Nauplii were counted on the third day after they emerged, returned to the culture container and counted again and sexed at maturity. All animals were fed daily a standardized suspension of brewer's yeast in distilled water.

Conditions of Irradiation

The ionizing radiation used in all experiments consisted of gamma rays (1.17 and 1.33 Mev) from ^{60}Co. The animals were irradiated in 10 ml of fresh culture water held in 50 ml polyethylene holder. In the cases when not all of the five tubes were being used to irradiate animals, the unused tubes were placed in the tube holder with 10 ml of culture water in order to maintain a constant geometry of irradiation. During the course of the irradiation, the irradiation chamber was continuously perfused with air.

In all experiments, parallel control cultures were maintained. These animals were subjected to the same handling as the irradiated animals and were placed in the irradiator for a time equal to the longest irradiation time used in that experiment. However, for the control cultures, the safety shield is not removed and hence they receive virtually no irradiation. A secondary control which was subjected to as little handling as possible was also maintained to help assess the extent of damage from handling. This secondary control showed that the handling during irradiation did not affect the survival of the Artemia.

RESULTS AND DISCUSSION

This experiment was conducted to study the effects of an acute dose of gamma irradiation, from the ^{60}Co source, upon the reproductive performance of Artemia in individual pair matings. During the course of a series of preliminary experiments, it became very clear that the stage of the life cycle at which the Artemia were irradiated had an important effect on the subsequently observed reproductive pattern.

Irradiation of the early nauplii stages in the life cycle produced marked effects on reproductive ability, of those which survived the irradiation, but only at relatively high doses of approximately 2000 rads and above. However, the irradiation of these nauplii at such doses produced detectable somatic damage. The irradiated nauplii showed a high mortality rate and such doses also slowed their rate of development to adulthood. This lower rate of development effectively eliminated irradiation of nauplii from this study, since animals receiving different doses became reproductively mature at varying times and hence the reproductive performance was confounded with developmental rate in such a way as to make analysis of any data difficult.

As the Artemia approached maturity, their reproductive ability became increasingly more sensitive to the effects of gamma irradiation. At the same time as they were becoming reproductively more sensitive to irradiation, they were showing greatly increased resistance to somatic damage, as evidenced by lowered mortality at the range of doses used in this experiment. Accepting the general principle that cells are most sensitive to ionizing irradiations when actively dividing (Bacq and Alexander, 1961), we can readily see why the nauplii are most sensitive to somatic damage and the later stages become more sensitive to damage in the germinal tissues.

However, in the fully matured and reproducing adults, this sensitivity is masked by the release of one or two broods of young by each female which apparently arise from oocytes and spermatocytes which have already been formed from the oogonial and spermatogonial cells before irradiation and are awaiting further development within the organism at the time of irradiation.

For the purposes of this experiment it was considered best to irradiate the animals at a time of maximum sensitivity to gamma rays and yet to irradiate them before the results would be obscured by broods produced from oocytes and spermatocytes which were formed before the irradiation. A second preliminary experiment resolved the stage of maturity for irradiation necessary to satisfy the above requirements. It was found that irradiation at either the 10th or 11th instar of Heath (1924) would irradiate germinal tissue at a time of maximum radiosensitivity and would still be before any radioresistant germinal products were formed. This also worked out to be the 22nd or 23rd day after the hydration of the eggs under the standard condition employed in this laboratory.

The animals for this experiment were hydrated, hatched and transferred according to the standard technique as previously described when discussing the conditions of culturing Artemia. After hatching they were placed in an eight gallon aquarium tank for development. Twenty-two days after hydration, the animals were removed from the aquarium with the aid of a fish net and a sample was mounted and examined under the microscope to determine the stage of development. It was found that the development was very uniform with a few animals in the 11th instar and between 80 and 90 percent in the 10th instar. The animals were separated into groups of 80 sexed animals. One group of 80 such animals was irradiated in 10 ml of culture fluid under the standard conditions of irradiation as previously described, at each of the following doses: 0, 300, 600, 900, 1200, 1500, 1800, 2100, 2400, 3000, 4500, and 6000 rads. The smaller preliminary experiments previously mentioned had indicated that the doses at 300 rad intervals to 2400 rads should bracket the entire range of irradiation within which reproduction would be possible. The three higher doses were included in case the animals irradiated at 2400 rads should show any reproductive ability. The control group of 0 rads was placed in the irradiator for the same length of time (40 minutes) as the group receiving 6000 rads, but in this case the safety door was not opened.

After irradiation each sample of 80 animals was placed in a separate container with one liter of culture water. Mating was accomplished by allowing the Artemia to pair and assume the copulatory posture in the culture water. After the males had clasped the females the pairs were transferred to the individual 500 ml containers and observed daily to record their reproductive performance. This process continued until 20 pairs which had received each of the doses wer isolated for further study. The first noted pair clasping occurred four days after irradiation, and by the eighth day after irradiation all of the required 240 pair matings had been isolated.

These 20 pair matings at each of the 12 doses were observed daily during the life span of the female for the production of broods. If a male was noted as dead in a culture, he was replaced by another male which had received the same dose. If a female died, that particular culture was terminated at the time of her death. When a brood was produced, the parents were carefully removed to a fresh culture container and observed daily for the production of subsequent broods.

The number of offspring in each brood was counted on the third day after they were produced. They were again counted and sexed at maturity. The data obrained in this experiment are summarized in Table 1. This shows that the range of doses employed in the experiment covered the range of reproductive radiosensitivity of Artemia, since with an acute dose of 2100 rads, administered at the time of maximum radiosensitivity the animals are rendered effectively sterile, but survive for essentially as long as the controls.

A comparison of this sterility level of 2100 rads for Artemia, with values abtained for insects (Grosch and Erdmann, 1955) would indicate that the reproduction performance of Artemia displays a sensitivity to irradiation which is of the same magnitude as in several orders of insects. Grosch and Sullivan (1954) established a sterility dose by use of x-rays for Artemia females of 2250 rads which is also in agreement with the data presented in this experiment.

Recent experiments reported by Squire and Grosch (1970) and Squire (1970) detail the effects of gamma irradiation on the reproductive performance of the brine shrimp, Artemia, when one sex is irradiated and mated to non-irradiated

Table 1. Summary of the effects of various doses of irradiation as determined from pair matings of irradiated animals. Based on 20 pairs at each dose. Means and standard errors are given for all per pair and per brood values.

Dose (rads)	Number of Broods	Broods per Pair	Nauplii Voided			Percent Survival to Adults	Mature Adults		
			Total	Per Pair	Per Brood		Total	Per Pair	Per Brood
0	87	4.35±.31	9,692	484.6±30.9	111.4±6.4	64.9	6,290	314.5±14.5	72.3±3.9
300	92	4.60±.38	9,916	495.8±29.4	107.8±5.3	67.8	6,723	336.2±13.0	73.1±3.4
600	89	4.45±.39	10,305	515.2±38.2	115.8±6.8	56.4	5,812	290.6±21.3	65.3±5.5
900	60	3.00±.30	7,005	350.2±24.2	116.7±5.2	59.3	4,154	207.7±11.1	69.2±5.1
1200	53	2.65±.38	8,321	416.0±34.7	157.0±7.6	50.7	4,219	211.0±20.2	79.6±7.2
1500	39	1.95±.28	4,831	241.5±28.7	123.9±8.1	40.3	1,947	97.4± 8.3	49.9±7.2
1800	26	1.30±.27	1,894	94.7±31.2	72.8±8.7	31.1	589	29.4± 5.6	22.7±6.4
2100	9	0.45±.21	237	11.8± 5.7	26.3±9.2	0	0	0	0
2400	0	0	0	0	0	0	0	0	0
3000	0	0	0	0	0	0	0	0	0
4500	0	0	0	0	0	0	0	0	0
6000	0	0	0	0	0	0	0	0	0

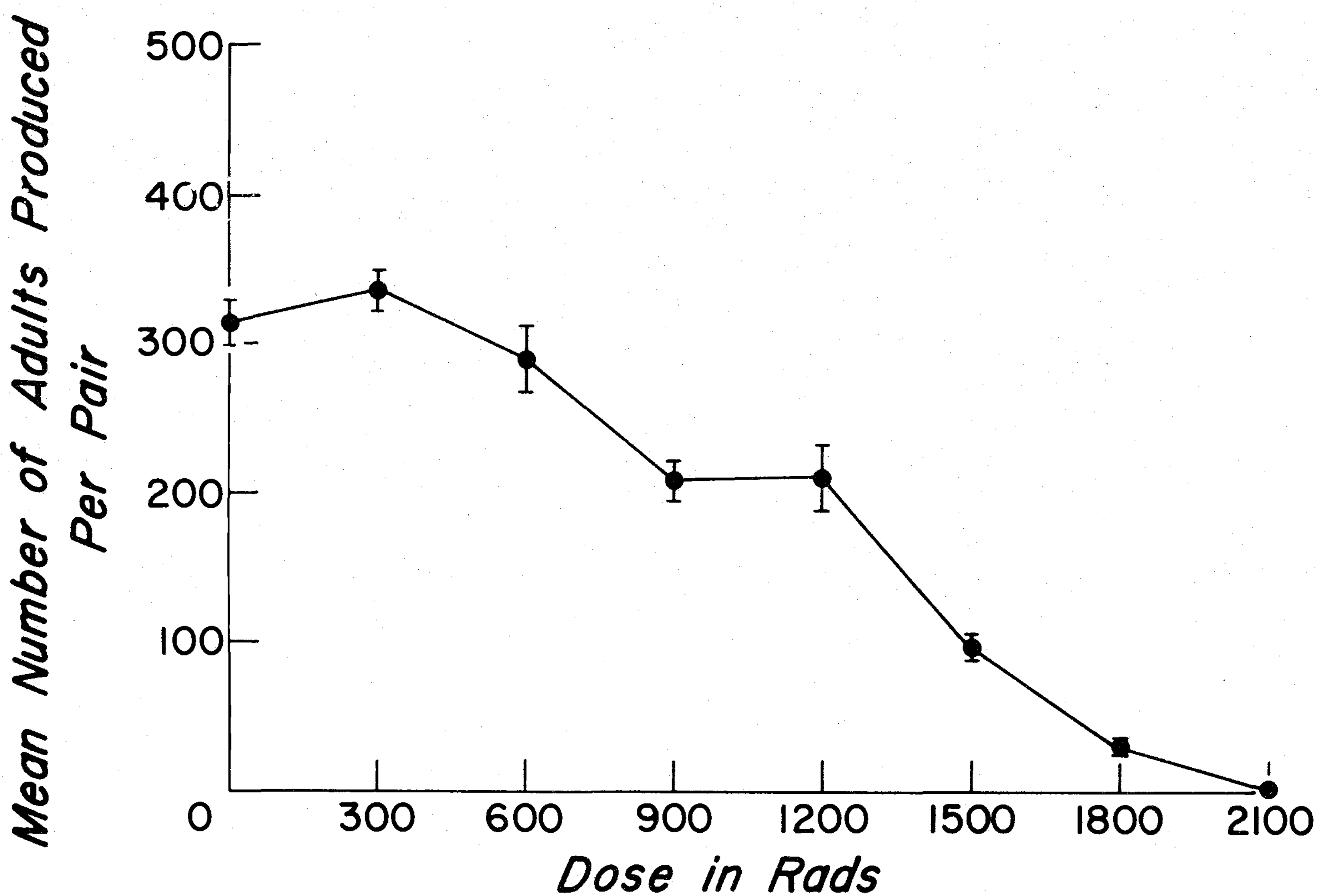

Figure 2. The mean and standard error of the number of adults produced by irradiated pairs of animals.

individuals of the other sex. Although these experiments are not directly comparable to the work reported here it would appear that the results are in accord with the values obtained in this research.

The number of adults produced per pair as a function of dosage is plotted for this experiment in Figure 2. The vertical lines included show the magnitude of one standard error of the mean above and below the mean.

The slight increase in reproduction per pair noted at 300 rads is not statistically significant, but the trend is not wholly unexpected. White et al. (1966) have shown that brine shrimp which received a dose of 500 rads of gamma rays were longer in size during development and matured sexually at an earlier date than control shrimp. Stimulation of growth by ionizing radiation has also been recognized in various other species, such as crabs (Engel, 1967) and amphibians (Brunst, 1965). Such an increased growth and early maturity might also result in increased reproduction as possibly indicated in the current experiments. The reality of such an increase will be examined in the future by the use of inbred strains of Artemia to reduce the within-sample deviations and the resolution can be increased by using a series of several doages between 0 and 600 rads.

The data from Table 1 can also be plotted in terms of the adults produced per brood versus the dosage administered. Such a graph is shown in Figure 2. This shows rather clearly that the number of mature adults produced per brood remains relatively constant until the dosage has reached 1200 rads. Then we see a rapid decrease in the per brood production of adults. Hence, some kind of threshold is present at above 1200 rads. Any dosage below this amount has little effect on the number of adults produced per brood. Viewing the same data another way, we can see from Table 1 that the reduction in net reproductive ability demonstrated at doses of 1200 rads and below as shown in Figure 3, is due primarily to a reduction in the number of broods produced and not to a decrease in the number of adults produced per brood. At 1500 and 1800 rads we can see a continued reduction in the number of broods produced as well as a marked decrease in the number of adults per brood.

CONCLUSIONS

Preliminary experiments demonstrated that the stage of the life cycle determined the dosage required to stop reproduction. At the most sensitive stage, the tenth to eleventh instar, a dose of 2100 rads was shown to render the animals effectively sterile.

In the study of the various components of reproductive ability it was shown that at doses of 1200 rads or lower the number of adults produced per brood remained the same. However, the number of adults produced per pair showed a decrease at 900 and 1200 rads and this decrease can be attributed to a decrease in the number of broods produced per pair.

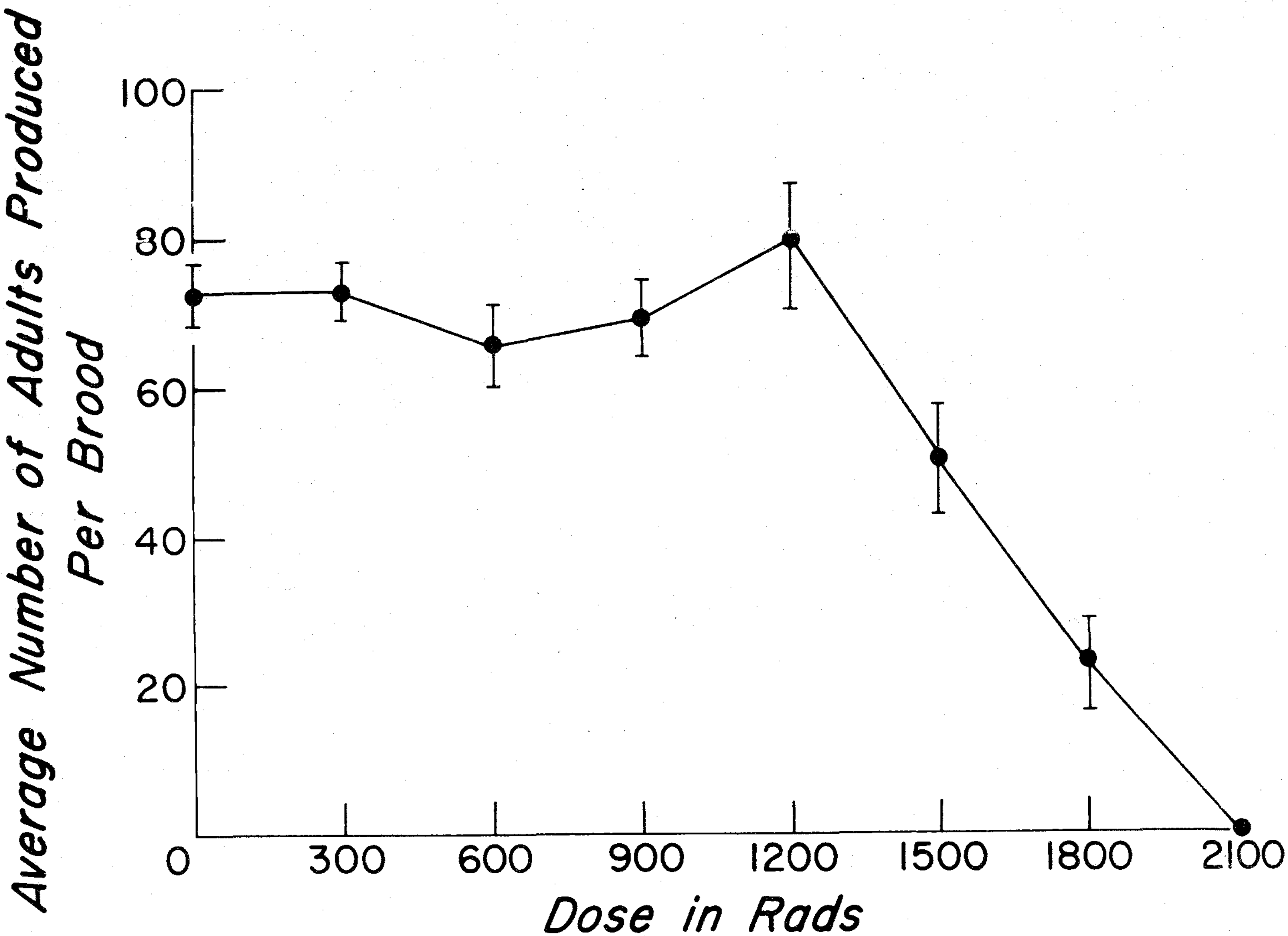

Figure 3. The mean and standard error of the number of adults produced for each brood of nauplii released.

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THE EFFECTS OF GAMMA IRRADIATION ON THE MAINTENANCE OF POPULATION SIZE IN THE BRINE SHRIMP, ARTEMIA*

by Robert L. Holton, William O. Forster, Charles L. Osterberg

ABSTRACT

Population cultures of the brine shrimp, Artemia, were irradiated with acute doses of gamma irradiation from a ^{60}Co source. The subsequent reproductive performance and size of the cultures were studied for a period of 20 weeks.

It was demonstrated that the population cultures may be maintained with only a small part of the reproductive potential exhibited in the pair matings. Therefore, we find that the results of pair matings must necessarily be used to assess the amount that the reproductive potential of Artemia is decreased due to various doses of irradiation.

Population cultures at all doses were shown to have the same sized populations at the end of 20 weeks. However, it was demonstrated that the populations irradiated at higher doses had not recovered to their full reproductive potential at the end of this time.

INTRODUCTION

Although it is possible to examine the radiosensitivity of the brine shrimp under the most sensitive conditions (Holton et al. 1971), such a study does not effectively assess the effect of irradiation on a population composed of all age classes. The work described here is an attempt to assess the impact of an acute dose of gamma radiation on the subsequent reproductive performance of population under rather carefully controlled laboratory conditions.

Grosch (1962, 1966) has demonstrated the effects of the addition of ^{65}Zn and ^{32}P to three liter population cultures of Artemia. He has concluded that although the number of adults counted in population cultures may be the same, the animals from experimental cultures have a shortened life span, deposit fewer zygotes per brood, and show poor survival to adulthood as compared to control animals which have not been subjected to radionuclide contamination. He also has determined that population cultures of control animals use only 0.2 percent of the reproductive

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potential that they exhibit in pair matings to maintain the population size. However, populations of experimental animals are required to use one percent or more of their potential to maintain the same population size. Hence, although we may not detect the effects of radioactive contamination when studying laboratory population cultures, such effects could be manifest in a competitive environment.

Of particular interest, however, are Grosch's (1966) results which show that the addition of as little as 20 μCi of ^{65}Zn to a three liter population culture of Artemia has consistently caused the cultures to become extinct. In the case of ^{32}P, the populations are able to stand the addition of greater amounts of activity. Cultures routinely survive the addition of an aliquot of 30 μCi ^{32}P per three liter culture, and one culture has survived the addition of as much as 90 μCi ^{32}P.

At least a part of the explanation for this different response to the two nuclides may be in terms of the fact that the ^{65}Zn has a 245 day physical half-life and the ^{32}P has only a 14 day half-life. A culture receiving the addition of 20 μCi of ^{65}Zn would be exposed to a higher level of activity over a longer period of time than a culture receiving 20 μCi of ^{32}P. Therefore, such a ^{65}Zn culture would be exposed, during the course of the experiment, to many more radioactive decay events than a ^{32}P culture which received the same initial dose of activity.

However, in this study we are interested in determining what part the ionization in living tissue plays in the observed effects, as compared to the effects due to transmutation and also due to the recoil energy of the decaying nucleus. The present study, using an external source of gamma rays from ^{60}Co, will allow for some degree of assessment of the effects of certain selected doses of ionizing radiation on population maintenance of the brine shrimp, without having to consider transmutation and recoil effects as potential sources of difficulty in the interpreting of the results.

In particular, this series of experiments was designed to establish dosage levels, in rads, at which the reproductive ability of Artemia was affected and to determine the dose required to reduce the reproductive ability of the population to zero and thus fix the level at which a laboratory population would be unable to reproduce itself and hence go to extinction under laboratory conditions.

METHODS AND MATERIALS

The organism used in this work and its life cycle have been described previously (Holton 1968, Holton et al. 1971). The particular Artemia used for this work were derived from the population in the Great Salt Lake in Utah.

The pair mating irradiation experiment, (Holton et al. 1971) which required the irradiation of animals at a specific stage of their life cycle allowed more accurate control of experimental conditions than was possible in the experiment to be described in this section. However, such irradiation fails to simulate the conditions of exposure to irradiation that a functioning population might encounter in an ecological setting. In the environment, a typical animal population often consists of all stages in the life cycle being represented at any given time. The population culture irradiation experiment described in this section is an attempt to approach the environmental situation by irradiating a population composed of animals from the 7th instar of Heath (1924) to mature adults which were reproducing at the time of irradiation.

Irradiation of the earlier nauplii stages was not included in this experiment for two reasons. First, at the levels of irradiation to be used, the subsequent reproductive performance of these early nauplii would be confounded with their altered developmental rate. A second reason for irradiating only the larger nauplii and adults was because of the impossibility of mechanically separating the smaller stages from the solid waste materials which accumulate in the population cultures. Because of this problem, it was possible to count only individuals from the 7th instar to the adult state during the later counts of the population culture. Hence, to insure a uniformity in determining the numbers of animals in the cultures, only those stages which could be recovered for later counting were included in the original irradiated sample.

The Artemia irradiated for this experiment were hydrated, hatched and handled by the standard methods. A series of ten different groups of eggs were hydrated every other day, and as they hatched, they were introduced into an eight gallon aquarium for continued development. The aquarium stock was fed daily in amounts necessary to maintain a normal growth rate. When the oldest animals in the aquarium had matured and were starting to produce young, samples of Artemia were prepared for irradiation.

A random sample of animals was removed from the aquarium by use of a dip net, after the animals had been thoroughly mixed to insure a sampling of all sizes of animals. The animals removed were placed on a 1100 μ bolting silk. A double rinse with fresh culture water of the animals on this filter allowed the few early stages present to pass through and retained essentially all animals from the 7th instar to the adults on the bolting silk. The animals retained on the bolting silk were then divided into groups of 300 animals. This size of culture was chosen in view of the report of Grosch (1962) that as many as 300 well developed Artemia were counted in his three liter population cultures at one time.

Four groups, of 300 animals each, were then selected at random for irradiation by the standard technique at each of the following dosages: 0, 500, 1500, 3000 rads. The four control groups were placed in the irradiator for the same length of time as the 3000 rad groups, but the safety door was not opened. Each group of 300 irradiated animals was then placed in three liters of standard culture water and placed in a gallon jar to start a separate population culture. All of these population cultures were fed one ml of the standard yeast suspension daily.

RESULTS AND DISCUSSION

The effects of this irradiation upon the population maintenance were studied in two different ways. Three of the cultures at each dosage were examined every four weeks for a 20 week period in the following manner. The entire culture was siphoned out of their container and carefully strained through an 1100 μ bolting silk. The animals on the bolting silk were rinsed twice with water decanted off the top of the culture to insure removal of all young nauplii. This procedure allowed all of the smaller nauplii to pass through the bolting silk and again retained the animals more mature than the 7th instar. A population count of these stages was then made. After counting was completed, the entire population was returned to the culture container with original culture water for further development. The data obtained from these counts is presented in Table 1.

The mean value calculated for each dosage at the four week intervals is plotted in Figure 1. Several things should be noted about this evaluation of the irradiation effects by total population counts. The number of animals found in the control populations had virtually doubled at the end of four weeks, indicating a real potential for population growth under these culture conditions. However, a comparison with the control animals in pair mating experiments (Holton et al. 1971) shows that only about 1/80 of the reproductive potential inherent in this population of Artemia is realized under these population culture conditions. This fact leads us to conclude that an environmental stress is severely limiting the population size. This conclusion is supported by the observation that the control populations increased only slightly during the next four weeks, and during the final weeks of the experiment the number of animals in the control cultures steadily decreased. Figure 1 shows that this decrease is linear over the final 12 weeks of the experiment and had shown no signs of leveling off at the termination of the experiment. It may be assumed that this control population would have reached an even lower level if the experiment had been continued for a longer period of time.

Table 1. The mean number of 7th instar to adult *Artemia* found in population cultures receiving various doses of irradiation. Each value is the mean and standard error, based on three replicate population cultures.

Sampling Interval	Dose (rads) 0	500	1500	3000
0 weeks	300± 0	300± 0	300± 0	300± 0
4 weeks	578±29	426±31	337±27	284±27
8 weeks	598±39	603±43	341±15	354±24
12 weeks	513±24	627±20	399±25	385±16
16 weeks	453±25	520±14	421±18	344±25
20 weeks	375±36	379±35	362±20	337±12

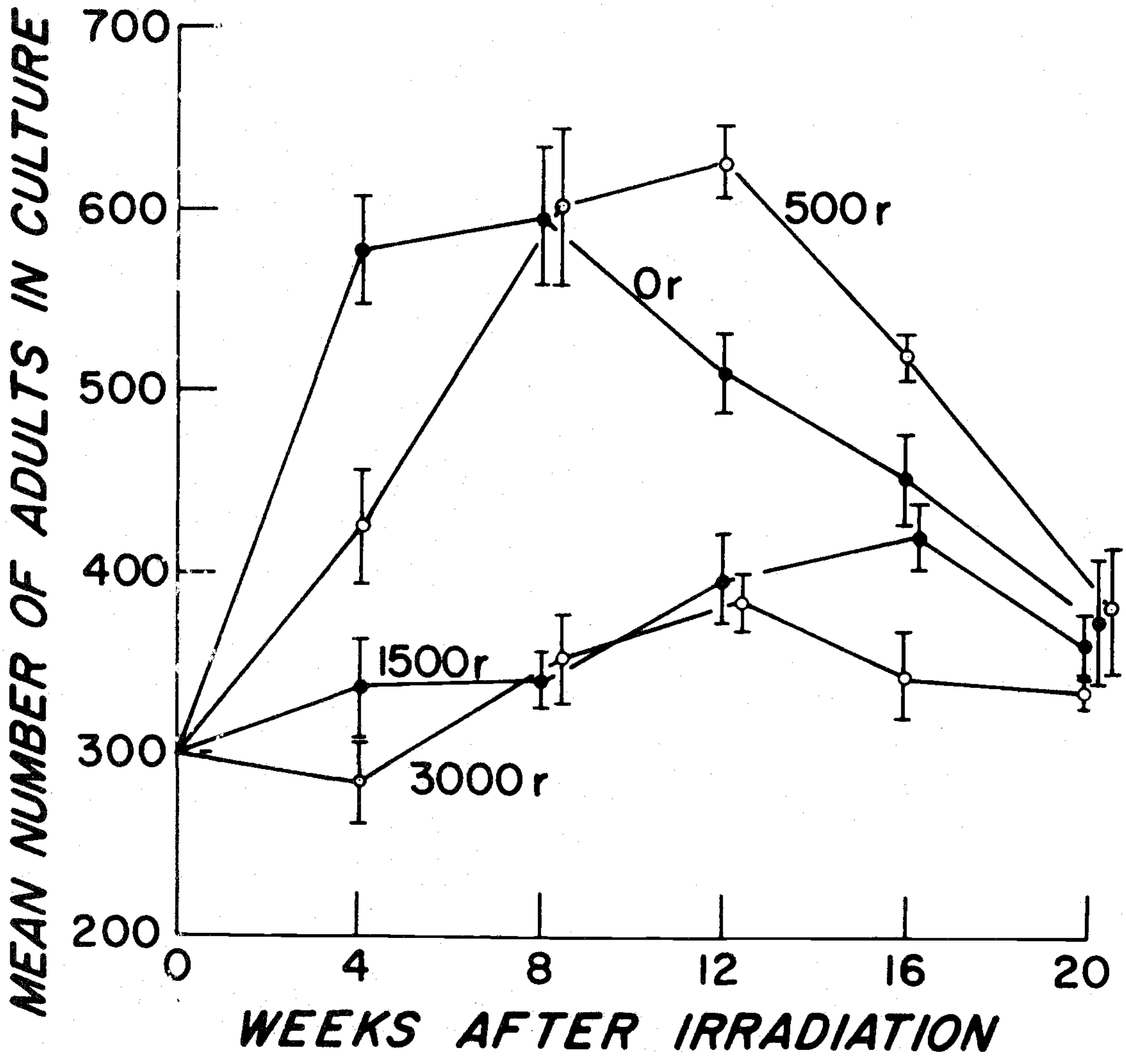

Figure 1. The mean number of seventh instar to adult *Artemia* found in population cultures receiving various doses of irradiation.

The three cultures receiving 500 rads showed a pattern of distinct population growth followed by a steady decline which was very similar to the control culture. However, in this case a four week lag in the growth pattern, as compared to the control populations, was observed. In view of the data presented in previous work (Holton et all. 1971) it is not possible to explain this lag. It was shown that at the most radiosensitive stage of the life cycle, a dose of 600 rads had no significant effect on the number of adults produced per pair, as compared to the control animals, and yet in this experiment we see a marked effect at the end of the fourth week between the control animals and those which received 500 rads.

The similar decrease in population size noted for both the 0 and 500 rad cultures in the final weeks of the experiment and the fact that the cultures reached almost identical mean values on the 20th week after irradiation may be interpreted to mean that there is some finite carrying capacity inherent under these culture conditions, and that all the populations are tending to approach this carrying capacity as a limit. Although a population, with little or no damage from irradiation, may temporarily overshoot this carrying capacity, the environmental stress will ultimately mount and reduce the population to a size commensurate with the potentialities of the environment.

The cultures receiving the doses of 1500 and 3000 rads showed the effects of the irradiation during the early weeks of the experiment with decidedly smaller populations than the control cultures, hence for the first 12 to 16 weeks the radiation exposure limited the size of these populations. However, at the end of 20 weeks all of the populations appear to be approaching a common size, which apparently is controlled by environmental conditions as discussed above. This might also be used as evidence that since after 20 weeks or about five generations, even the population which received 3000 rads is maintaining itself about as well as the control population, and therefore has essentially recovered from any reproduction damage resulting from the insult with gamma irradiation. However, this hypothesis of little or no reproductive damage being evident after five generations is not supported by the results of the second part of this experiment cited below. It is shown that the individual pairs from the population cultures receiving 1500 and 3000 rads show a significantly lowered reproductive potential when compared to the control cultures. Hence, a more realistic assessment of the situation would be to conclude that after 20 weeks the populations of all four cultures are being limited by environmental factors to essentially the same size.

The fourth culture receiving each of the four different doses was handled in a different way. In this case, ten individual pair matings of breeding adults were isolated from each culture at four week intervals. The mated pairs of brine shrimp were randomly selected from the cultures. As a pair appeared at the top of the culture, it was removed with a small dip net and placed in a 500 ml container where their reproductive performance was studied for the life span of the female, with the same technique as was used in a pair mating experiment (Holton et al. 1971). Such a method of selecting pairs of Artemia for study chooses only those pairs at the surface of the culture, and if such pairs are not a random sample of all pairs in the culture, this procedure is biased against those pairs which spend a majority of their time at the bottom of the culture. This procedure would be especially biased if the pairs swam at the surface of the culture only at a certain age and therefore eliminated other age classes from the sample.

The data obtained from the study of the pair matings made from the population cultures is summarized in Table 2. However, it is much more informative to extract specific values from Table 2 and to plot these values to study various individual components of the reproductive performance of Artemia and, therefore, to assess the relative importance of the various parameters in the reproductive performance of the species.

Figure 2 shows the mean number of broods produced by each pair removed from the cultures for study during the course of the experiment. Since it was shown in a pair mating experiment (Holton et al. 1971) that brood production was the most sensitive parameter when Artemia were insulted by irradiation, it is interesting to note that in this study the brood production is also shown to be greatly affected by the doses of gamma rays involved. Several specific facts can be seen in Figure 2. The brood production was affected relatively little at the first sampling period, which occurred within six hours of the time the animals were irradiated. At this time many females already had one or two broods of eggs which were maturing in their oviducts or uteri. The fertilization and release of these eggs provided the relatively less affected brood production at this first sampling interval.

At the four week sampling period we see a significant decrease in brood production for all irradiated samples. The decrease for the 500 rad group stands in contrast to the 600 rad group in a pair mating experiment (Holton et al. 1971) where no significant decrease in brood production was noted. The only explanation that can be advanced to explain this phenomenon would be that the effects on brood production will tend to show up to a greater degree within the first filial generation that was sampled at four weeks in this experiment than in the generation which was exposed to the irradiation. The importance of this possibility would suggest that it warrants intensive study in the future.

The principal interest in this population culture irradiation experiment was to ascertain the degree of recovery of reproductive performance at successive intervals after irradiation. Figure 2 shows us that the brood production after the fourth week began a slow but constant recovery. We can conclude that a doses of 1500 rads or over that more than 20 weeks, or five generations, are required for the brood production to return to the control level.

Table 2. Summary of the effects of various doses of irradiation on population cultures of *Artemia*, as determined by pair matings from the population cultures. Based on ten pairs at each sampling interval. Means and standard errors are given for all per pair and per brood values.

	Number of Broods	Broods per Pair	Nauplii Voided Total	Nauplii Voided Per Pair	Nauplii Voided Per Brood	Percent Survival to Adults	Mature Adults Total	Mature Adults Per Pair	Mature Adults Per Brood
3000 rads									
0 weeks	26	2.6±.44	1,821	182.1±31.2	70.0±11.8	20.9	381	38.1±20.4	14.7±12.4
4 weeks	6	0.6±.37	671	67.1±28.0	111.8±16.8	22.9	154	15.4±12.0	25.6±14.7
8 weeks	7	0.7±.38	664	66.4±27.9	94.9±15.2	26.7	177	17.7±12.3	25.3±18.3
12 weeks	11	1.1±.40	837	83.7±28.5	76.1±10.1	27.4	229	22.9±20.6	20.8±14.5
16 weeks	9	0.9±.41	796	79.6±27.0	88.4±11.0	33.5	267	26.7±19.8	29.7±16.8
20 weeks	16	1.6±.53	1,078	107.8±28.8	67.4±12.3	37.7	406	40.6±21.1	25.4±13.5
1500 rads									
0 weeks	29	2.9±.52	2,983	298.3±35.6	102.9±11.8	41.8	1,247	124.7±30.5	43.0±11.1
4 weeks	16	1.6±.45	1,516	151.6±29.4	94.8±13.0	33.3	505	50.5±20.7	31.6± 6.8
8 weeks	20	2.0±.68	1,873	187.3±30.9	93.6±11.4	34.7	650	65.0±17.7	32.5± 8.9
12 weeks	23	2.3±.47	2,008	200.8±31.0	87.3±12.7	44.6	896	89.6±16.0	39.0± 7.4
16 weeks	24	2.4±.52	2,367	236.7±30.3	98.6±12.5	41.8	989	98.9±14.1	41.2± 9.0
20 weeks	29	2.9±.40	2,739	273.9±33.5	94.5±12.3	51.0	1,397	139.7±18.9	48.2± 7.5

(continued on page 54)

Table 2.(continued)

	Number of Broods	Broods per Pair	Nauplii Voided Total	Nauplii Voided Per Pair	Nauplii Voided Per Brood	Percent Survival to Adults	Mature Adults Total	Mature Adults Per Pair	Mature Adults Per Brood
500 rads									
0 weeks	40	4.0±.63	4,444	444.4±39.7	111.1±11.7	55.6	2,471	247.1±24.5	61.8± 6.7
4 weeks	27	2.7±.53	3,789	378.9±38.2	140.3±11.9	53.2	2,016	201.6±20.2	74.7± 6.1
8 weeks	33	3.3±.66	3,435	343.5±36.7	104.1± 9.3	54.4	1,869	186.9±23.8	56.6± 8.1
12 weeks	31	3.1±.37	3,678	367.8±28.1	118.6±10.4	56.6	2,082	208.2±22.2	67.2± 7.3
16 weeks	36	3.6±.48	3,798	379.8±37.8	105.5± 9.8	54.7	2,078	207.8±27.1	57.7± 6.0
20 weeks	39	3.9±.70	4,259	425.9±42.9	109.2±10.5	59.0	2,513	251.3±21.9	64.4± 5.7
0 rads									
0 weeks	42	4.2±.64	4,636	463.6±42.6	110.4±13.0	62.1	2,879	287.9±27.3	68.5± 7.8
4 weeks	39	3.9±.56	4,121	412.1±37.8	105.7±12.7	70.1	2,889	288.9±24.0	74.1± 6.7
8 weeks	38	3.8±.41	4,227	422.7±38.9	111.2±12.4	65.6	2,773	277.3±23.5	73.0± 7.2
12 weeks	43	4.3±.65	4,239	423.9±41.1	98.6±11.0	60.1	2,548	254.8±26.4	59.3± 7.1
16 weeks	38	3.8±.61	3,712	371.2±39.3	97.7±11.2	67.4	2,509	250.9±21.6	66.0± 6.8
20 weeks	42	4.2±.55	4,133	413.3±40.1	98.4±10.9	62.0	2,562	256.2±24.1	61.0± 8.5

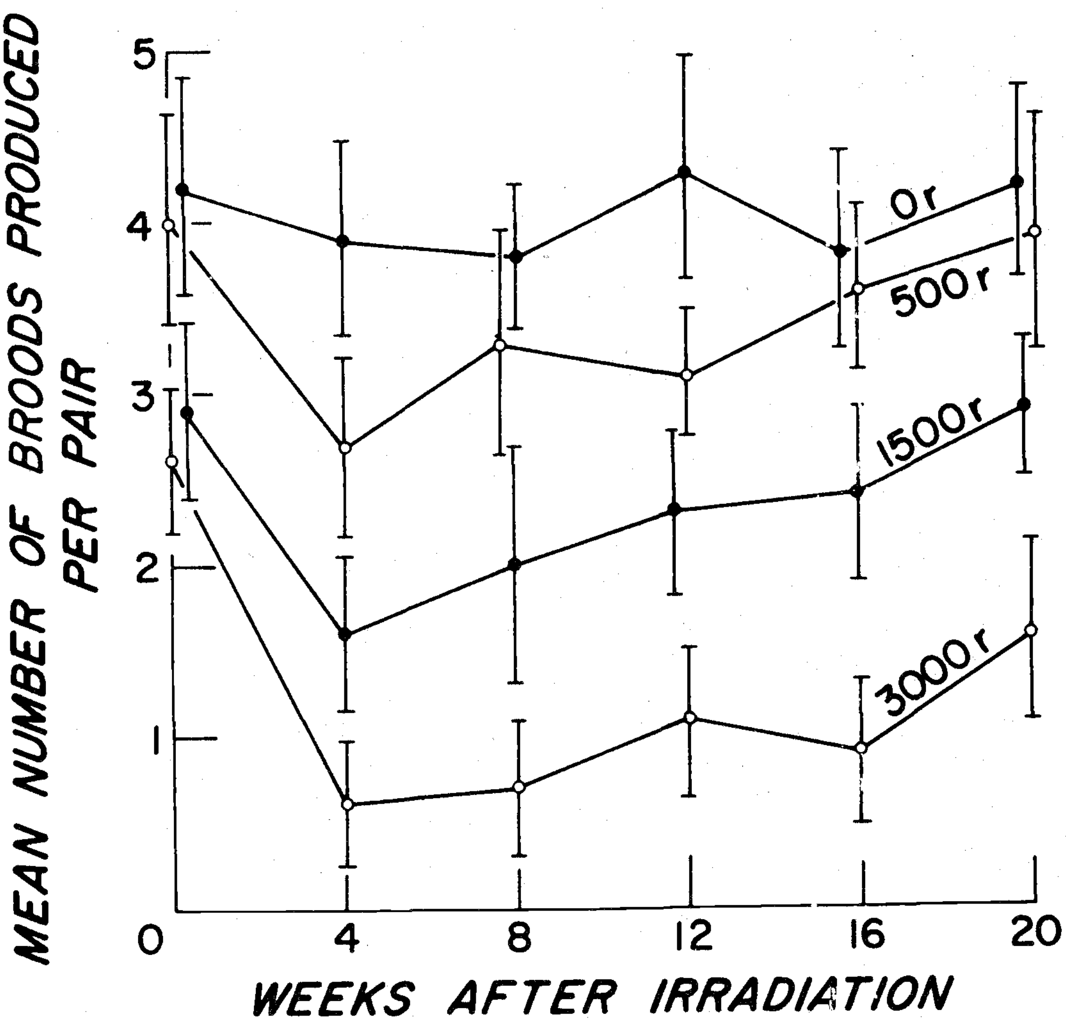

Figure 2. The mean and standard error of the number of broods produced per pair of Artemia, removed from irradiated populations at various time intervals.

A second parameter involved in the reproductive performance is plotted in Figure 3. Here we see that the number of nauplii produced on successive weeks by various samples of females from irradiated populations shows essentially the same trend as seen in brood production. However, we do note some differences. The animals from the 3000 rad culture show no significant increase in nauplii production from the 4th to the 20th week, even though the number of broods produced was shown to increase. Hence, our attention is called to Table 2, where we confirm this trend by noting a decrease in the number of nauplii produced per brood from the 4th to the 20th week. No explanation is apparent to explain such a trend. The difference in number of nauplii produced between the control and the 500 rad culture is shown to be slight at all times. However, the 1500 rad culture shows a significant decrease in nauplii production and also shows again that after 20 weeks the population has not recovered from the reproductive damage due to irradiation.

A third factor contributing to total reproductive performance is revealed by Figure 4. Here the percentage of nauplii produced which survive to adulthood are plotted. The control population is shown to rather consistently have a 65 percent survival of nauplii. This value is higher than average control survival reported by Grosch in 1962, but would be well within the range of survival values that Grosch (1966) reported in later experimental work.

The percent surviving for each of the experimental groups shows a general tendency to increase at successive sampling periods with the population irradiated at 3000 rads, showing a steady increase in survival. At 1500 rads, we see the same trend of improved survival from the 4th week to the 20th week. However, it is interesting to note the difference between the 3000 and the 1500 rad populations at the zero and four week sampling intervals. The 1500 rad population shows a very definite decrease in survival between these two periods. However, with the 3000 rad sample we see that the lowest survival rate occurred at the first sampling period and that at four weeks a slight improvement was already noted. This differential pattern of survival at the two doses may be interpreted to indicate that different mechanisms are operating in determining the survival rate at the different times. At the first sampling period, survival is a function, at least in part, of the ability of zygotes already formed to withstand the effects of irradiation. Figure 4 shows that at this sampling period, 3000 rads is responsibile for a pronounced decrease in survival of such zygotes when compared to the survival rate should be interpreted as a measure of the amount of genetic damage carried in the germinal tissue, and we see that at this time the difference between the effects on survival of 3000 and 1500 rads is much smaller.

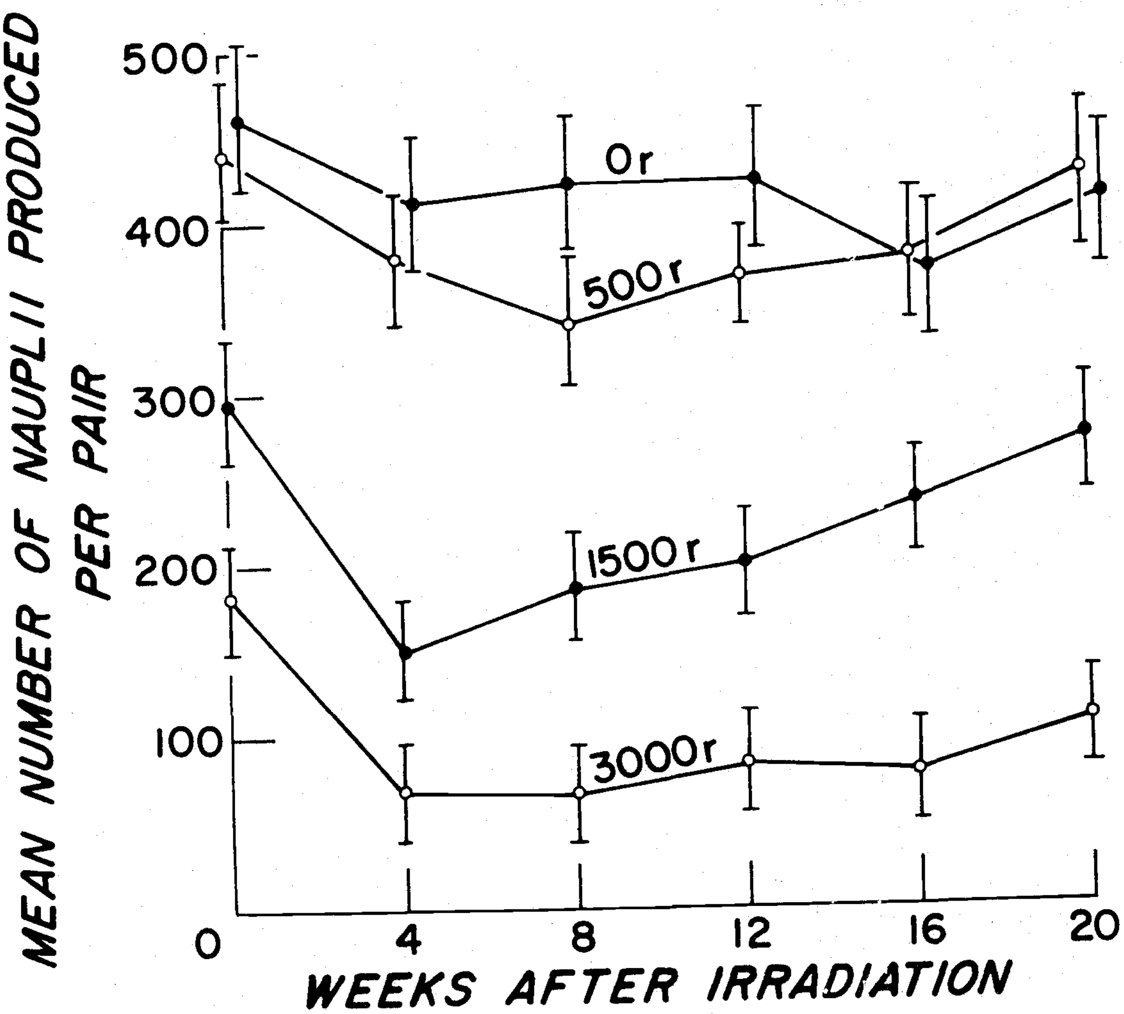

Figure 3. The mean and standard error of the number of nauplii produced per pair of Artemia, removed from irradiated populations at various time intervals.

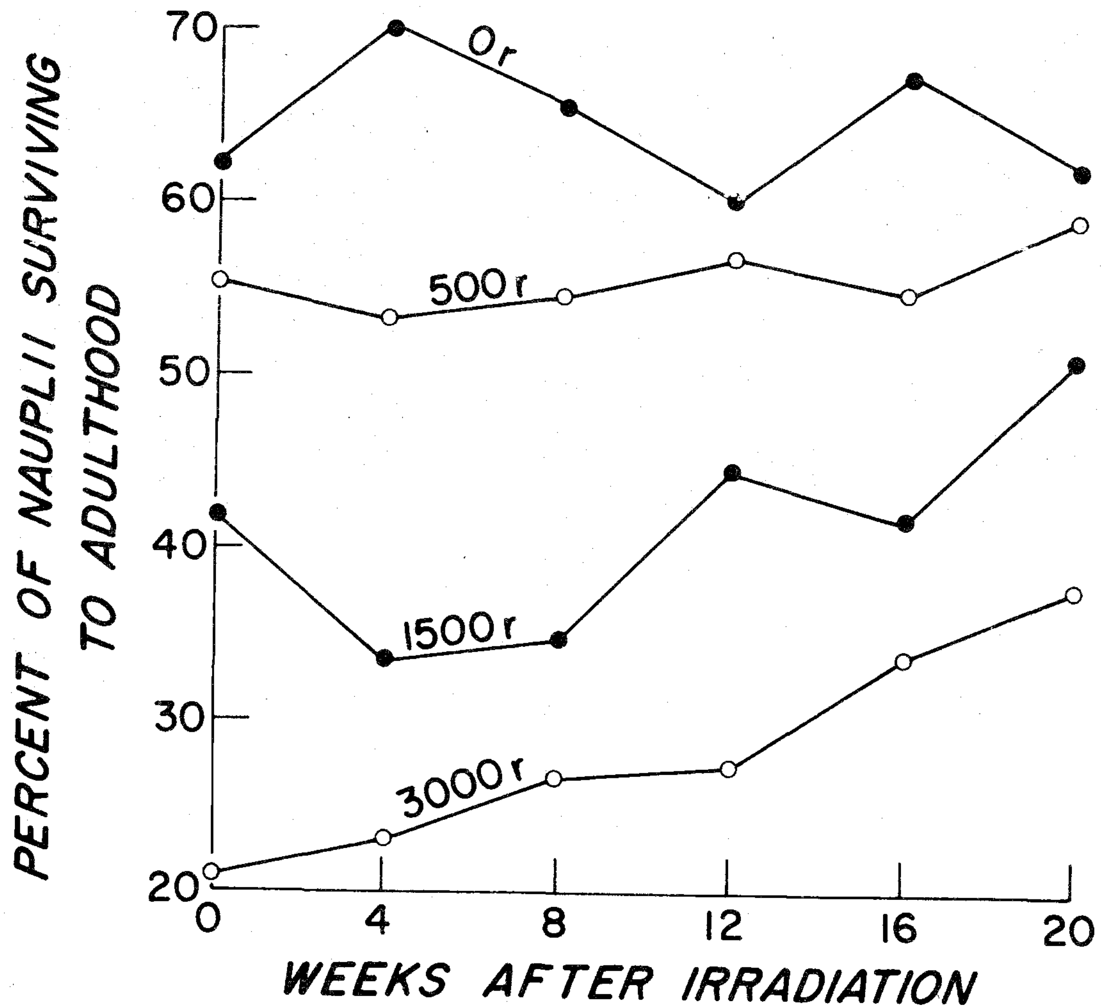

Figure 4. The percent of nauplii, produced by parents removed from irradiated populations at various time intervals, surviving to adulthood.

Another parameter is presented in Figure 5. Here, the number of mature adults produced per brood is the same for both the control and the 500 rad populations. Only at the 1500 and 3000 rad doses do we find the number of adults produced per brood decreased due to the effects of the irradiation.

It should also be noted that at four and eight weeks the difference in number of adults produced per brood is very slight for the 1500 and 3000 rad populations. However, from the 12th week to the end of the experiment, we note that the 1500 rad cultures makes a marked improvement in the number of adults produced per brood, while the 3000 rad population shows very little improvement.

The final parameter is really the factor of ultimate concern and depends upon each of the previously discussed components of the reproductive ability. This net reproductive potential within the laboratory conditions of this experiment is presented in Figure 6 as the total number of sexually mature adults which are produced by each pair of Artemia from the irradiated populations.

We note that the pair matings isolated from the control culture, on the average, produce about 270 sexually mature adults per pair. The lower production exhibited during the final three sampling periods as compared to the first three sampling intervals cannot be readily explained. The population culture exposed to 500 rads suffered an initial significant depression in net reproductive rate, but the results indicate that it has approached complete recovery at the end of 20 weeks.

In the case of the culture which was exposed to 1500 rads, we see that the net reproductive rate dropped to less than 20 percent of the control rate four weeks after irradiation. It then began a progressive recovery and, by the final week of the experiment, was exhibiting about 50 percent of the reproductive potential of the control culture.

The production of mature adults by pair matings from the culture receiving 3000 rads dropped to less than 10 percent of the control culture. Although this culture did exhibit an improvement in reproductive performance over the course of the experiment, at the final sampling the reproduction was still only about 20 percent of the rate exhibited by the controls. It is important to point out that the rate of recovery of net reproductive ability is much greater for the 1500 rad population than it is for the 3000 rad population.

The results presented in Figure 6 show that a real decrease in reproductive potential is experienced in both the 1500 and 3000 rad cultures and is still present at the end of 20 weeks. The total population counts indicated the 1500 and 3000 rad cultures were maintaining the population size as well as the control culture by the end of 20 weeks. However, we see here that though they were maintaining a normal population size, they still show the effects of irradiation by the display of this lowered reproductive potential.

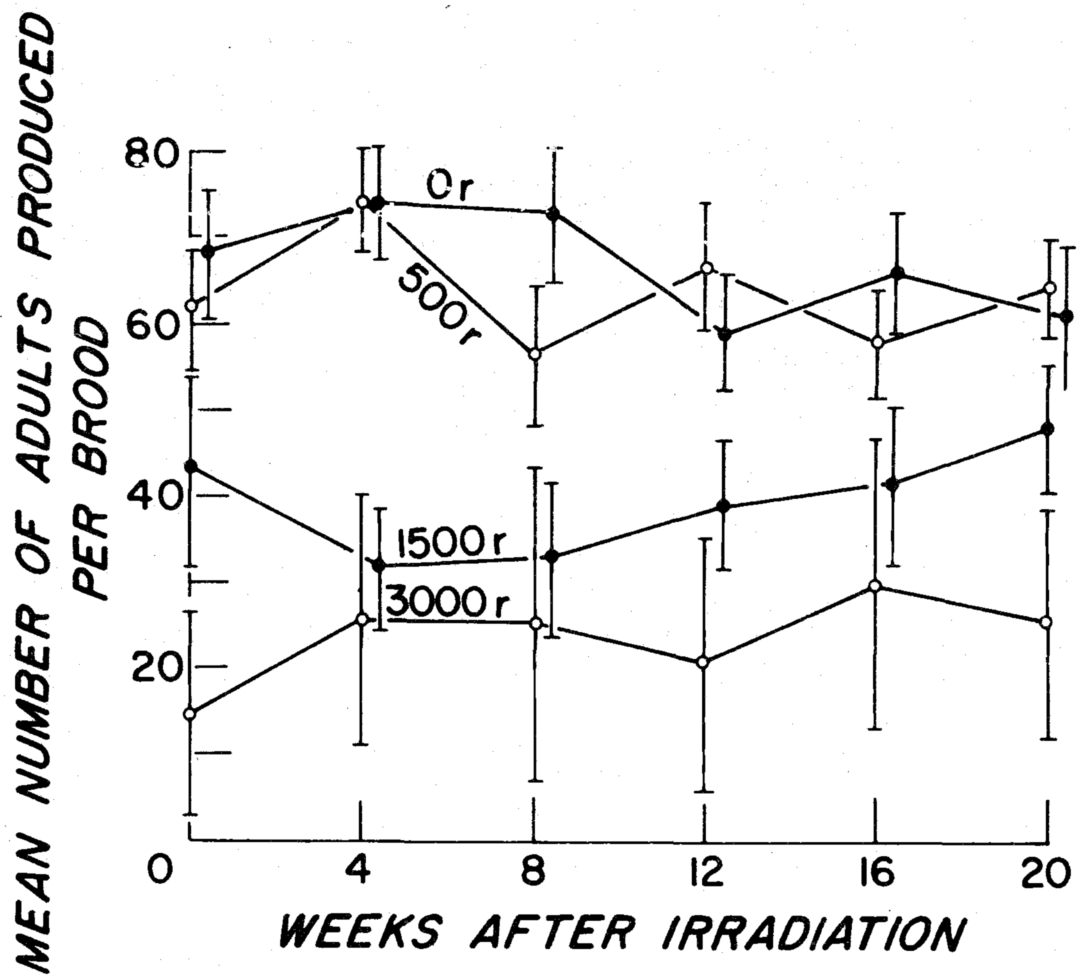

Figure 5. The mean and standard error of the number of adults produced per brood by Artemia, removed from irradiated populations at various time intervals.

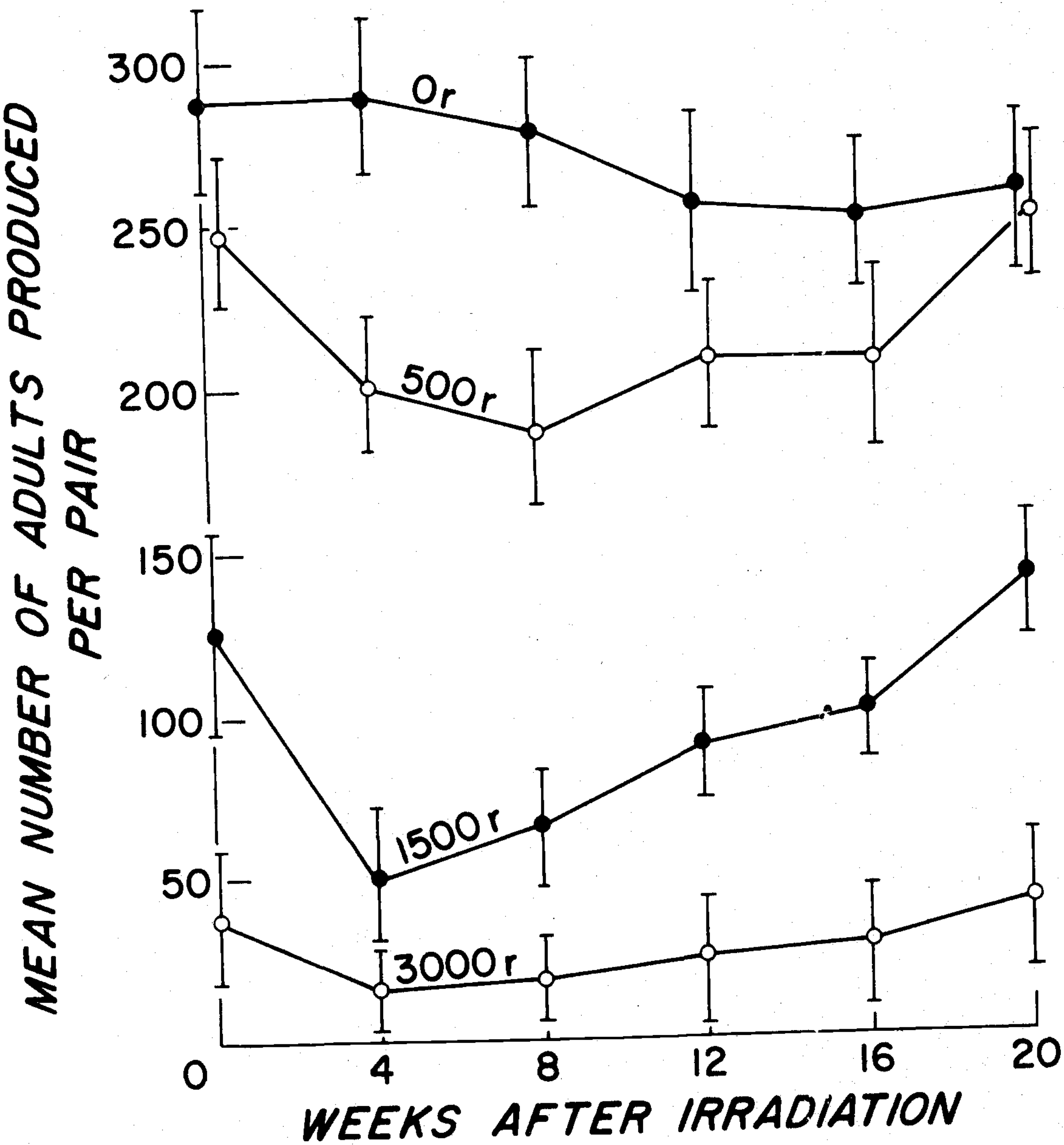

Figure 6. The mean and standard error of the number of adults produced per pair of Artemia, removed from irradiated populations at various time intervals.

CONCLUSIONS

The observed effect of a particular dose of irradiation depends on the nature of the observation. Counts made of population cultures which received different doses may show the same population levels and hence indicate that those populations which have received the higher doses have recovered from the effects of irradiation. Pair matings from these same cultures have been shown to indicate very different reproductive abilities between the populations which have received different doses. This fact should be kept in mind, especially when thinking about the effects of irradiation in the environmental situation. Even if population cultures, under ideal laboratory conditions, show no effects of the irradiation at a particular dose, it is possible that their reproductive potential has been decreased. This same dosage might affect the functioning field population which is subjected to competition with other species as well as environmental stress. Under these environmental conditions, a population could conceivably be driven to extinction with a radiation dose that showed little or no effect in a laboratory population culture.

The results presented by the analysis of pair matings in the population culture experiment indicated that after a relatively long time of 20 weeks or about five generations, the populations which received doses of 1500 and 3000 rads were still far from recovering completely from the effects of irradiation. This is in agreement with the results of Grosch (1962, 1966) who concluded that a minimum of 12 generations must elapse before a population culture which has survived the addition of 30 µCi ^{32}P per three liter culture can recover to the point of surviving the addition of a second dose of 30 µCi ^{32}P.

Further study is suggested in certain areas by the results presented here. The results discussed earlier, indicating that the effects of irradiation on the number of broods produced may be greater with the first filial generation than with the generation that was exposed to irradiation, are important enough to warrant intensive study in the future. The levels for the production of sterility and for effecting various parameters of total reproductive performance can be determined more precisely by using a series of more closely spaced doses to refine the resolution of the present experiments. It would also seem necessary to extend the present experiment by the use of a low level source to provide for chronic irradiation of the Artemia population. Such experiments would allow interesting comparisons, both with this research and with the results of Grosch (1966).

In conclusion, we should note that the results presented here would tend to confirm the theory that irradiation at the levels presently occurring in the environment will have little or no detrimental effect on the reproductive ability of animal populations. However, the results do indicate that in the event of greatly increased environmental contamination, that any reproductive damage sustained will persist over a long period of time before the populations can recover their full reproductive potential. During the course of such recovery, the nature of the existing ecosystem might be irreversibly altered.

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NEW RECORDS FOR FOUR DEEP-SEA SHRIMPS FROM THE NORTHEASTERN PACIFIC

BY

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In 1961 the Department of Oceanography of Oregon State University began a long term ecological study of that part of the Pacific off the Oregon coast. Among the many deep-sea shrimps collected during the course of this study are four species which were taken in hauls made at positions well outside their previously recorded ranges. It is the purpose of this paper to discuss the distributions of these species as they are now known. All the specimens have been deposited in the collections of the Department of Oceanography, Oregon State University. The collection of the specimens at sea by Department of Oceanography vessels was supported by U. S. Atomic Energy Commission Contracts AT(54-1) 1726 and AT(45-1) 2227, Task Agreement No. 12, RLO-2227-T12-2.

Order DECAPODA
Suborder Natantia
Section Penaeidea
Family Penaeidae
Hemipenaeus spinidorsalis Bate, 1881

Hemipenaeus spinidorsalis was originally described from specimens trawled by the "Challenger" from near Tristan da Cunha in the South Atlantic and from near the Philippines in the Pacific (Bate, 1881, 1888). Faxon (1895) recorded the species in the eastern Pacific from off Central America and the Galapagos Islands. It has been taken at depths between 1867 and 3749 m (Ramadan, 1938). The two specimens recorded here were taken in a beam trawl to a depth of 3687 m on 4 June, 1970 between 44°40.7'N 133°28.1'W and 44°40.9'N 133°24.5'W. The specimens are a male with a carapace length (postorbital) of 40 mm and a female with a carapace length of 53 mm.

Hemipenaeus spinidorsalis is closely related to H. carpenteri Wood-Mason. These species share a number of characters, which according to Ramadan (1938) may entitle them to subgeneric recognition: they posses a spine at the end of the carina of the third abdominal segment; the three anterior pereiopods have a much longer carpus than the other species of the genus, and their meri are not flattened; they possess a podobranch on the 12th somite (third pereiopods.), an epipodite on the 13th somite (fourth pereiopod) and exopods on all pereiopods.

The two specimens possess characters as given by Faxon (1895 and Burkenroad (1936) which distinguish H. spinidorsalis from H. carpenteri: rostrum reaching beyond end of eyes and more than one-fifth length of carapace; antennular stylocerite reaching to the tip of externodistal tooth of proximal segment of antennular peduncle; and in the male, having median blade of bipartite appendix masculina in the form of a long triangular tooth and shorter than lateral blade, which is concave within and furnished with setae on its distal border (see Faxon, 1895, Plate L, figs. 1e and 2).

Plesiopenaeus armatus (Bate), 1881

Plesiopenaeus armatus was originally described from specimens trawled by the "Challenger" from the South Atlantic, the Australian archipelago, the North Pacific (34°37'N 140°32'E and 36°10'N 178°0'E), and from the South Pacific (Bate, 1881, 1888). Subsequently it has been recorded, under one name or another (Burkenroad, 1936 and Ramadan, 1938 discuss the synonomy of the genus and species), from the Indian (Alcock, 1901; Ramadan, 1938) and Atlantic (Smith, 1884; Faxon,1896; Bouvier, 1905, 1908; Milne-Edwards & Bouvier, 1909; Sund, 1920; Roberts & Pequegnat, 1970) Oceans. It has been taken at depths between 750 and 5400 m.

The present specimen was taken in a beam trawl to a depth of 3724 m on 3 June, 1970 between 44°40.2'N 133°35.7'W and 44°39.5'N 133°38.3'W, and so is the first record of the species from the northeastern Pacific. It is a female with a carapace length of 77 mm (combined rostrum and carapace length of 127 mm). The specimen agrees with descriptions of the species, possessing characters given by Burkenroad (1936) and Ramadan (1938) which distinguish it from other species in the genus: last four abdominal terga carinate dorsally, a mobile spine on merus of first and second pereiopods, and a strong ischial tooth on first pereiopods.

Section Caridea
Family Oplophoridae
Acanthephyra micropthalma Smith, 1885

Acanthephyra microphthalma was originally described from specimens trawled from the western Atlantic off the east coast of the United States (Smith, 1885, 1886). Elsewhere in the Atlantic it has been recorded from off Portugal by Coutière (1911) and from southwest of the Azores by Sivertsen & Holthuis (1956). Alcock (1901) recorded it from the Bay of Bengal. In the Pacific it has only been recorded from the Celebes Sea and the southern Pacific by Bate (1888) as A. longidens Bate. It has been taken at depths between 2000 and 4700 m (Sivertsen & Holthuis, 1956).

The present specimen was taken in a beam trawl to a depth of 3655 m on 1 June, 1970 between 44°27'N 132°14'W and 44°24.6'N 132°12.9'W, and so is the first record of the species from the northeastern Pacific. The specimen, which is a female with a carapace length of 22 mm, agrees with the descriptions and figures of the species in the literature.

Systellaspis cristata (Faxon), 1893

Systellaspis cristata was originally described from specimens taken by the "Albatross" from the Gulf of Panama (Faxon, 1893, 1895), and has subsequently been recorded from the Indian (Alcock & Anderson, 1896; Anderson, 1896; Alcock 1899, 1901; Balss, 1925) and Atlantic (Balss, 1925; Holthuis, 1951; Springer & Bullis, 1956; Figueria, 1957; Fisher & Goldie, 1961; Crosnier & Forest, 1968; Foxton, 1970) Oceans. It has been recorded from hauls made to 3200 m.

Although Forss (1965) figured and discussed a damaged specimen of *Systellaspis cristata* from off Oregon (taken from a depth range of 1000 - 500 m, on 20 October, 1964 between 44°28'N 125°20'W and 44°34.5'N 125°31.4'W), it is nevertheless satisfying to record the species from the area again. Two additional specimens have been identified from OSU Oceanography collections. The first, a female with a carapace length of 11 mm, was taken in an Isaacs-Kidd midwater trawl towed through the depth range 200 - 0 m, on 20 July, 1961 between 46°14.4'N 124°40.4'W and 46°14.4'N 124°33.6'W. A second female specimen (carapace length 11.5 mm), also from an Isaacs-Kidd midwater trawl, was taken on 23 September, 1969 at a staion located 65 miles off the central Oregon coast (44°39.2'N 125°39.8'W), from a depth range of 500 - 0 m. Both specimens agree with the description of the species given by Holthuis (1951).

DISCUSSION

The actual depth of capture of specimens taken by open trawls and dredges is always in doubt since these may take specimens during descent and ascent, in addition to the normal samples taken on the bottom. Because of this, it is proper to ask whether the shrimps *Hemipenaeus spinidorsalis*, *Plesiopenaeus armatus*, and *Acanthephyra micropthalma*, which were collected only by bottom trawls, are benthic or pelagic.

Examination of stomach contents from the specimens of *H. spinidorsalis* and *P. armatus* showed the following to be present: calcareous shell fragments; Radiolaria; Foraminifera; and unidentified crustacean remains. In addition, the stomach contents from *H. spinidorsalis* included small sections of brown tube composed of cemented debris, while those from *P. armatus* included fairly large pieces of skeletal plates and spines from ophiuroid arms, several segments of a hollow calcareous tube, and a large amount of what appeared to be sediment.

The evidence presented by the stomach contents from these specimens thus indicates that they had resorted to the bottom to feed. This conclusion, along with the fact that all the previous capture records for the two species are only from trawl or dredge samples, suggests a benthonic existence for both *H. spinidorsalis* and *P. armatus*.

Although most adult Penaeidae, whether neritic or oceanic, are benthonic, a pelagic existence does occur sporadically throughout the family, and it is possible that behavior of both types are found together in certain abyssal species of the family (Burkenroad, 1936). Conceivably then specimens of H. spinidorsalis and P. armatus might swim up from the bottom at times, so that they might be taken by pelagic hauls. That these species do have a strong s imming capability is suggested by their long and well-developed pleopods.

Burkenroad (1937) has pointed out however, that "the term benthonic when applied to Decapoda Natantia, can refer at most to a vital dependence upon the bottom, rather than to an entirely substratal existence." If this is accepted, then the apparent obligatory resort to the bottom to feed by the specimens of H. spinidorsalis and P. armatus would bring these species within the range of the term, even though at times they might conceivably be found in the water column.

The situation is somewhat different in the case of Acanthephyra microp-thalma. This species, along with Systellaspis cristata, belongs to a family (Oplophoridae) which appears to be exclusively pelagic in habitat (Kemp, 1939). Examination of the published capture records for this species reveals, however, that with the exception of one, all are from trawl of dredge samples. The exception is that reported by Coutière (1911) who recorded the species (as A. longidens Bate) from a "Bourèe net" towed at a high rate of speed. The samples collected by means of this net consisted entirely of shrimps considered to be pelagic, the vast majority belonging to the Oplophoridae. The stomach contents of the present specimen consist solely of unidentified crustacean remains, with a complete lack of any remains indicating bottom foraging as was the case in the other two species. In addition, the pereiopods do not appear to show any special adaptations for a benthic existence, but appear similiar to those of other members of the genus.

Thus, it can be concluded that A. micropthalma is a species which is probably not confined to the immediate neighborhood of the bottom, but which does show structural evidences of inhabiting very great depths (very poorly developed eyes and soft integument). The presence of this species in the sample thus would be due to its having been caught either as the trawl descended or ascended. If this is the case, the vertical distribution of the species is almost certainly below 1000 m since it has never been taken in the many midwater trawls from 0 - 1000 m which have been taken off Oregon.

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A Notacanthid *Macdonaldia challengeri* Collected off the Oregon Coast

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STEIN, D., AND J. BUTLER. 1971. A notacanthid *Macdonaldia challengeri* collected off the Oregon coast. J. Fish. Res. Bd. Canada 28: 1349–1350.

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.

STEIN, D., AND J. BUTLER. 1971. A notocanthid *Macdonaldia challengeri* collected off the Oregon coast. J. Fish. Res. Bd. Canada 28: 1349–1350.

L'auteur mentionne un cinquième spécimen d'anguille épineuse abyssale rare, *Macdonaldia challengeri*, ce qui étend à la côte d'Orégon l'aire de répartition connue de cette espèce dans le Pacifique-Nord.

Received April 14, 1971

A female notacanth *Macdonaldia challengeri* Vaillant (1888), 490 mm standard length (OSU collection number 1891), was captured in a 3-m beam trawl at a depth of 2450 m, 120 km, west of Cape Falcon, Oregon (45°39.4′N, 125°57.3′W) by R/V *Yaquina* on March 19, 1970. The bottom temperature at this station was 2.03 C, salinity was 33.75‰, and oxygen was 0.829 ml/liter. The bottom sediment was mud.

Four specimens of *M. challengeri* have been previously reported: the holotype off Japan in 3429 m (Vaillant 1888); one in the Bering Sea in 2971 m (Gilbert 1896); and two off Vancouver Island in 2103–2196 m (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 S. McDowell (unpublished data).

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 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 highly variable in this family, however, even between individuals captured in the same trawl (S. McDowell personal communication).

The description of the specimen generally follows that of Peden (1968), with the following elaboration: two nostrils immediately adjacent, not separated 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 reaching anus. Intestine yellow; ovaries paired, long, thin, dorsolaterally in posterior two-thirds of body cavity. Body cavity extending short distance behind anus. Peritoneum dark brown.

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

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A TECHNIQUE FOR THE ESTIMATION OF INDICES OF REFRACTION OF MARINE PHYTOPLANKTERS[1]

by Kendall L. Carder[2], Richard D. Tomlinson and George F. Beardsley, Jr.

ABSTRACT

Light scattering and particle size distribution measurements were performed on a growing culture of the unicellular phytoplankter, Isochrysis galbana. The culture represented a narrow, polydisperse distribution of nearly spherical particles. Assuming the culture to be homogeneous in refractive index, a technique was developed that provided an estimate of the index of refraction of the culture for the wavelengths 5460 Å and 5780 Å. The relative index of refraction (relative to that of water) of the culture varied with time from 1.026 to 1.036 over a twelve day sampling period, and seemed to be related to changes in the surface-area/volume ratio of the cells. The indices of refraction determined using green light (5460 Å) corresponded closely with those found using yellow (5780 Å), with slight fluctuations, perhaps due to changes in cell pigmentation ratios.

INTRODUCTION

Light propagation in the sea is a function of both the quantity and optical quality of suspended particulates in the water. Particle quantity is quite easily determinable by filtration or electronic counting (e.g., Coulter Counter) techniques, but optical quality has been more difficult to ascertain. For the purposes of light propagation studies, the optical quality of particulates can be considered to be limited to particle size, shape, and index of refraction (relative to seawater).

The sizes and shapes of oceanic particulates have been described by means of a number of techniques (e.g., optical and electron microscopes), but their indices of refraction have been virtually unreported.

The determination of the indices of refraction of oceanic particulates is very difficult because of their small size. Ochakovsky (1966) and Beardsley et al. (1970), suggest that more than half of the open-ocean particles are smaller than one micron in diameter. This means that they average roughly one wavelength in radius. Refraction techniques are inadequate in this small size range even if the particles are regular in shape. As a result, only ranges of the relative index of refraction of oceanic particulates have been reported, usually based upon the indices of the component substances making up the particles. Burt (1956) and Jerlov (1968) indicates ranges of the relative index of refraction running from 1.0 to 1.4, with that of bacteria occurring near the lower end and hard substances (S_iO_2, $CaCO_3$, etc.) near the upper end. Bryant et al. (1969) found quantitative agreement of theoretical optical cross sections predicted by Mie theory and anamalous diffraction theory with laboratory observations from Escherichia coli cells, spinach chloroplasts, and yeast cells. Their techniques are also applicable to phytoplankton suspensions, but require extensive instrumentation and appear to be quite time consuming.

[1] submitted to Limnology and Oceanography

Measurements of the indices of refraction of various species of phytoplankton remain unreported, even though they represent the primary particle producers in the open ocean. Such information is necessary for a better understanding of the wide variability in the scattering per unit geometrical cross section reported by Pak et al. (1970), Carder et al. (1971), and Schlemmer and Carder (1972).

BACKGROUND

Mie (1908) demonstrated that the light scattered by a dielectric sphere placed in a plane-parallel beam of monochromatic light is a function of its size and index of refraction (relative to that of the medium) for a given wavelength of light. Since the scattering due to a dilute, homogeneous concentration of spheres is additive, Mie theory is quite useful for studying scattering in the oceans.

Van de Hulst (1946) provided some simplifications to the Mie theory for particles having a relative index of refraction near 1.0. He showed that the extinction efficiency factor Qext. could be expressed as

1) $\quad Qext. = 2 + (4/\rho^2)\ (1 - \cos\rho) - \frac{4}{\rho}\sin\rho$, where $\rho = \frac{2\pi d}{\lambda}(m - 1)$, "d" is the particle diameter ($0 \leq d < \infty$), λ is the wavelength of light in the medium ($0 < \lambda < \infty$), and "m" is the index of refraction of the particle relative to the medium. For non-absorbing particles the scattering efficiency factor K_s is equal to Qext, and equation 1 then also represents the scattering efficiency factor. Figure 1 illustrates that K_s is monotonic only for small values of ρ. To attempt to use values of K_s, λ, and "d" to define "m" for larger values of ρ would be more difficult, but could be accomplished by varying λ sufficiently for recognition of the curve shape.

Jerlov (1953) noticed that for seawater the radiant flux scattered at $\theta = 45°$ was proportional to the total flux scattered. Deirmendjian (1963) theoretically showed the proportionality constant of this relationship around $\theta = 40°$ to be 0.1 regardless of the size distribution function. He also suggested that the measured intensity of light scattered around $\theta = 40°$ is directly proportional to the concentration of particles, provided that the distribution is continuous with a real and constant index of refraction.

TECHNIQUES

In Beardsley et al. (1970) we have verified that the volume scattering function, $\beta(\theta)$ for $\theta = 45°$ can be approximated for seawater by

2) $\quad \beta(45°) = k \sum_{i=1}^{n} (K_{s,i})\ (S_i)$ where $K_{s,i}$ is the scattering efficiency factor of the i^{th} particle, S_i is the cross-sectional area of the i^{th} scattering particle, "n" is the total number of scatterers, and "k" is an empirical constant of proportionality. If the particles of interest have a fairly narrow size distribution, equation 1 can be written as

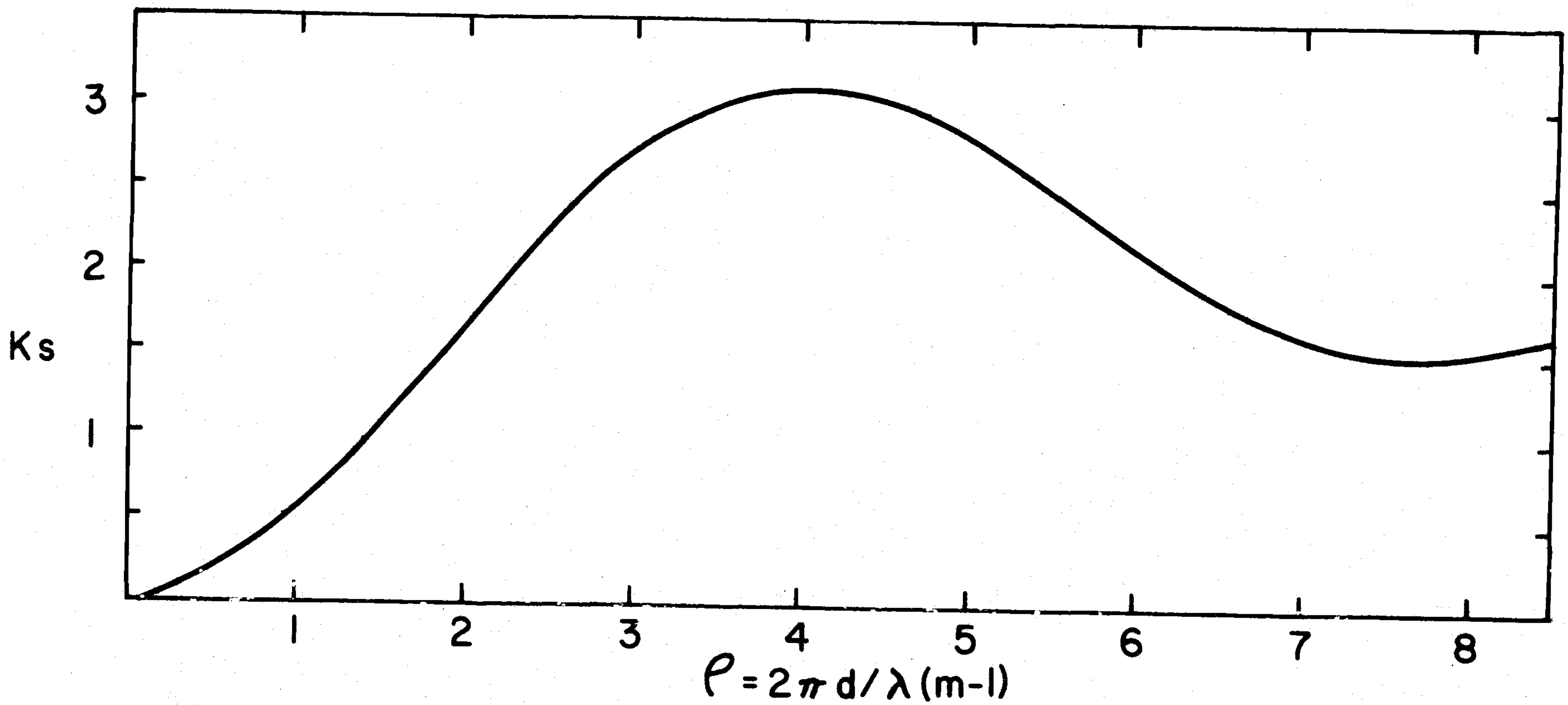

Figure 1. Scattering efficiency factor (for m near unity).

3) $\overset{*}{\beta}(45^o) \doteq k \overset{*}{K}_s n \overset{*}{S}$ where $\overset{*}{K}_s$ and $\overset{*}{S}$ are mean values. Solving equation 3 for $\overset{*}{K}_s$ produces

4) $\overset{*}{K}_s \doteq \frac{\beta(45^o)}{k\, n\, \overset{*}{S}}$. Since for optically large particles $\overset{*}{K}_s \doteq 2$ (Van de Hulst, 1946; Jerlov, 1968), "k" can be determined experimentally using polydisperse suspensions of large latex spheres.

Since K_s is not monotonic over its entire range of values and approaches the limit 2.0 for large values of ρ, it is important to select particles falling in the monotonic range of $\overset{*}{K}_s$ to obtain a one-to-one correspondence between $\overset{*}{K}_s$ and ρ.

Because phytoplankters are the primary producers of oceanic particulates, a knowledge of their indices of refraction is a necessary step in describing the submarine light field. Phytoplankton cultures represent relatively narrow polydisperse distributions of particles with generally narrow ranges of refractive index. Both of these characteristics are essential for the application of techniques developed above.

The unarmored phytoplankter, Isochrysis galbana, was selected for this study because of its optical size, relatively high transparency, and nearly spherical shape. Its values of $\overset{*}{K}_s$ fall on the monotonic portion of Figure 1 ($\rho < 2$), so that the value of $\overset{*}{\rho}$ corresponding to a given $\overset{*}{K}_s$ is unique.

ALGAL CULTURE METHODS

The species of alga used in this study was Isochrysis galbana, Class Chrysophyceae, Division Crysophyta. This unicellular organism, which lies in the nannoplankton size range (2-20 microns) on the scale given by Dussart (1965), has been thoroughly described in the literature by Parke (1949). The optical work accompanied a ^{65}Zn uptake and retention study for which the culturing techniques were designed. For this experiment, the initial inoculum was obtained in axenic culture from the laboratory of Dr. Frieda B. Taub at the University of Washington in Seattle. Subcultures were grown in autoclaved, filtered seawater held at 16.00 $\pm$ 0.25°C. The growth medium utilized prior to inoculation of the uptake and retention experiments was similar to that first characterized by Davis and Ukeles (1961). The organisms were grown under conditions of constant irradiance (1.7 milliwatts/cm^2) and aeration.

SAMPLING PROCEDURES

Light scattering and particle size distribution measurements were taken on small aliquots. Optical sampling was begun during the exponential growth phase of the culture. Each sample was diluted with autoclaved, filtered sea water in order to reduce coincidence levels of the Coulter Counter to below 1% of the total number of particles.

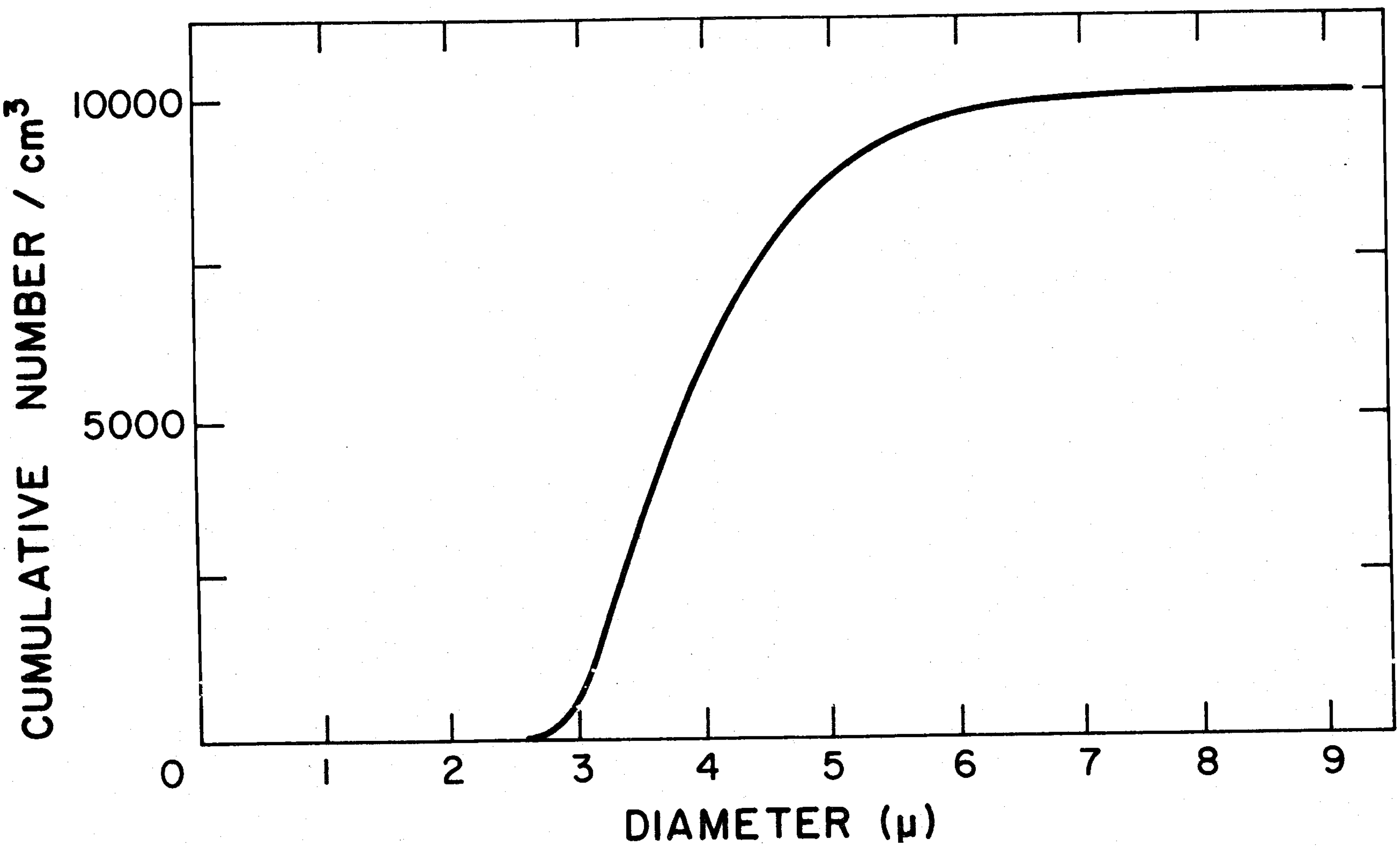

Figure 2. A typical cumulative distribution of Isochrysis galbana cells.

Table 1. Cell growth and light scattering data for a batch of Isochrysis galbana.*

Elapsed Time (days)	n/cm^3	Dilution	$\overset{*}{D}(\mu^2)$	$\overset{*}{D^2}\ (\mu^2)$	$\beta(45°) \times 10^{-2}$ $(m\text{-}sr)^{-1}$	ks	ρ	(m-1)
0	14,918	1:20	4.65	22.41	3.19	0.969	1.47	0.0225
					2.70	0.820	1.34	0.0259
					2.50	0.759	1.28	0.0265
1	10,200	1:40	4.64	21.25	2.83	1.33	1.78	0.0265
					2.49	1.17	1.62	0.0316
					2.27	1.06	1.55	0.0315
6	9,964	1:40	4.28	19.39	2.87	1.51	1.93	0.0313
					2.27	1.19	1.67	0.0344
					2.00	1.05	1.54	0.0340
8	10,974	1:40	4.24	18.92	3.00	1.47	1.89	0.0312
					2.46	1.20	1.67	0.0349
					2.32	1.13	1.62	0.0358
12	9,902	1:40	4.24	19.00	2.34	1.26	1.77	0.0287
					1.83	0.988	1.49	0.0313
					1.77	0.955	1.45	0.0326

*For each sampling period, the values of $\beta(45°)$, k_s, ρ, and m-1 are listed in order of blue, green, and yellow wavelengths.

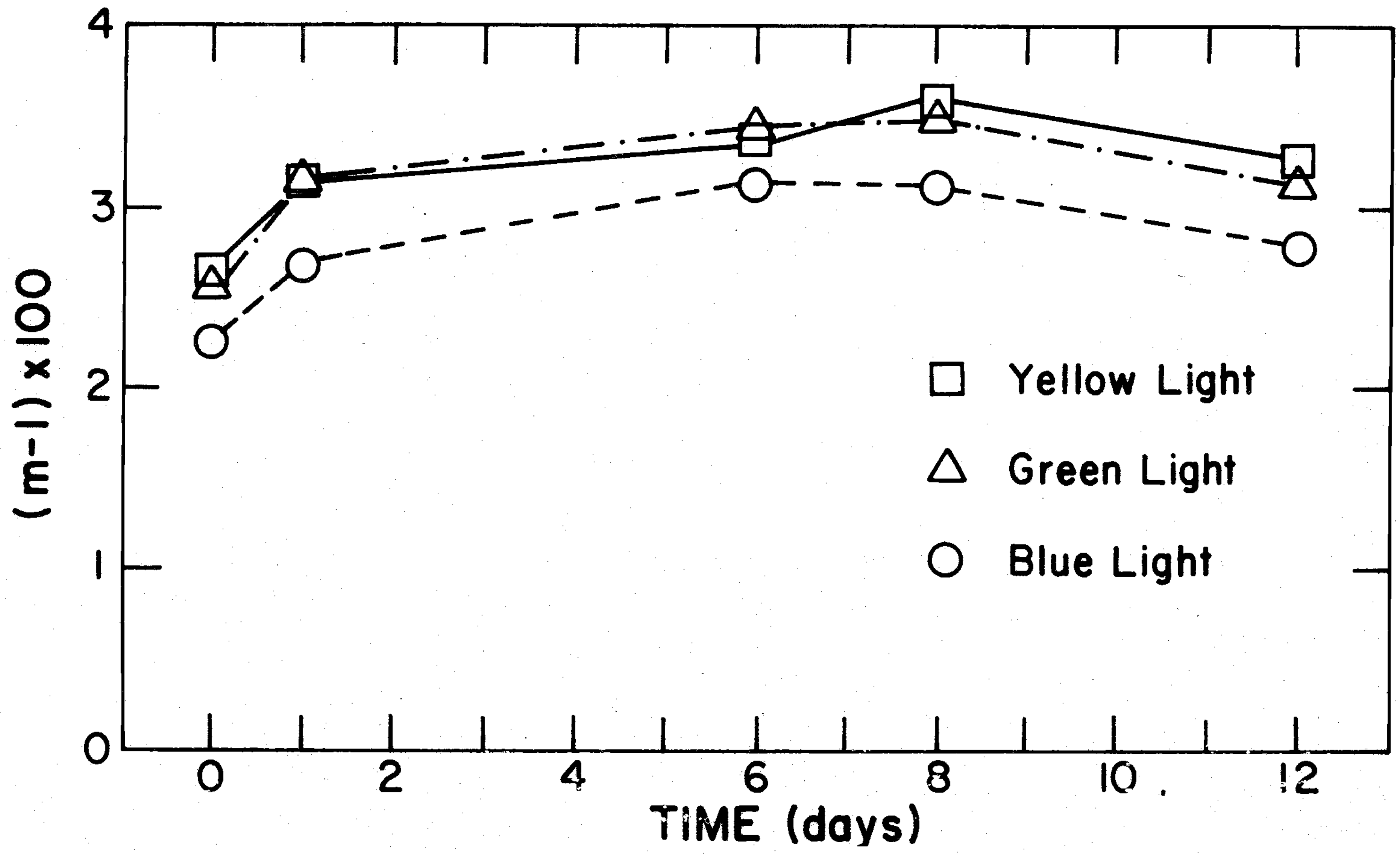

Figure 4. The effects of time and wavelength on the index of refraction of *Isochrysis galbana*.

Table 2. Analysis of variance with wavelength as blocks and time (days) as treatments.

Source	df	SS	MS	F
Blocks	2	0.4691	0.2345	82.28(*)
Treatments	4	1.513	0.3782	132.70(†)
EE	8	0.0228	0.00285	
Total	14	2.0049		

(*) 1% Confidence level: $F_2(.01) = 8.65$

(†) 1% Confidence level: $F_4(.01) = 7.01$

Table 2 also shows a significant wavelength effect. Blue light measurements in general produced smaller relative indices of refraction than did the green and yellow light as indicated by Figure 4. Theoretically there should be no wavelength effect since wavelength variations have already been accounted for in the parameter ρ. But the assumption has been made that $K_S \doteq Q_{ext.}$, which is true only for non-absorbing spheres. Since Isochrysis galbana cells are slightly greenish yellow in color and contain nuclei, this assumption is less valid for blue wavelengths and other absorption bands, that for green and yellow.

More quantitative analyses are needed to define the role plant pigments play in the selective absorption of light. Most absorption spectra for plant pigments are generated using a solvent such as ether or acetone as in Strickland (1965). French (1960) summarized the absorption band positions of various chlorophylls in ether and in live plants finding that the wavelengths of the absorption maxima increase in changing from measurements in ether solutions to in vivo measurements.

In vivo absorption measurements are at best difficult due to the overlapping of absorption bands of several pigments and to selective scattering. Latimer and Rabinowitch (1956), nevertheless, generated an in vivo spectral absorption curve for a suspension of Chlorella, a phytoplankter expected to have similar spectral characteristics to those of Isochrysis galbana. They found the relative absorption coefficient of blue light (4360 Å) to be about thirteen times that of green light (5460 Å) and about ten times that of yellow light (5780 Å). The green and yellow wavelengths fell near the minimum of the visible portion of the spectral absorption curve, so little error is introduced by assuming that Isochrysis cells are non-absorbing for these wavelengths. Increases in spectral absorption result in decreases in the "apparent" index of refraction of cells when this "nonabsorptive" technique is used. Due to the relatively high absorption of blue light by chlorophyll, the indices of refraction derived using blue light are in error and must be discarded.

The increase in the index of refraction of yellow light relative to that of green light after day six (Figure 4) is an interesting phenomenon. Although the relative increase is quite small and could be due to experimental error alone, another possibility might be that a change in the relative concentrations of various pigments occurred after day six. Yentsch and Vaccaro (1958) have measured sharp decreases in the chlorophyll-to-carotenoid ratio in algal cultures during nitrogen deficiency. Such a variation in the pigmentation ratio could explain the relative decrease in the "apparent" index of refraction using green light, since β-carotene is more absorptive of green wavelengths than of yellow. Since no nutrient data was taken during this experiment, this hypothesis is pure speculation at this time.

In this experiment, most of the spectral variation in the refractive ratio fell within the limits of the 2% experimental error. This means that either the spectral fluctuations are due to experimental error or that another factor (e.g., nutrient deficiency) needs to be considered. Further experimentation is required to resolve this question.

CONCLUSIONS

A technique was developed to estimate *in vivo* the real (non-absorptive) part of the index of refraction of *Isochrysis galbana* relative to seawater (S=35%). It was found to range from 1.026 to 1.036 for the two incident wavelengths 5460 Å and 5780 Å. It varied significantly with the mean particle diameter which changed with time by as much as 9%. This was probably due to concurrent changes in the surface area-to-volume ratio since the cell wall represents one of the most refractive parts of the cell. If the assumption that algal absorption of yellow and green light is negligible were incorrect, it would cause these experimental refractive index values to be slightly low. The literature, however, indicates that absorption of these wavelengths by the primary algal pigments is small. The indices of refraction found using blue light (4360 Å) could not be used due to its high absorption by the algal pigments which caused an "apparent" lowering of the refractive index.

Since algal pigment ratios are indicators of the nitrogen sufficiency of an algal culture medium, the spectral sensitivity to pigment ratio changes of the "apparent" relative index of above may prove to be useful in monitoring the effective nitrogen levels in growing algal cultures.

Although the *in vivo* measurement of the refractive index of one species of marine phytoplankton does not allow many generalizations to be made concerning the light-scattering properties of suspended marine particulates, it does suggest a few. Since *Isochrysis galbana* is an unarmored type of phytoplankter, its index of refraction is near the lower limit of the range of indices expected for marine phytoplankters and representative of those indices expected for "soft" organisms. Since the light scattering for a given geometrical cross section of marine particulates increases with depth (Pak *et al.*, 1970), this suggests that the harder, more refractive parts of organisms are all that remain of them at depth. Consequently, the mean refractive index relative to seawater of suspended marine particulates is expected to be greater than 1.036.

Optical measurements of diatoms, cocolithophores, etc. need to be made in order to better understand the range of effects that various phytoplankters have upon the optical properties of the oceans, especially in upwelling areas.

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FOOTNOTES

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GROWTH OF A SEA URCHIN, ALLOCENTROTUS FRAGILIS, OFF THE OREGON COAST

by James L. Sumich and James E. McCauley

ABSTRACT

Allocentrotus fragilis (Jackson) was obtained from six stations at depths of 100 to 1260 m on the continental shelf and upper slope off Newport, Oregon.

Ages and growth rates of *A. fragilis* were determined by two methods: 1) from size-frequency distributions of trawl collections from 200 m, and 2) from growth zones on skeletal test plates. 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 suggested, with spawning occurring in early spring and early autumn. No individuals collected below 400 m were reproductively mature. A procedure was developed to make growth zones of the skeletal test plates visible. Dark growth zones are thought to correspond to semi-annual periods of growth; one half the number of dark growth zones indicating the urchin's age.

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 to von Bertalanffy's growth equation. Growth rates determined from plate growth zones appeared to be similar for *A. fragilis* from 100-600 m, but decreased for specimens from 800 to 1260 m. The asymptotic size decreased with increasing depth below 200 m.

INTRODUCTION

The pink sea urchin *Allocentrotus fragilis* (Jackson) inhabits the continental shelf and upper slope of the west coast of North America from Baja, California to Vancouver Island, British Columbia, from a depth of 50 to 1150 m (Mortensen, 1943). The physiology, reproduction, and ecology of this species have been studied by Moore (1959), Boolootian *et al.* (1959), and Giese, (1961); and McCauley and Carey (1967) have discussed and summarized its distribution. *Allocentrotus fragilis* occurs in large numbers off Oregon where it is found on unconsolidated sediments, ranging from sand to clay silts (McCauley and Carey, 1967); and it is the dominant benthic organism, in terms of biomass, at 200mm off Newport, Oregon (Carey, 1972). Yet, no information on size specific growth and longevity of *A. fragilis* or other deep-water echinoids is available.

Ages and growth rates of sea urchins have been determined by one or a combination of the following methods: 1) tagging and observation of selected individuals in their natural habitat, 2) laboratory observation of urchins 3) size-frequency distributions, or 4) analyses of cyclic growth indicators in spines and test plates.

Individual tagging, such as that used by Ebert (1965), is an effective way of following the growth of individual urchins, but is restricted to areas where urchins may be collected, tagged, and replaced for later recovery. Laboratory growth studies are normally restricted to shallow water urchins, because deep water species such as A. fragilis often do not survive the rigors of collection or do not survive long in the laboratory (Boolootian et al., 1959). Giles (personal communication) kept a few A. fragilis from 200 m off Oregon in aquaria for about five months but made no conclusions about growth rates. Size-frequency distributions, used successfully by Fuji (1967) and Ebert (1968) to establish the ages and growth rates of two intertidal species of Strongylocentrotus, require periodic large samples representative of a population.

A variety of patterns observed in the hard parts of various marine invertebrates have been related to periodic variations in the structure or pigmentation during growth. These are exemplified by growth lines of pelycepod shells (Clark, 1968; House and Farrow, 1968) and seasonal pigment bands in the shells of abalone (Olsen, 1968). Many echinoids also exhibit alternating light and dark bands in the plates of the test and in spines which are superficially similar to the annual growth rings found in woody plants.

Some echinoids, including A. fragilis, have spines which are too small for the ring count method. The dark bands observed in the test plates of echinoids have received less study as age indicators, than have spine rings, yet interpretation is theoretically much simpler. Breakage and loss of plates do not normally occur, whereas spine loss and damage is common (Ebert, 1967a; Weber, 1969). The earliest formed plates are always associated with the urchin for its entire non-larval life and therefore should represent the age of the urchin more accurately.

Deutler (1926) ground the plates of a variety of echinoids to make the dark bands visible, and Moore (1935), using a similar method with the genital plates of Echinus esculentus Linneus, found good agreement between the number of dark bands and age of the urchins as determined from size-frequency distributions. A darkly pigmented zone was added to each plate during the summer, and a lighter non-pigmented zone was added during the winter.

A much less tedious method of making dark bands visible, described by Jensen (1969), involved clearing the plates with an organic solvent. She found a pattern of test plate band formation for the North Atlantic urchin Strongylocentrotus droebachiensis (D. F. Muller) that suggested a maximum number of dark zones in the test plates representing the urchin's age in years.

For the present study, a modification of Jensen's method was used in conjunction with size-frequency distribution analyses to determine the age and growth rate of A. fragilis.

METHODS AND MATERIALS

Allocentrotus fragilis was collected by the Oregon State University Department of Oceanography as part of regular sampling programs. Samples from depths of 100, 200, 400, 600, 800, and 1260 m were obtained along a line extending west from Newport, Oregon near latitude 44° 39'N using otter and beam trawls. Population density at 200 m was estimated from an odometer-wheeled beam trawl collection.

The urchins, preserved in neutral formalin, were returned to the laboratory, scrubbed with a stiff brush to remove the spines and measured from ambulacrum to the opposite interambulacrum. The two halves of an emptied test were rinsed, then placed in 25% household bleach (e.g. "Chlorox") for maceration, but removed from the bleach solution before disarticulation of the test plates occurred. One interambulacral column and the adjacent ambulacral column of test plates extending from the peristome to the periproct were separated from the remainder of a test half. The plates were arranged in order, flat, on a 1 x 3 inch microscope slide with the inner side of the test plates up, and heated on a hot plate at 85°C for three hours to remove all moisture. After cooling, the plates were wetted with xylene, then saturated with "Permount" and allowed to dry. Dark bands were counted under a 6x dissecting microscope.

RESULTS

At the six stations sampled, *A. fragilis* was taken consistently only at the 200 m station (Table 1). The values are given only as a rough indication of *A. fragilis* abundance at each station, because trawling times were not always the same.

A beam trawl collection made on 15 March, 1970 at the 200 m station yielded 687 *A. fragilis*. Approximately 3200 m^2 of bottom area were sampled. Only otter trawl samples were obtained at the other stations. McCauley and Carey (1967) have shown, using a Benthos Time-Depth Recorder^R, that the otter trawl may be off the bottom as much as 75% of the time, making estimates of the area sampled extremely difficult and unreliable. Even so, data provided in Table 1 show that *A. fragilis* is much more abundant at the 200 m station than at the other stations. Although trawling times were not consistent, shallow stations (100 and 200 m) tended to be trawled for shorter times making the estimates of abundance conservative at these stations.

The smallest *A. fragilis* test diameter, 8 mm, was assumed to be the minimum size catch capability of either the beam or the otter trawl nets, and test diameters smaller than the stretched size of the net liner (12 mm) were probably not representative of the sampled population.

Table 1. Summary of A. fragilis collections at lat. 44°39' since April, 1963.

Station Depth -	100m	200m	400m	600m	800m	1260m
Number of otter trawls	10	38	4	6	26	6
Trawls with A. fragilis	1	38	3	3	4	1
Percent with A. fragilis	10	100	75	40	15	17
Max. number A. fragilis/trawl	16	750	35	93	89	5

Table 2. Summary of A. fragilis gonad wet weights from stations below 200 m.

Depth (m)	Number of specimens	Gonad wet weight (g) mean ± 1 S.D.	range
400	14	0.22 ± 0.43	0.00-1.73
600	21	0.02 ± 0.05	0.00-0.22
800	21	0.02 ± 0.04	0.00-0.14
1260	5	0.00 ± 0.00	0.00-0.01

Five *A. fragilis* from 1260 m (latitude 44°36'N, longitude 125°02'W) extends the bathymetric range 110 m deeper than 1150 m (reported by Mortensen 1943).

Size-frequency Distribution Analysis

The usefulness and accuracy of size-frequency distributions as indicators of age depend on the following assumptions 1) size-frequency peaks of successive age groups must be discernible; 2) growth rates within an age class are normally distributed; 3) the population sample should include representative numbers from all size classes present in the population; and 4) spawning must occur periodically with a spawning duration short in relation to the length of the reproductive cycle. Trawl collections of *A. fragilis* from stations other than 200 m were neither numerous nor periodic. Size-frequency analyses of these collections were not attempted due to small numbers of individuals per trawl and to the lack of successive periodic collections at any one station.

The test diameters of *A. fragilis* from eleven trawl collections taken between October, 1968 and March, 1970 from the 200 m station were measured. The size-frequency distributions for the September and October, 1969 samples represent complete trawl collections and are shown in Figure 1. The remaining trawl collections were either subsampled at sea, or consisted of only large adult urchins exhibiting no discernable size classes.

The trawl collections taken in September and November 1969 have two well-defined size classes of small urchins, each with means centered 10-11 mm apart. By assuming that each peak represented a separate age class and that the two November peaks were derived from the slightly smaller September peaks, two different measures of *A. fragilis* growth rate were determined. If the increase in the mean test diameter of each size class during the two month interval between the September and November collections was 3.2 mm for the smaller peak and 2.6 mm for the larger peak, this was equivalent to approximately 20 mm of annual test diameter increase for the small size class, and 16 mm for the larger peak. This assumed annual size increase was approximately twice as large as that computed from the mean size difference between successive age classes (10-11 mm). The lack of agreement between the results of the two methods suggested that the growth rate calculated for the two-month interval from September to November 1969 was substantially greater than the average annual growth rate, that the size classes determined from size-frequency analysis corresponded to semi-annual rather than annual recruitment classes, or that the trawls sampled separate populations.

Very little information exists about monthly or seasonal growth rate fluctuations of echinoids. Fuji (1967) obtained monthly measurements of the diameters of five year classes of the intertidal *Strongylocentrotus*

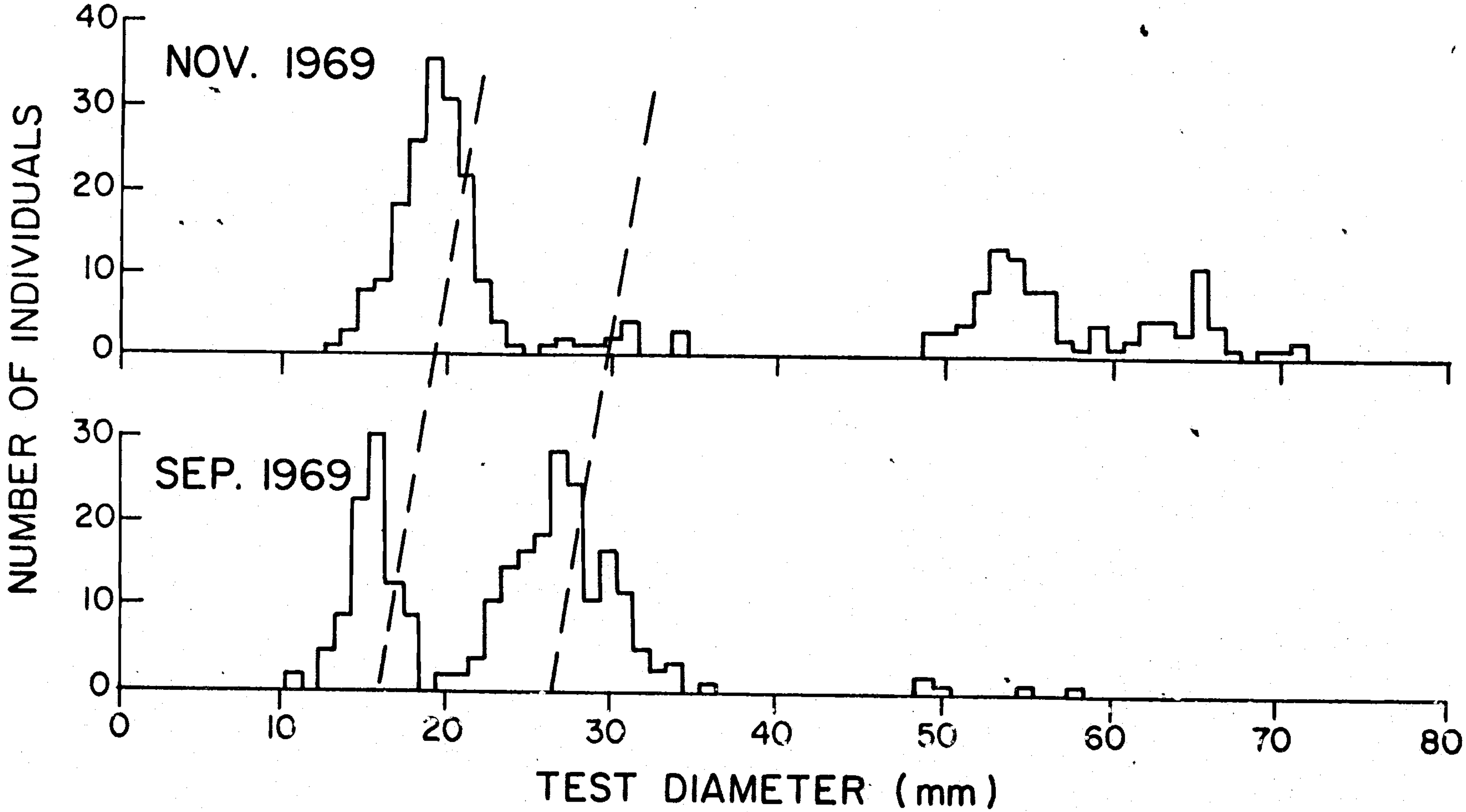

Figure 1. Time series of A. fragilis size-frequency distributions from 200 m. Dashed lines intersect the means of well-defined size classes indicating assumed size increase with time.

intermedius (A. Agassiz) and found that each year class exhibited a constant annual growth rate which differed from the other year classes. Similar observations of deep-water echinoids have not been made.

Reproductive Periodicity

Reproductive periodicity was studied only in specimens from the 200 m station, as the remaining stations lacked successive samples required for such a study.

The minimum size at sexual maturity was estimated by plotting gonad wet weight as a function of test diameter for 200 m station specimens (Figure 2). The maximum gonadal weight was low for animals less than 45 mm test diameter, then increased rapidly for specimens larger than 50 mm diameter. The actual minimum size at sexual maturity may be less than 50 mm, but an unexplained paucity of specimens with test diameters between 35 and 50 mm restricted the study of gonadal development in this range.

Gonad indices, determined from the gonadal biomass, have been widely used as indicators of reproductive state and spawning period of echinoids (Boolootian *et al.*, 1959; Giese, 1961; Boolootian, 1966; Fuji, 1967). The gonad index has generally been calculated as the ratio of gonad wet weight to the total wet weight of the animal (Boolootian, 1966). With *A. fragilis*, accurate wet weights quite often could not be obtained because of crushing and abrasion of the tests and spines during trawling and because the amount of fluid contained within the test or adhering to it could not be controlled. Therefore test diameter rather than test volume or total wet weight was selected as a simple, but effective indicator of size because the urchins used were approximately the same size. A gonad index was computed from the following formula:

$$\text{Gonad Index} = \frac{\text{gonad wet weight}}{\text{test diameter}} \times 100$$

The gonad index values ranged from less than 0.1 for immature specimens up to 3.3 for mature individuals.

Gonad wet weight determinations suggested that some urchins from the 400 m station were reproductively mature but all specimens from 600, 800 and 1260 m had gonad indices of less than 0.3 and appeared immature (Table 2). Although data for the deep stations are limited, gonad indices suggest that *A. fragilis* does not achieve sexual maturity below 400 m.

Specimens from 200 m which were larger than the estimated minimum size at sexual maturity show marked semi-annual peaks in gonadal weight, strongly suggesting two spawning seasons per year; one in late summer, and one in later winter (Figure 3). Two age classes are thus spawned each year.

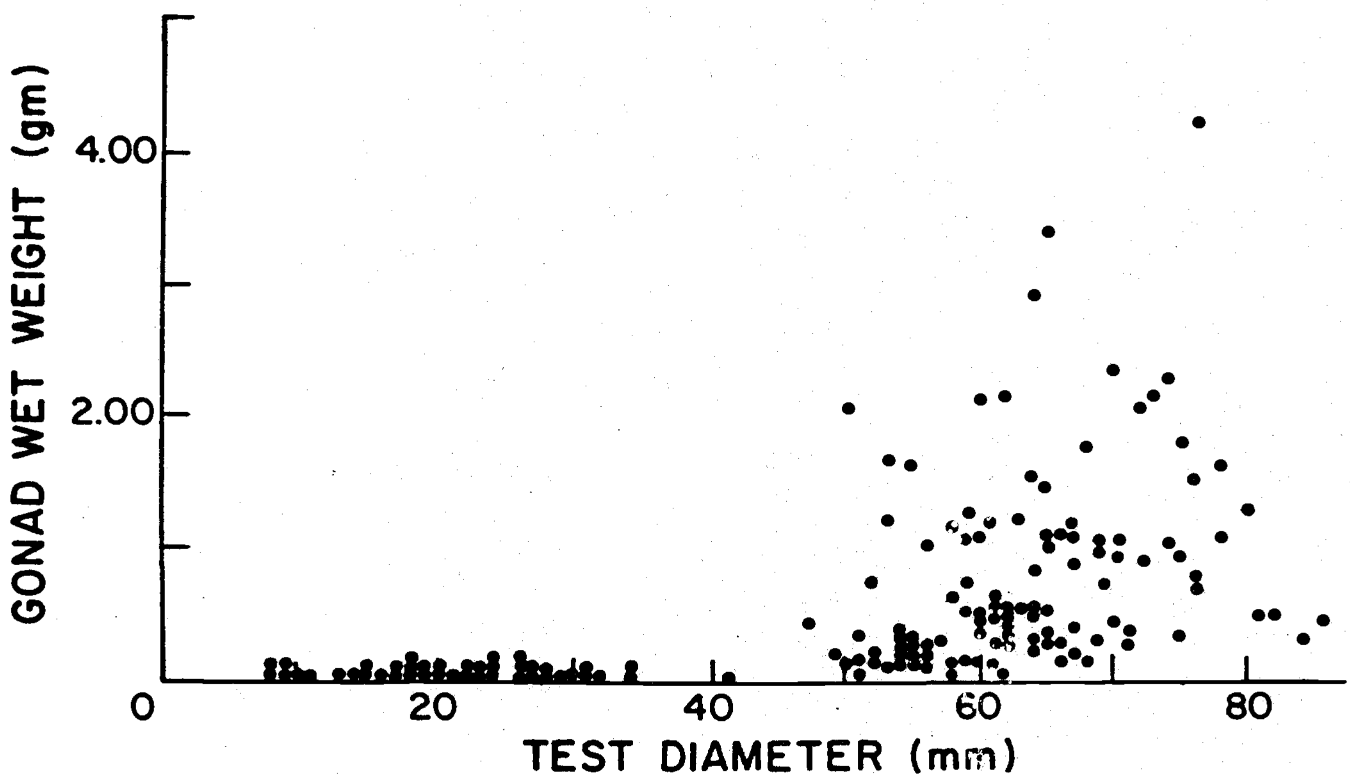

Figure 2. Variation of gonad wet weight with test diameter of A. fragilis from 200 m.

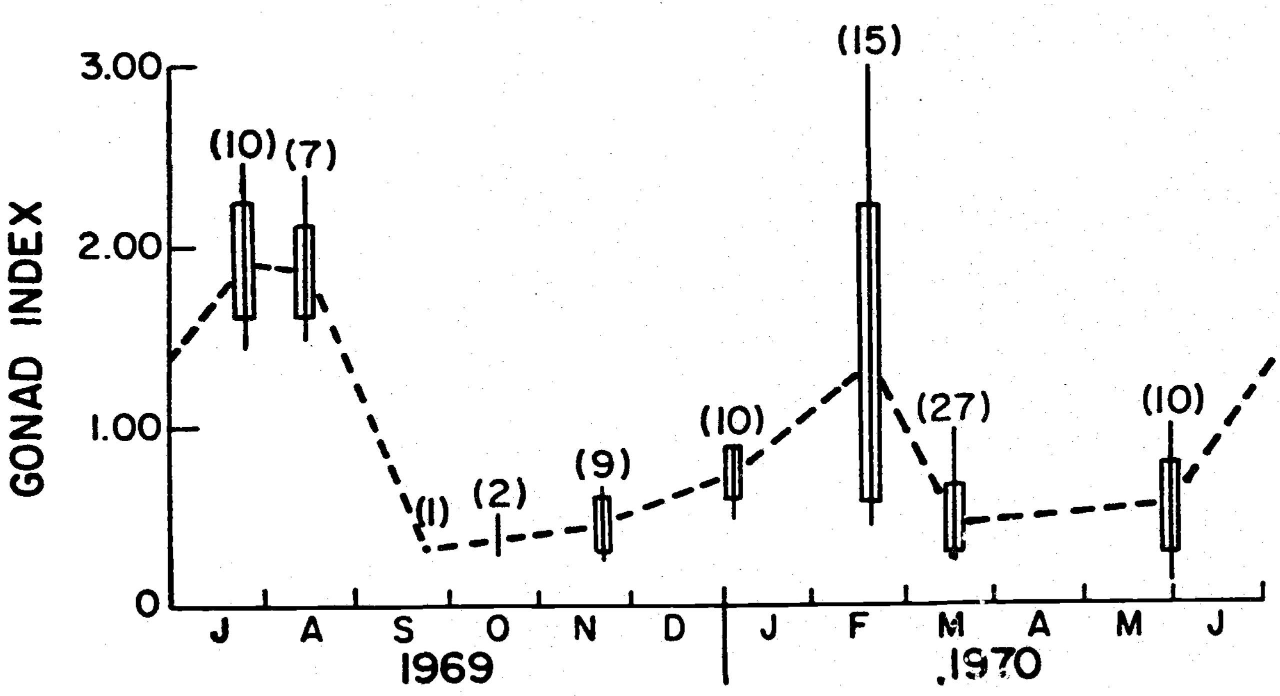

Figure 3. Monthly gonad index variation of A. fragilis greater than 49 mm in test diameter. Range of values is shown as a central vertical line. One standard deviation on each side of the mean is represented by a rectangle. The numbers of specimens are shown in parentheses.

again. This process was repeated until all growth zones within an interambulacral series had been counted. (See Figure 4.)

The maximum number of dark growth zones were determined for one interambulacral plate series of each urchin examined. The least number of dark growth zones found was one, in specimens 8-9 mm in diameter; the greatest number was 15 in a specimen 80 mm in diameter. Both specimens were collected from the 200 m station. The number of dark growth zones of the individuals was related to the distribution of test diameters. Some scatter and overlap occurred in specimens larger than 50 mm, but the size-frequency peaks less than 40 mm in diameter generally were composed of specimens with the same number of growth zones and specimens of successive age classes had consecutive numbers of dark growth zones.

The test diameters were plotted as a function of the maximum number of dark zones of the test plates of each specimen. A growth curve for A. fragilis at 200 m was constructed using the test diameter means and standard deviations of each "growth zone class" (Figure 5). The von Bertalanffy type of growth curve was fitted to the mean growth zone sizes using the method of least squares described by Tomlinson and Abramson (1961). Urchins from 200 m have approximate growth rates of 9 mm per growth zone period for 15 mm urchins, and 7 mm per growth zone period for 30 mm urchins.

These growth rates compare favorably with those determined by the mean size difference of successive age classes. This means that the frequency of spawning and the frequency of growth zone formation are the same. However, these growth rates do not agree with the growth rates estimated from the mean annual size increase of the age class.

Synopsis of Growth Rate Determinations

Agreement between the results of gonadal studies and of the different methods of growth rate determination can occur only if each age class and each new dark growth zone is added semi-annually. Moore (1935) considered the growth zones of Echinus esculentus to be bands of food-derived pigment which were incorporated seasonally into growing skeletal material during the season of rapid intertidal plant growth. Growth zones in the plates of A. fragilis seem to reflect semi-annual fluctuations of the amount of pigmented organic material available from surface productivity, suggesting that the two pigmented zones formed annually are the result of semi-annual plankton blooms in surface water.

Examination of A. fragilis gut contents shows that this species is a particulate detrital feeder, and could incorporate into its test seasonally fluctuating amounts of plant pigment produced during spring and fall phytoplankton blooms. However, no published information on the chemical composition of the pigmented bands of any echinoid test plates is available to confirm this.

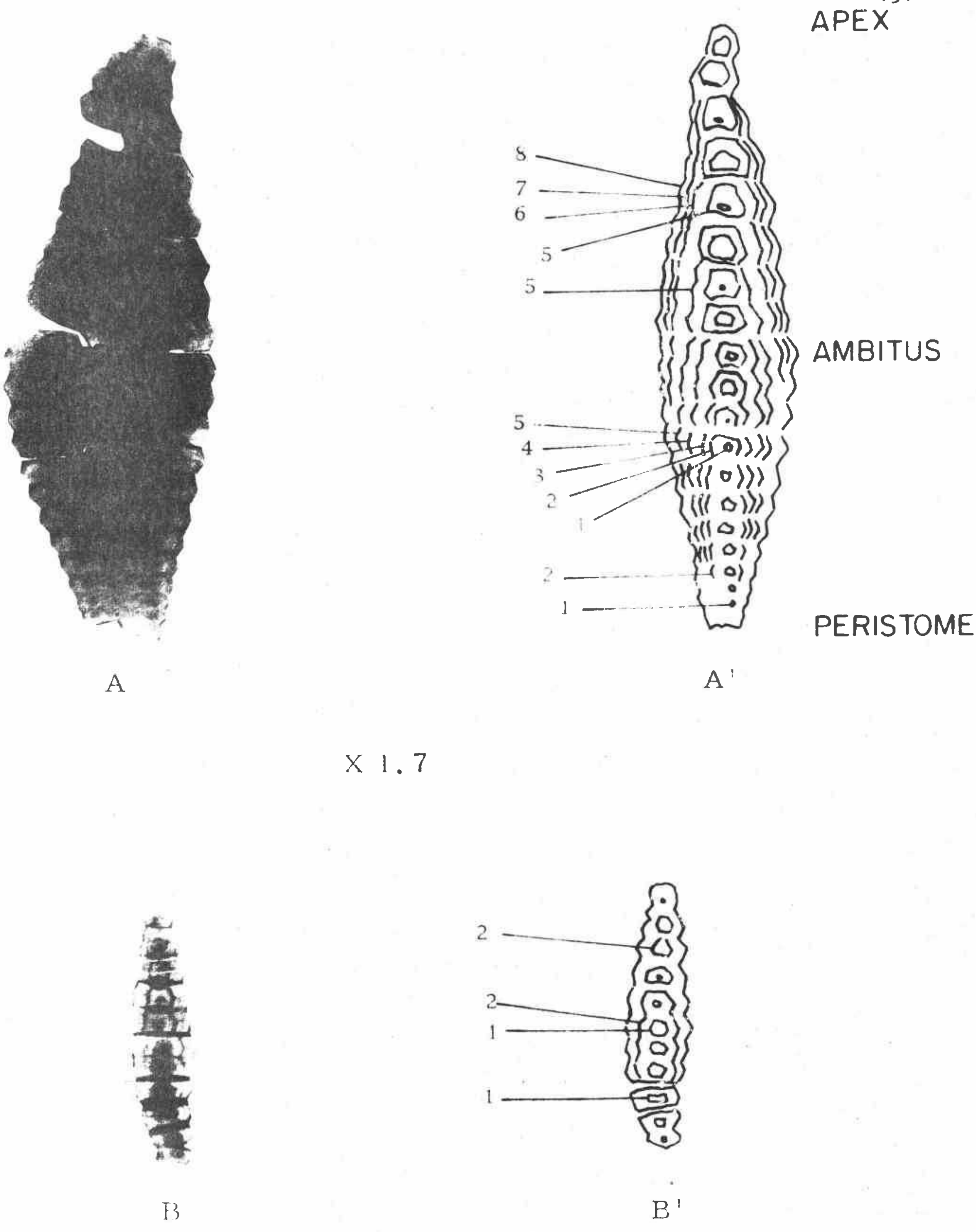

Figure 4. Photographs and tracings of interambulacral columns of two A. fragilis specimens from 200 m. A. From a specimen 53 mm in test diameter and B. From a specimen 17 mm in test diameter. The dark growth zones are numbered in A' and B' according to the order in which they were formed.

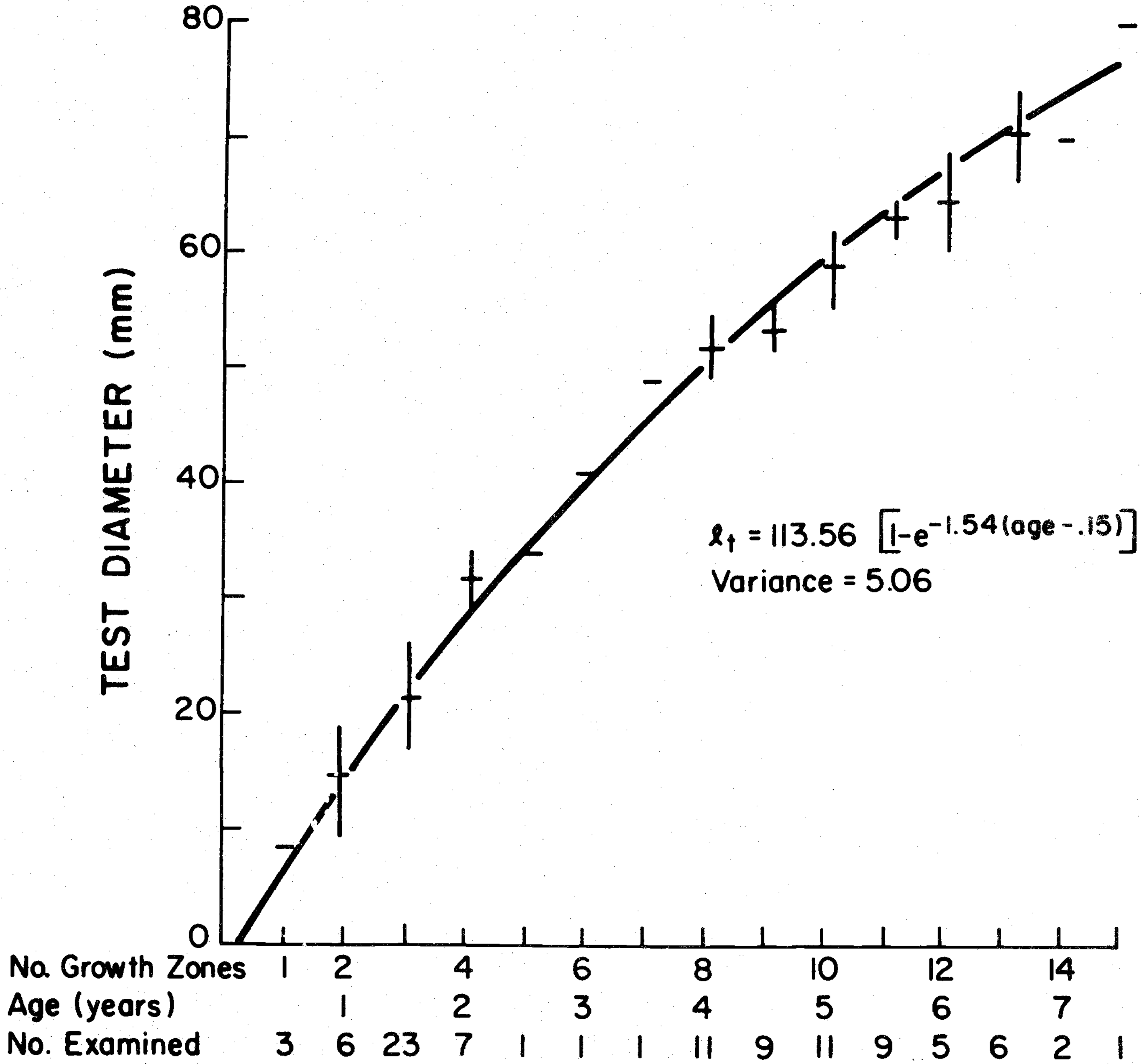

Figure 5. Least-squares fit of von Bertalanffy growth curve for *A. fragilis* from 200 m. Means ±1 standard deviation of each growth zone class are shown.

Earlier studies on the reproductive periodicity of A. fragilis at Monterey Bay, California, established a spawning period between January and March (Boolootian et al., 1959; Giese, 1961; Boolootian, 1966), but no reference was made to an autumn spawning period. There the spawning of A. fragilis is closely related to the onset of local upwelling, a condition common for benthic invertebrates which produce planktonic larvae. The spawning periods of A. fragilis off Oregon also appear to be closely associated with periods of high primary productivity of the surface waters (Anderson, 1964)

Moore (1959) found that at equivalent temperatures A. fragilis and S. franciscanus (A. Agassiz) larvae developed similarly up to at least the five-day stage. After five days, his experiments were terminated. Details of the later larval development of A. fragilis are not known, but S. franciscanus larvae required 62 days to complete development from fertilization to metamorphosis (Johnson, 1930). Newly metamorphosed S. franciscanus are less than 1 mm in diameter. If the rates of late larval development of both species remain nearly equal, larval metamorphosis and settling of A. fragilis would be expected approximately two months after spawning. Off Oregon, settling would probably occur in April-May and October-November of each year.

Growth Zone Counts

Visible dark bands, or growth zones, in test plates of 5 to 30 specimens from each trawl collection were counted. The maximum number of growth zones in A. fragilis is not exhibited in any one plate of an interambulacral column. Plates near the peristome are the oldest. As the urchin grows, the width of existing plates increases and new plates are formed in the apical region. As more plates are formed they migrate from the apical region toward the ambitus, where they increase greatly in width, but not in height. It is in the wide lateral areas of the plates that growth zones are best seem and counted. This growth process is shown in Figure 4.

As the test diameter continues to increase, older plates migrate past the wide ambitus region toward the more narrow peristome. Lateral growth ceases as they pass the ambitus because the test area in which they are now located is more longer increasing in size. Cessation of lateral growth halts the formation of growth zones in these plates; but zones continue to be formed in the plates above the ambitus. Thus, the oldest plates near the peristome exhibit only earlier formed growth zones, not more recent zones. Younger plates, near the apical area, do not exhibit early growth zones but show only the more recent, some of which are not exhibited by older plates.

Growth-zones were counted beginning with the center of the oldest plates near the peristome, counting growth zones laterally, moving up the corresponding growth zone to a younger plate, and counting laterally

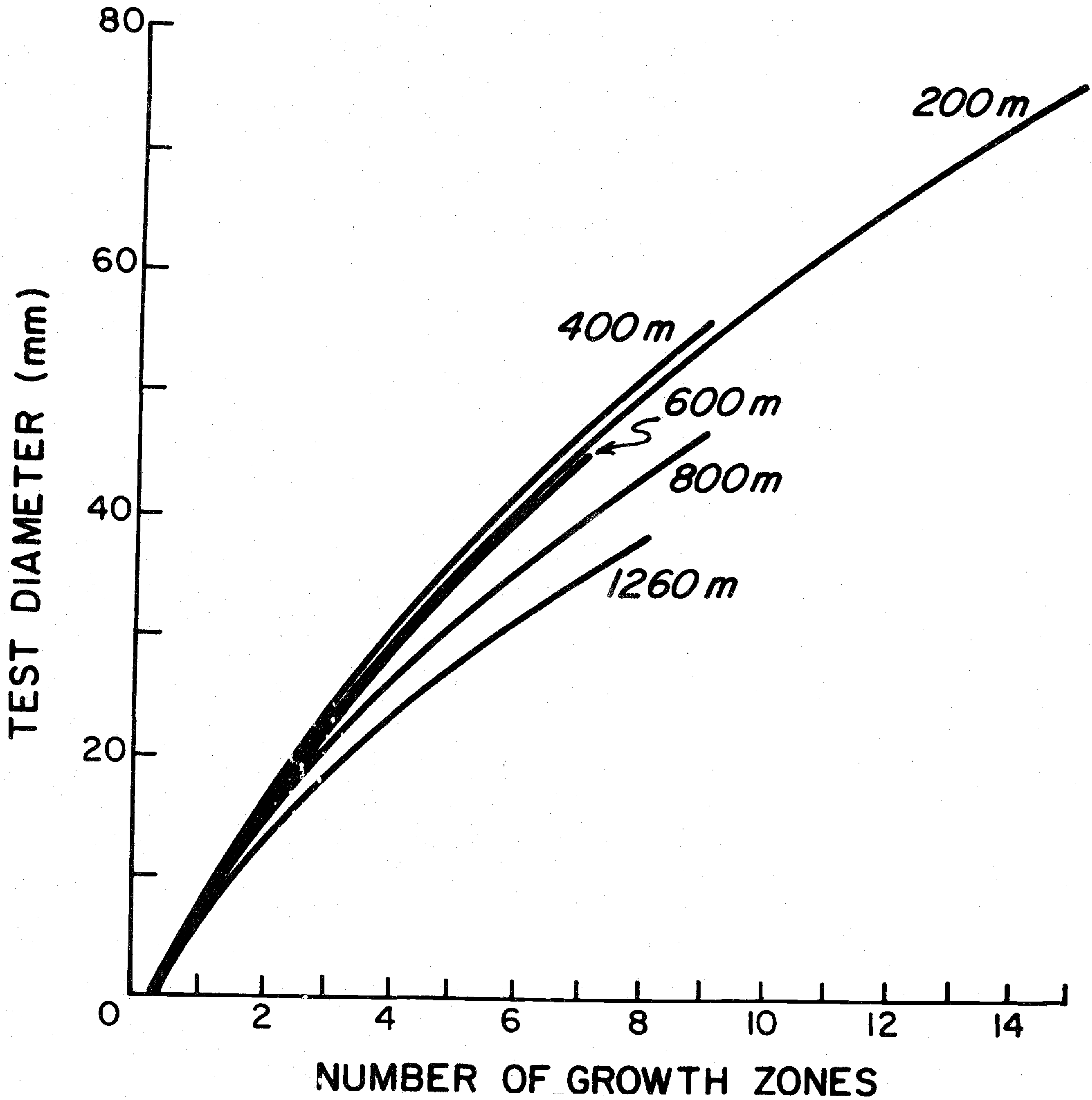

Figure 6. Compilation of A. fragilis growth curves from all stations. The 200 m growth curve is from Figure 5. Other curves are fitted by eye to data presented in Table 3.

Assuming two growth zones are formed each year, the data in Figure 5 suggest growth rates of 20 mm per year for 20 mm urchins and 18 mm per year for 30 mm urchins from the 200 m station. These growth rates were essentially equal to those calculated from the shift of the mean size of each age class between September and November 1969.

Although information on maximum ages for other strongylocentrotoid urchins is sparse and to a large extent based on circumstantial evidence, some comparisons may be made. Fuji (1967) followed the growth of *S. intermedius* for five years, until the urchins were near the maximum size for that locality. Swan (1961) found, using size-frequency studies and laboratory growth studies, that S. *droebachiensis* attained a test diameter of 52-54 mm in four years, but Jensen (1969) reported 11 annual growth zones in the test plates of a 51 mm *S. droebachiensis* specimen from Norway. *Strongylocentrotus purpuratus* are thought to live at least ten years (Ebert, 1967a).

The maximum *A. fragilis* age of seven and one-half years, determined from growth zone counts of an 80 mm specimen, compares favorably with the reported maximum ages of other strongylocentrotoids. Individuals up to 88 mm in test diameter were collected in this study and larger specimens have been reported. Thus, this species may be expected to live for at least ten years.

Age and growth rates for *A. fragilis* from the remaining stations were computed from data presented in Table 3 in a manner similar to those at 200 m, but data were insufficient to apply the Tomlinson and Abramson (1961) least squares method of curve fitting. Growth curves for these stations were fitted by eye. These curves and the fitted curve of the 200 m station are shown in Figure 6. The age range of *A. fragilis* from the 100 m station was small and no growth curve was plotted; however, its growth rate appears to be similar to that at 200 m. The growth curves for all stations were assumed to have the same x-intercept, representing the assumed duration of the larval stage.

Little apparent difference exists between the growth rates for *A. fragilis* from 100, 200, 400, and 600 m. This similarity suggests that food availability does not vary significantly between these stations. However, the growth rates for the urchins from 800 m and 1260 m are markedly less than the rates for the more shallow stations. Maximum age and maximum test size are also less at the deeper stations. It is tempting to propose such factors as low food availability or poor larval settlement as possible causes for the reduced growth rates, smaller maximum size and age, and reduced densities exhibited by *A. fragilis* at the deeper portions of its bathymetric range. However, the general lack of information regarding the feeding habits, substrate preferences, patterns of larval settlement, and responses to hydrologic conditions of *A. fragilis* and many other deep water species of benthic animals makes such suggestions premature and emphasizes the need for further research in these areas.

Table 3. Frequency distribution test diameters of A. fragilis below 200 m. Arabic numerals represent numbers of animals for each size class. Roman numerals represent numbers of dark growth zones found in urchins of that size class.

test diameter (mm)	400m Jun 1966	600m Apr 1963	600m Jun 1964	800m Aug 1966	1260m Jun 1966
16					
17				1 II	
18					
19				1 II	1 III
20				1 III	
21				1 III	
22		1 III		1	
23				1	
24			1		
25		2			
26		1 IV	1 III	2 V	
27		6	1	3 IV	1 V
28		4	2 III	2 IV	
29	1 IV	11 IV	1	1	
30	1 IV	8 IV	1	2	
31	2	8		8 V	1 VI
32		6	2 IV	7 V	
33		8	2 IV	4 VI	
34		6	1	3 V	
35	1 V	8 V	2	6 V	
36	2 V	3	3	9 VI	
37	1 V	4	3 V	6 IV	
38	1	3 V	6 IV	9 VI	
39		4 V	2	3 VI	2 VIII
40	1	2	1 V	3	
41	1	3	1	3 VII	
42	3	1 V		5	
43	2		1 V	2	
44	3			1	
45	1 VI	1		2 VIII	
46	2 VI			1	
47	3			1 IX	
48		2 VII			
49	1				
50					
51	2				
52	2 VII				
53	3 VII				
54					
55					
56					
57	1 IX				
58					

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Environmental Considerations for Estuarine Dredging Operations

by

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INTRODUCTION

The influence of dredging and spoil disposal operations within estuarine waters has been a subject of increasing concern. This concern has often been focused on the quality of the waters within the main water bodies of estuaries, with primary concern devoted to the turbidity and dissolved oxygen content of these waters. Despite the known ecological importance of estuarine bottom deposits and the interfacial waters immediately above these deposits, the water quality within these regions has generally received far less consideration. It is the purpose of this paper to describe certain ecological aspects of estuarine benthic systems which should be considered with regard to estuarine dredging operations.

THE ESTUARINE BENTHIC SYSTEM

General Benthic System

Any approach to an understanding of estuarine benthic systems must involve the complex interactions of the biological, chemical, physical and hydraulic processes which compose these systems. The basis for understanding such systems involves the development of conceptual models of the actual systems. An investigator seeks to develop a simplified model capable of satisfactorily describing certain important aspects of an actual system whose complete complexity is beyond the capacity of the investigator to perceive. In developing a model of a system one must trade between detail and perspective. Too great a detail makes it difficult to define the relationships between the many components of the model. Sacrifice of detail leads to a better perspective yet eliminates useful information from the model.

In the following sections, the authors will present a conceptual model of estuarine benthic systems that will hopefully contribute to a better understanding of the influences of estuarine dredging operations. Not all aspects of these systems will be discussed herein. Omission of certain processes, reactions or other influences should not imply that these omissions are unimportant. Despite these omissions (both known and unknown) the following discussions should impart to the reader the complexities which make up estuarine benthic systems.

Both inorganics and organics are deposited to estuarine benthic systems. Inorganics, including sands, silts and clays, are introduced to estuaries from the ocean and upstream rivers as well as from scour and resuspension within the estuary. Organics originate from sources outside the estuary, as well as from primary production within the estuary.

The system which results from such deposition is illustrated in FIG. 1. Reference to this figure will serve to clarify the following discussion.

The decomposition of deposited organics is most often largely microbial with bacteria predominating. (The influence of larger detrital and deposit feeders is discussed in the following section.) The type of bacterial decomposition occurring at any location is determined principally by the availability of hydrogen acceptors. Dissolved oxygen, DO, is used as the hydrogen acceptor when available. In the absence of DO, oxidized forms of sulfur, principally sulfate, become the principal hydrogen acceptors. The absence of suitable concentrations of both oxygen and oxidized sulfur necessitates the use of endogenous hydrogen acceptors. (For a discussion of endogenous and exogenous hydrogen acceptors see Schroeder and Busch, 1966). Because nitrate concentrations are nearly always far less than sulfate concentrations within estuarine systems, nitrate reduction, which will occur before sulfate reduction, will not be further discussed at this time.

The availability of exogenous hydrogen acceptors (DO and sulfates for purpose of this discussion) depends upon the degree of mixing and advection within the deposits. Vertical mixing, and thus the transport of exogenous hydrogen acceptors, is increased by greater water velocities, high concentrations of dissolved oxygen and sulfate within the overlaying water, high permeability of the deposits, and a high rate of turnover by the larger organisms. This latter factor is, in part, dependent on the interstital water quality. Advection through the deposits in both directions depends on the permeability of the deposit and the direction and magnitude of the hydraulic gradient.

The quality of the interstitial and interfacial waters is largely determined by the nature and extent of bacterial decomposition which, in turn, is dependent on the availability of hydrogen acceptors and organics. The availability of hydrogen acceptors and organics determines the nature and extent of bacterial decomposition which, in turn, largely determines the quality of the interstitial and interfacial waters. The availability of oxygen is one of the most important factors affecting the structure and functioning of estuarine ecosystems. In addition to DO imported by water movement, oxygen is added to the overlying water by two principal processes; reaeration and photosynthesis. The interstitial DO concentration of deposits is determined by a balance between DO transport from above (by mixing and advection) and DO utilization (both chemical and biological) within the deposits. The DO profiles within the deposits will, in part, determine the nature of the benthal community.

When the input of organics to the deposits exceeds the transfer of DO, aerobic decomposition is not sufficient to decompose all of the organics. Sulfate reduction then proceeds below the aerobic region. The reduction of sulfates by the sulfate reducing bacteria results in the release of hydrogen sulfide which is found in aqueous solution as part of the pH dependent system

$$H_2S \rightleftharpoons HS^- + S^= \qquad (1)$$

In the present discussion, all components of equation (1) will be defined as "free sulfide." At a pH of 6.5-7.0, the free sulfide is approximately evenly divided between H_2S and HS^- with $S^=$ being negligible. Free sulfides are also produced during anaerobic putrefication of sulfur containing amino acids, but this process is felt to be of lesser importance in the marine environment, (Fenchel, 1969).

Free sulfides have the property of forming insoluble compounds with heavy metals. Iron is the most common heavy metal present in estuarine deposits. Free sulfide quickly reacts with available iron within the deposits to form ferrous sulfide, FeS, which gives benthic deposits a characteristic black color, (Berner, 1969). The input of this iron into the deposits often results primarily from the deposition of insoluble inorganics, which contain ferric oxides and other insoluble forms of iron. Not all of this iron, however, is available to react with the sulfides. Some additional reactive iron originates from the decomposed organics. This latter source is usually less and thus the supply of available iron within the deposits is often largely dependent on the nature and extent of inorganic deposition, (Berner, 1967). Other heavy metals such as zinc, tin, cadmium, lead, copper and mercury all have solubility products significantly below that of ferrous sulfide. The presence of ferrous sulfide thus indicates that ionic solutions of these metals within the interstitial waters are not likely to be significant.

Free sulfide concentrations within benthic deposits will remain at low levels (generally below 1 mg/l) when available iron is present. If available iron is depleted, free sulfides will increase until the production of free sulfides at a given location is balanced by the advective and diffusive transport of free sulfides out of that location. Measured free sulfide concentrations within interstitial waters of tidal flat deposits were found up to approximately 130 mg/l though some loss of free sulfide may have occurred during the analysis. Theoretical investigations indicate that maximum possible concentrations might be several times higher. Experimental and theoretical results have demonstrated that free sulfide concentrations of approximately 1 mg/l can persist in shallow tidal flat open waters as a result of benthic sulfide release even when the DO of these waters is in the 4-6 mg/l range, (Bella et al, 1970).

High concentrations of free sulfides within the deposits and the resulting release of free sulfides into the aerobic regions of the deposit and into the overlying waters are important for two reasons. First, in an aerobic environment, free sulfides exert an oxygen demand. Such an increased oxygen demand can lead to a reduction of the aerobic zone of the deposit and a reduction of DO within the overlying waters. Second, free sulfide, particularly hydrogen sulfide, is toxic at low concentrations to fishes, crustaceans, polychetes and a variety of benthic micro-invertebrates, (Fenchel, 1969; Colby and Smith, 1967).

Because of the low level of mixing within waters immediately overlying deposits, DO concentrations can be lower and free sulfide concentrations can be higher within several millimeters above the bottom. Though these interfacial regions constitute a very small fraction of the estuarine water mass, they are of high ecological importance. Sampling within these regions is extremely difficult and more research to develop sampling techniques is needed.

If the solubilization of organics at a given depth exceeds the downward transport of DO and sulfates to that depth, decomposition of organics below this depth must proceed through the use of endogenous hydrogen acceptors (not shown in FIG. 1). Increased accumulation of organics can be expected, particularly if the absence of available iron results in free sulfide concentrations sufficiently high to inhibit endogenous decomposition. Methane fermentation will occur below the region of sulfate reduction if conditions are suitable. Formation of gases (principally methane) within these regions may lead to the disruption of the bottom, and thus the release of free sulfides to the overlying water.

Larger Plants and Animals

Many factors influence the nature of the animal community within the estuary. Among these are physical, chemical, geological, meteorological, hydraulic, and biological factors, all interacting to make each estuary unique. Among the characteristics of benthic systems that have been discussed are these important factors: animals require dissolved oxygen and a variety of organic substances, and free sulfides are toxic at varying concentrations. The animal community influences these benthic characteristics by mixing deposits and breaking down organics, and in so doing, modifies the environment. Thus, they themselves become an important factor in natural faunal succession.

When man interferes with the natural development of an estuary by dredging, filling, or other such activities, he alters some of the factors that are important in the system. These changes are initially of greatest concern when they affect economics; where there are massive fish kills, where clam beds are obliterated, or where, for some reason, a commercially important species cannot be harvested in the usual manner. It must be stressed, however, that conditions within the benthic systems will have far reaching less obvious effects. The National Marine Fishery Service has estimated that 65% of the commercial fishery resources (volume or value) are estuarine dependent. Of the 10 most valuable species, 7 must spend significant periods of their lives in estuaries. These include salmon, menhaden, oysters, crabs, clams, and flounders.

The economically important species depend on a food web that involves many less well-known species. The food is all originally derived from plant sources. Intertidal regions of estuaries are particularly productive regions of these food sources. This is particularly true on the east coast where large salt marsh areas abound. Dead and decaying organic material from these areas are removed by high tides and carried into the estuary where they become an important food for small crustaceans and other animals that are food for species of economic importance. This food is also carried out to sea where it becomes a food source for more oceanic species.

In addition to the fishery value of estuaries, there are other important biological uses. Birds use estuaries for breeding, feeding, and resting, especially the tidal flat areas. When an estuary becomes disturbed by too much human activity, some birds will change their habits to find estuaries that are suitable. The Black Brandt, a small migratory goose, overwinters in estuaries along the west coast of North America. The total population of the Black Brandt have remained relatively constant over the past 22 years. However, the populations wintering in California have decreased from 48,000 to 66,000 in the late forties to less than 1,000 in the late sixties, probably due to the disturbance of California estuaries. At the same time populations have increased in remote Mexican estuaries (Chattin, 1970). The total impact of this population shift on other species is not fully known.

The animal component of estuarine benthic eco-systems can generally be thought of as infauna and epifauna, those animals that live within the sediments, and those that live on its surface or just above it. Some infauna make ephemeral pockets in the sediment which are filled as the animal moves on; others make more permanent burrows and bring overlying water into the sediment. Much of the infauna is microscopic, living among the sediment particles. This interstitial fauna plays a significant role in the ecosystem but has not been as well studied as it should be and we are only beginning to appreciate its importance. Although it is convenient to separate the benthic animals into epifauna and infauna, it is sometimes more useful to examine the types of feeding behavior that they exhibit.

In general there are three important feeding types in the benthic environment: selective particle feeders, deposit feeders, and filter feeders. The remainder of this section will be concerned primarily with these three categories. Reference to FIG. 2 will serve to compliment this discussion.

Selective particle feeders may be herbivores, predators, or scavengers. They may feed on whole organisms which they actively capture, or they may feed on fragments of plants or animals. Crabs, some worms, most fishes, and other more mobile species fall into this category. The food contains little inorganic material and is generally first broken down by mechanical processes and then by chemical processes. The residues, inorganic materials, undigestible organics, and resistant bacteria, are combined with mucous and coated to form distinctive fecal pellets. Fecal pellets generally settle to the bottom and may make up from

30% to 50% of the sediment and in extreme cases, where quiet bottom waters occur, they may account for up to 100% of the sediment. (Moore, 1931a, b). The fecal pellets of carnivores are generally loose pellets, those of herbivores harder, and those of deposit feeders hardest. Many of the pellets have characteristic shapes, size, and sculpturing, and are of taxonomic importance. Some are quite fragile while others may persist for more than 100 years.

Filter feeders are those that sieve the water and remove particulate material. Mussels, some clams, and some worms are examples of this category. Most filter feeders use cilia to create currents of water over a mucous network which entangles particles. These are called ciliary mucous feeders. Mussels are a good example. Other species, particularly tube dwellers, may force water through the tube with peristaltic body movements. Urechis caupo, the sausage worm, is an example. The particle laden mucous is then taken into the digestive system. Some clams "sort" the particles before they are taken into the digestive system and discard the unusable sizes in mucous masses as pseudofeces. The food that passes through the digestive tract does not usually require mechanical maceration and is digested chemically. The feces of filter feeders are primarily organic.

Deposit feeders are of two kinds. Some move through the sediment and take in the sediment as they go, digesting what they can of the organic material and discarding as feces the undigestible organics and the inorganic residues. These animals are mostly worms in estuaries and are not generally in direct contact with the waters which overly the sediments. Other deposit feeders bury themselves in the sediment but have siphons or other extensions through which they "suck up" detritus that has recently fallen to the sediment surface. Certain clams and worms feed in this way. Again these species feed unselectively on the available food and are usually unable to sort food very efficiently. Food of deposit feeders is broken down chemically, and in some cases mechanically, and the residues are formed into fecal pellets which contain much greater quantities of inorganic materials than do feces of other feeding types.

Soluble organic wastes of all feeding types are discarded into the water or interstitial water depending on the habitat of the particular species. It should be mentioned that not all animals fit neatly into these feeding categories. Some deposit feeders may be somewhat selective, and some selective feeders may be quite non-selective if food is scarce. Some animals like starfish that utilize extracorporeal digestion are true predators but do not otherwise fit neatly into the selective feeding type.

Certain animals, particularly ciliary-mucous feeders have a marked effect on the turbidity of the overlying water (Carriker, 1967). These organisms remove particulate matter from the water and compact much of it in the form of pseudofeces which are larger than the suspended particles and therefore sink more rapidly to the bottom. This reduction in turbidity permits more light to reach the benthic algae, enhancing the photosynthetic process and increasing the daylight DO. At the same time, the removal of CO_2 tends to raise the pH during the daylight hours.

Animals tend to break down larger particles through maceration and digestion. The formation of fecal pellets places these particles on the bottom rather than returning them to the water to increase the turbidity. The fecal pellets are finally degraded by bacteria, but may pass through several deposit feeders before final mineralization.

Animals also influence vertical mixing of the sediment. There is a great deal of mechanical mixing as burrowing species construct their tubes or move through the sediment. Fecal pellets of infaunal species are frequently brought to the surface and deposited there. Burrows may extend more than a meter into the sediment and the constant reworking of sediment insures a relative homogeneity of the sediment to that depth. Burrows also provide a route for oxygen to reach into the sediment, and although sediments may be anaerobic a few millimeters beneath the surface, there will usually be an aerobic region immediately surrounding each burrow if the overlying water is not devoid of oxygen. Conversely burrows serve as a route through which waste materials such as fecal pellets and dissolved organics can move out of the sediment. Burrowing activities also serve to release inorganic nutrients to the surface water where they may be utilized by photosynthetic plants. Wave action over a beach filled with tubes may cause a pumping action through the tubes, increasing aeration and, possibly, erosion of the wall of the tubes.

Some plants, however, help to stabilize the benthic environment by forming dense mats of filamentous algae over the surface of the sediment, thereby reducing erosion by water movement and rain (on exposed intertidal areas). The reduction in vertical mixing may contribute toward the build-up of free sulfides as previously discussed. Reduction of erosion in turn reduces turbidity of the overlying water. Other plants such as eel grass send roots into the sediment, and many burrowing animals construct tubes that also reduce erosion. These roots and tubes also provide shelter for infaunal species and may contribute to their food as well.

The major role of green plants is to convert solar energy into a form that can be used by plants and animals. Through the photosynthetic process inorganic substances are converted into high-energy organic compounds. This process is primary production and is the ultimate source of food for all organisms. Phytoplankton are important primary producers in the estuarine ecosystem, contributing to the detritus that sinks to the sediment. Benthic algae and eelgrass are also important contributors. In the photosynthetic process plants use carbon dioxide and release oxygen.

Through their food webs, animals provide pathways for transporting various materials through the marine environment. Organic materials are first produced by plant components of the environment and transferred through herbivores and several levels of carnivores to the sediments. Feedback occurs frequently so that the web concept is more descriptive than the food chain. In the sediment these materials are mineralized to their inorganic end-products and then may again enter the cycle by getting into the water and to plants.

Another important effect of animals near the sediment surface is the creation of water currents by the animals. Mussels and clams circulate much water through their filtration systems and at times these currents can be observed in the surface waters above. Animals that create such currents are usually ciliary-mucous feeders, but fishes and other mobile species can disrupt the surface of the sediment and cause local regions of turbidity.

The role of particles in the marine water is often not appreciated. Heavy metals may adsorb to these particles and if the particles remain in suspension they may be carried far to sea before they settle. On the other hand, these metal-laden particles may be pelletized by various animals and deposited in the estuarine floor. The role of animals in removing such particles may be very important indeed.

Many of the effects that have been discussed deal with the transportation of materials from the water to the sediment, but there is transport in the other direction as well. Benthic species almost always have pelagic larvae. Essentially all of these larvae must feed and develop within open water regions, returning to the sediment for later life stages. Pelagic stages thus insure wide dispersal of these species. Propagation of benthic animals thus depends on the ability of pelagic life stages to leave the sediment.

A Classification of Estuarine Benthic Systems

Under conditions of relatively constant organic and inorganic inputs, five types of estuarine benthic systems described in TABLE 1 can develop. These five types are determined by the exogenous hydrogen acceptors available to decompose the deposited organics and the amount of iron (and other metal which form insoluble sulfides), largely resulting from deposited inorganics, available to react with free sulfides. Further subdivision of these five types based, as an example, on the extent of methane fermentation or pyrite formation will not be pursued herein.

FIG. 3 qualitatively illustrates the general response of estuarine benthic systems as described in previous sections of this paper to different continuous inorganic and organic loading rates. Each of the five regions in FIG. 3 corresponds to the five types described in TABLE 1. The solid lines of FIG. 3 are positioned by the availability of hydrogen acceptors while the dashed line is positioned by the availability of iron. The precise quantitative definition of each of these five regions depends upon a wide range of conditions including, but not limited to, amount of available iron in the inorganics, nature of the organics, hydraulic conditions, extent of biological turnover, and concentrations of DO and sulfate within the overlying waters. An accurate quantitative description of each of the regions in FIG. 3 is not now possible although such capabilities are being pursued using improved versions of a published mathematical model of estuarine benthal systems (Bella, 1971). FIG 3, however, does illustrate the general response of the system shown in FIG. 1 to different deposition conditions. Qualitative changes in FIG. 3 due to different conditions can be easily pictured. Larger amounts of available iron within the inorganics, as an example, would lead to a lowering of the dashed line defining regions 4 and 5. Smaller amounts of iron within the inorganics would result in a counter-clockwise rotation of the dashed line defining regions 4 and 5. A greater turnover of the deposits would lead to an extension to the right of regions 1 and 2 due to the increase of available exogenous hydrogen acceptors.

Past investigations of marine benthic deposits do give some indication as to the quantitative descriptions of the different regions shown in FIG. 3. Results of the Puget Sound study (1967) demonstrate a large decrease of benthic fauna (both in numbers and types) and a strong hydrogen sulfide odor when volatile solids became greater than ten percent of the total solids. This percentage might roughly define, for these locations, the upper bound of region 5 in FIG. 3.

Different benthic estuarine systems will support different sets of plants and animals. The amount of DO available for respiration, the toxic effect of free sulfides and the amount and suitability of organics for good supply will all serve to determine the nature of resident populations. Other factors such as particle size distribution, salinity and temperature will also determine the composition of the benthic communities.

The regions described in FIG. 3 define the steady-state benthal types (shown in TABLE 1) that would approached if a given set of deposition conditions persisted. The actual types present at a given time are a result of past depositions. Current loading conditions define types which the systems are then approaching. When loading conditions change, systems of one type may shift toward a different type. Seasonal changes of benthic loadings within Oregon estuaries appear to produce significant seasonal changes of types. Sufficient data, however, are not now available to describe such changes adequately.

MAN'S IMPACT ON ESTUARINE BENTHIC SYSTEMS

Within a given estuary a wide range of localized inorganic and organic benthic deposition rates, DO concentrations, sulfate concentrations, scour velocities, and other factors determine estuarine benthic types that can be expected. These conditions, moreover, can be expected to change with time. Thus, differences can be expected over temporal and spacial dimensions of any estuary. Within unpolluted estuaries, regions 1, 2 and 3 (of FIG. 3) will likely predominate. The wide variety of benthic systems normally found in tidal estuaries makes possible a larger biological diversity which, in turn, likely contributes to the ecological stability of the entire estuarine system.

A wide range of man's activities including dredging operations can produce significant changes in temporal and spacial distribution of benthic types. Such changes can result in a decrease in the variety of benthic systems within space and time. Such a reduction of system diversity, if extensive, would likely reduce biological diversity.

Man's activities might also result in a general shift, likely toward benthic type 5 (region 5 of FIG. 3) which would likely be considered undesirable because of lower DO concentrations and higher free sulfide concentrations. Environmental changes often cannot be explained by a simple casual relationship to a single activity. Thus, the environmental impact of dredging must be considered along with a host of other activities (both man-made and natural). In the following subsections, the possible influences of man's activities on estuarine benthal systems are briefly discussed with particular emphasis given to dredging operations. Reference to FIG. 3 will help to clarify these discussions.

Changes in Organic Deposition

A general increase of organic deposition to benthic systems can result from the input to the estuary of additional organics (such as from waste outfalls), from the input of inorganic nutrients which lead to an increase of primary production within the estuary, or to the deposition of organics re-suspended at some other location by dredging operations. Such increases result in a shift of benthic states toward region 5. Dredging operations can, however, remove organics from previously degraded systems and thus assist in their recovery.

Changes in Inorganic Deposition

Increased deposition of inorganic material can result, if sufficient, in suffocating benthic plants and animals. Toxic materials in these deposits can also harm these communities. Again, controlled removal of toxic materials by dredging may assist degraded systems to recover.

Potential problems can also occur from reduced sediment transport to estuaries due to upstream dams, jetties, channelization, and reduction of seasonal sediment scouring. Such reduction may lead to a lowered input of available iron to the systems and thus result in a shift toward regions 4 and 5 of FIG. 3. This shift would be most pronounced if a general increase in organic deposition also occurred.

Transient Conditions Due to Dredging

Dredging of type 4 and 5 benthic systems would likely have a greater immediate impact on water quality than would the dredging of types 1, 2 and 3. The release of free sulfide would be most objectionable because of its oxygen demand and toxicity. However, because of the rapid reaction rate of free sulfides and oxygen in estuarine waters, the short term release of free sulfide during dredging of sludge deposits might be preferable to the long term release by undisturbed deposits. Thus, in some cases, dredging operations could be used to assist the recovery of a system which had been degraded to a type 5 system. Such dredging, however, would likely release heavy metals which had been held in the deposits as insoluble sulfides. Heavy metals such as mercury and cadmium could have both short term and long term toxic effects.

Increased turbidity due to dredging operations can have adverse effects on estuarine systems. Turbidity decreases the light penetration, thereby reducing photosynthesis. Turbidity also can cause mechanical blockage of gills and ultimate suffocation of many species, simply because the gills cannot absorb enough oxygen from the water. Likewise, food filtering mechanisms, which are often associated with respiratory organs, may also become blocked by too many particles in the water.

The settling of fine sediment from turbid waters over benthic species may have catastrophic effects on life cycles if pelagic larva or egg cannot leave the sediments or if pelagic larvae are prevented from settling in a satisfactory environment. For example, oyster spat cannot attach to the necessary shell substratum if this shell is covered with a layer of fine sediment.

The type of benthic system that develops at a given location can be dependent on the biological turnover previously discussed. A transient environmental condition, such as a temporary depletion of dissolved oxygen, might eliminate a community which is contributing to this turnover. A new benthic type might then develop. The re-establishment of the previous community might not be immediately possible due to this change in type even though the unfavorable environmental condition which caused this change had passed. Thus, unfavorable periodic conditions could have a continuous influence on benthic systems.

Tideland Filling

Filling tideland with dredging spoils or other materials can have widespread adverse effects in an estuary. In general, the tidal flats are highly productive areas that contribute a major portion of the food to an estuary. Removal of this valuable tideland can be critical, not only because food itself is removed but because the total high tide volume of the estuary is reduced. Many estuarine fishes live in the channels at low tide and move over the tidal flats as they are covered to feed (a habit of fishes which may account for better fishing on an incoming tide). Likewise shore birds and a few mammals move into the exposed areas at low tide to feed.

The variety of species in the tidelands is great; there are usually many species present. When tidelands become covered, diversity is reduced and the potential of the life in the estuary to recover from even a minor catastrophe is likely reduced.

Hydrodynamic Changes

Deepening of channels, filling of tidelands, construction of dikes and jetties, stabilization of banks and other such activities all serve to change the hydrodynamic regime of estuaries. Changes in advective and diffusive transport and scour can result in significant changes in organic deposition, inorganic deposition, salinity distributions, temperature distributions, distribution of pelagic life stages, inorganic nutrient distribution, dissolved oxygen distribution and other environmental factors which influence the estuarine ecosystem in complex (and often unknown) ways; often these changes show themselves most graphically in altered plant and animal distribution.

Construction of Dikes, Jetties, Wharves, etc.

Dikes, jetties, wharves, etc. can alter estuarine ecosystems in several ways. These structures usually provide a solid substratum on which a highly diverse population of attached plants and animals may develop. However, they can isolate regions from the estuarine system, thus drastically altering their nature and function. Partial diking of a tidal flat region can lead to an increased trapping of organics and fine particles. Benthic systems within such regions then may degrade to a type 5 system.

Spoil Disposal

Sediment removal and spoil disposal can result in a shift in benthic types at both the sites of sediment removal and disposal. As an example, the oxidation of sulfides and organics during the removal and disposal operations might result in a shift from an original type 5 system at the removal site to a type 2 or 3 system at both sites. The reverse may occur, however, if during disposal, differential settling of organics and inorganics occurred. After settling, the spoil deposits may shift toward type 5 due to the higher organics within the upper regions of the deposits.

Long Term Particle Size Change

Significant long-term decreases in sediment particle sizes within developed estuaries can occur (Fleming, 1970). Adequate data to demonstrate such long-term decreases, however, are not available for most tidal estuaries. Decreases in particle size may occur as a result of upstream dams, continued dredging, construction of jetties, and other similar activities. Particle size reduction could significantly decrease the permeability of deposits and thus contribute toward reduced transport of exogenous hydrogen acceptors. This would in turn lead to a reduction, to the left, of regions 1 and 2 of FIG. 3. A reduction of particle size may also impair the movement of certain benthic animals with deposits.

SUMMARY AND CONCLUSIONS

A conceptual model of estuarine benthic systems is presented. This model assists in the explanation of observed environmental changes of benthic systems. A variety of possible environmental responses to man's activities (including dredging) is discussed, though actual field evidence demonstrating some of these responses is lacking, and in many cases, would be most difficult to obtain.

The true complexities of estuarine ecosystems extends far beyond the scope of this paper, and may never be fully comprehended (particularly with regard to long-term effects). While operational rules, and water quality standards, can serve to minimize the more obvious adverse effects, management decisions must be based on a recognition of the limitations of current knowledge. This recognition of limitations is a strong argument for preserving a variety of estuarine systems in a relatively undeveloped state. Such preservation would permit the continued study of minimally disturbed estuarine ecosystems and would reduce the probability of widespread irreversible damage.

ACKNOWLEDGMENT

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TABLE 1. CLASSIFICATION OF ESTUARINE BENTHAL SYSTEMS.

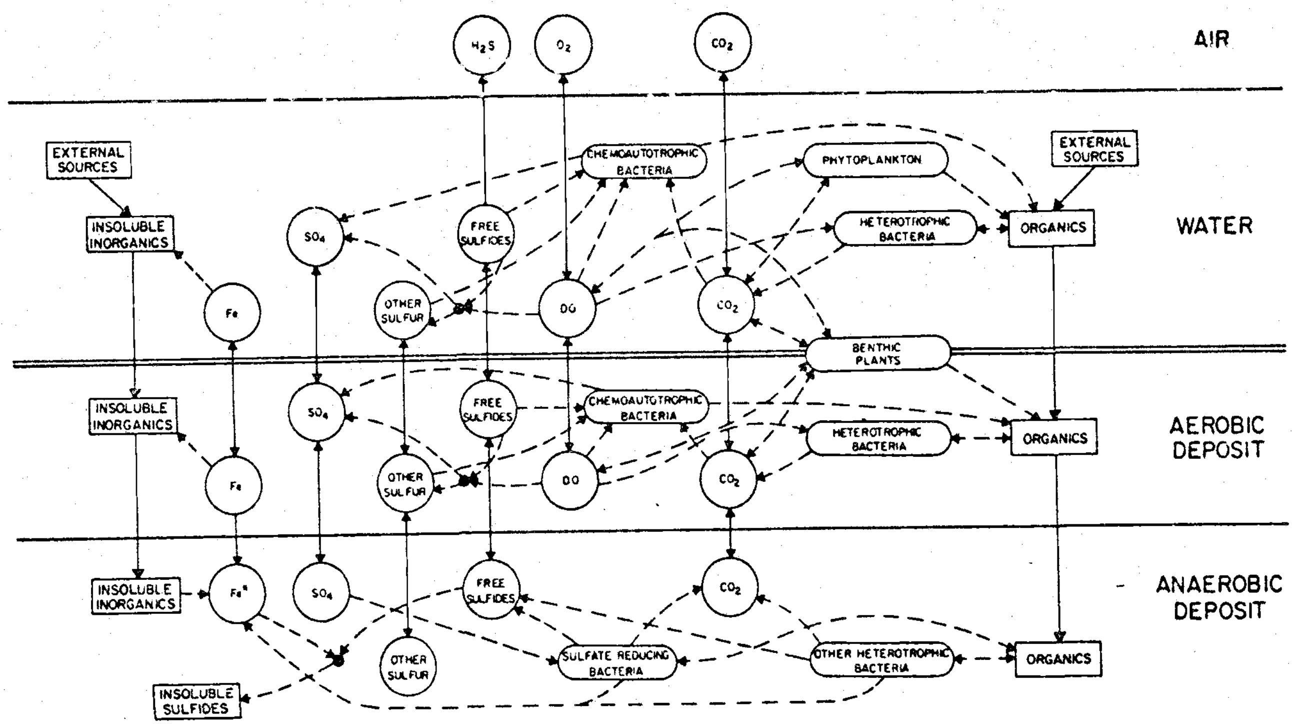
Deposit Type	Aerobic Decomposition	Sulfate Reduction	Intersitial Free Sulfide	Methane Fermentation [c]
1	Dominant	Limited (Organic limiting)	Low	Small
2	Significant [a]	Significant (Organic limiting)	Low	Small
3	Significant [a]	Significant (Sulfate limiting)	Low	Significant
4	Limited to Significant [a, b]	Significant (Organic limiting)	High	Small
5	Limited [a, b]	Significant (Sulfate limiting)	High	Significant [d]

a Dependent on DO in overlying water.

b Aerobic zone in deposit limited by free sulfides

c Also increased accumulation of organics particularly if conditions are not favorable in Methane Fermentation.

d Possible inhibition by free sulfides.



SOLID LINES REPRESENT PHYSICAL TRANSFER PROCESS

CHEMICAL REACTION NOTED BY ●

** DENOTES AVAILABLE Fe (also Zn, Sn, Cd, Hg and Cu)*

FIG. 1. CONCEPTUAL MODEL OF BENTHIC SYSTEM

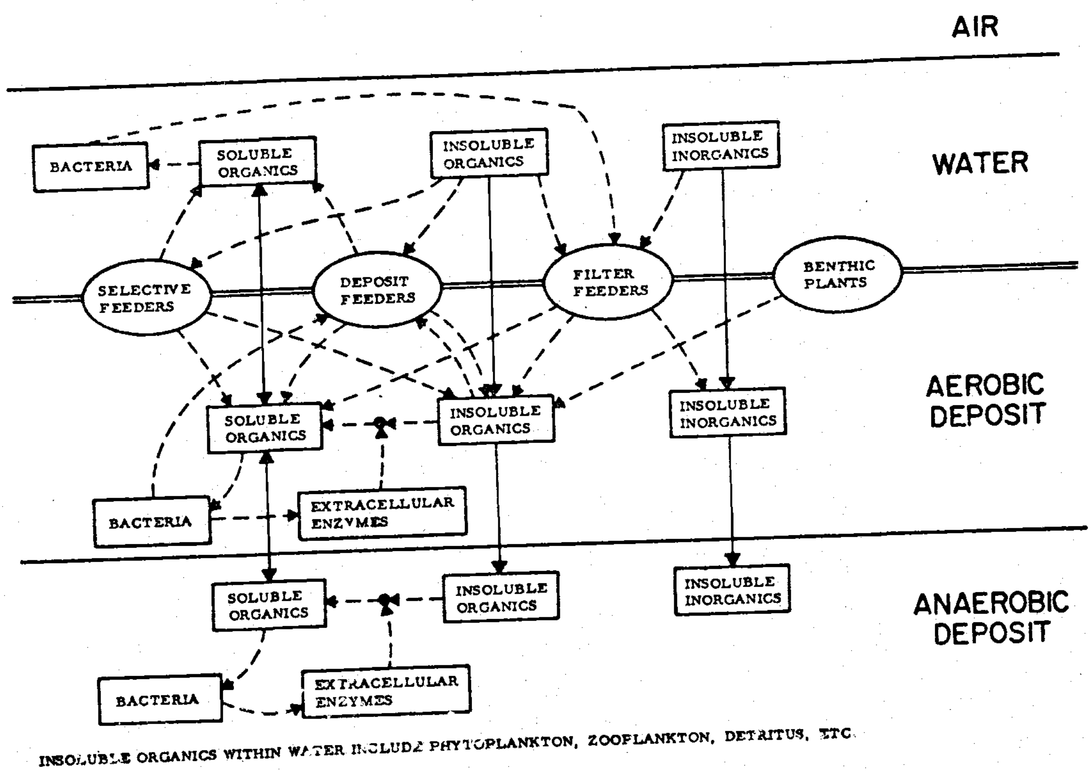


FIG. 2. CONCEPTUAL MODEL OF LARGER ANIMALS WITHIN BENTHIC SYSTEM

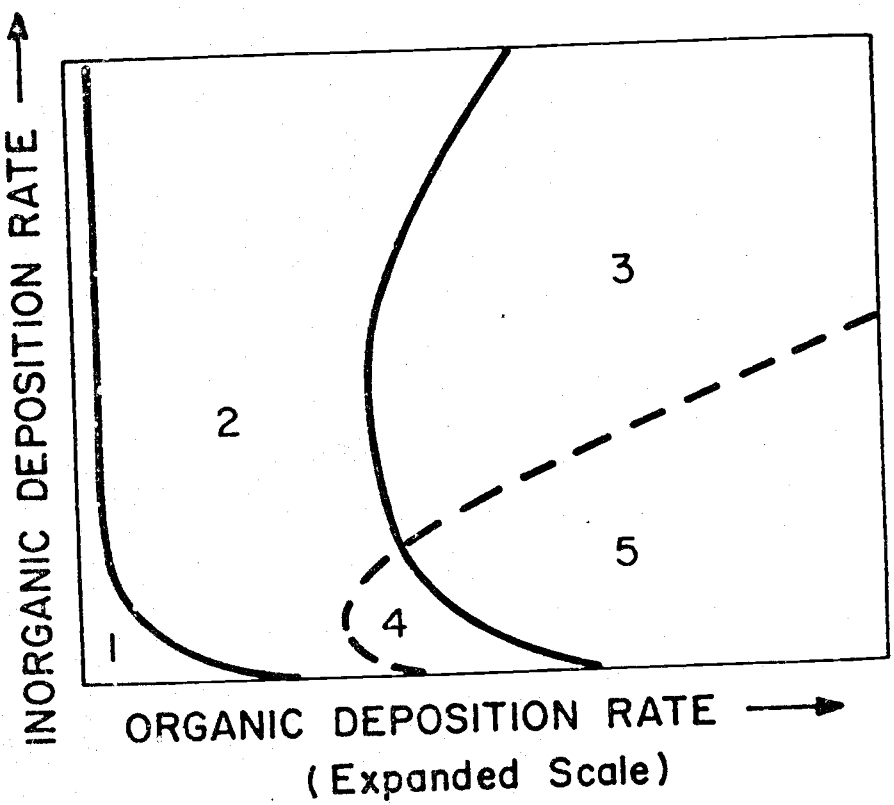


FIG. 3. RESPONSE OF BENTHIC TYPES TO DEPOSITION RATES

ESTIMATING PRECISION FOR THE METHOD OF STANDARD ADDITIONS

Ingvar L. Larsen, Norbert A. Hartmann
and Jerome J. Wagner

ABSTRACT

An estimate of the uncertainty term expected in the method of standard additions using linear regression analysis is presented. The approximation agrees favorably with the standard deviation for values which are not corrected for a blank as well as with the population standard error of difference for corrected samples. Analysis for zinc in an environmental sample yielded a concentration range within the expected value.

ESTIMATING PRECISION FOR THE METHOD OF STANDARD ADDITIONS

The precision for an experimental process is usually determined through replication. When applied to calibration line data however, sample replication may not only be insufficient but even misleading (1). In addition, when applied to the method of standard additions, replication becomes tedius as well as time consuming. An estimated error term based upon linear least squares regression applied to the method of standard additions is presented as an approximation to the experimental error.

The method of standard additions is often used to determine the concentration of an element in an interfering matrix (2). Caution however, should be exercised when using this technique to insure that the initial calibration of the instrument be accomplished with standards contained in as similar a matrix as the sample, both chemically and physically, in order to estimate the appropriate "blank" correction. In this way correction for light scattering due to the matrix can be approximated. Rains (3) discusses some aspects of elimination or control of interferences in atomic absorption spectrophotometry.

In the method of standard additions, a small known concentration of the desired element is increasingly added to several samples of the unknown test solution and the resulting solutions as well as an untreated one are then analyzed. The response readings from the particular instrument are then plotted linearly against the added concentrations and the amount of unknown element present is determined by extrapolating a line to the abscissa. (If the line is not linear, often a transformation can be performed such as the conversion of light absorption to absorbance.) The best line which can be fitted to the data minimizes the sum of the squares of the vertical distance between data points and the constructed line, referred to as the line of least squares (4).

accepted by Analytical Chemistry: now in revision

The least squares line can be described by the equation

$$\hat{Y} = M \cdot X + I \quad (1)$$

where $\hat{Y}$ is the value predicted (absorbance) by the equation for a given value of X (concentration), M is the slope of the line, and I is the intercept of the line with the ordinate axis. Using data obtained from an analytical determination of treated and untreated samples, the slope of the least squares line can be calculated as follows:

$$\text{Slope, } M = \frac{n\Sigma XY - \Sigma X\Sigma Y}{n\Sigma X^2 - (\Sigma X)^2} \quad (2)$$

where X refers to the concentration of the standard solution, Y is the linear instrument response reading, and n is the total number of readings made.

Equation (1) is referred to as the regression of Y on X, X being the independent variable and Y the dependent variable. The X values are assumed to be known without error, whereas the Y values are randomly distributed about some mean Y value (5, 6).

The intercept of the line with the ordinate axis is calculated as follows:

$$\text{Intercept, } I = \overline{Y} - M \cdot \overline{X} \quad (3)$$

where $\overline{Y}$ is the arithmetic mean of the total Y readings, $\overline{X}$ is the arithmetic mean of the total X values, and M is the slope of the line.

An estimate of the variability of the data points about the least squares line is the standard error of regression and is calculated as follows:

$$\text{Standard error of regression, } S_r = \pm \sqrt{\frac{\Sigma Y^2 - \frac{(\Sigma Y)^2}{n} - \frac{\left(\Sigma XY - \frac{\Sigma X \Sigma Y}{n}\right)^2}{\Sigma X^2 - \frac{(\Sigma X)^2}{n}}}{n - 2}} \quad (4)$$

If the slope, M, as given by equation (2) is significantly different from zero, then from theory concerning prediction in linear regression analysis (6, 7) an estimate of the uncertainty of the extrapolated line to the abscissa (designated as Z) by the method of standard additions is approximated as follows:

$$\text{Estimated error of } Z,\ Sz = \pm \frac{(Sr)}{M} \sqrt{A + B}\ , \tag{5}$$

and a confidence level is given as:

$$\pm (t)\ (Sz) \tag{6}$$

where $A = \frac{n + 1}{n}$, $B = \frac{(Z - \overline{X})^2}{\Sigma(X - \overline{X})^2}$, $Z = \frac{-I}{M}$, t is the Student-t value for the desired confidence level with n-2 degrees of freedom, and the other symbols are as previously defined.

EXPERIMENTAL

Prepared Samples

In order to test the precision of Z with experimental values, a stock solution of zinc was prepared for analysis. From this solution twelve replicate analysis were made by the method of standard additions, each consisting of an untreated and treated samples containing 0.5, 1.0, and 2.0 parts per million (ppm) added zinc. A Perkin-Elmer model 303 atomic absorption spectrophotometer and a digital concentration readout accessory (DCR-1) were used to measure the zinc concentration. Seven replicate readings per sample were performed giving a total of 28 readings per analysis. (Inadvertantly 3 of the samples of the entire analysis had one less reading.) The data from each analysis (absorbance versus concentration) were fitted to a linear squares model and the fitted line extrapolated to the abscissa. Table I illustrates data for a specific sample analysis. A calibration line was established by reference to similarly prepared standard solutions containing 0.5, 1.0, 2.0, and 3.0 ppm zinc as well as a blank solution. Before and periodically during the course of the entire analysis reference was made to these standard solutions and blank to insure proper calibration and background readings of the instrument. Results of the estimated error term for each analysis as given by equation (5) from least squares regression data are shown in Table II. These estimated uncertainty terms show some variability, as expected, since in repeated sampling from the same universe, the uncertainty will vary in width and position from sample to sample, particularly with small samples, but should include ideally the true value P percent (P is the selected confidence level) of the time (7). The precision term, Sz, as calculated from equation (5) provides an estimate of the variability expected from sample to sample as exemplified by the standard deviation of the twelve replicate analysis.

Correcting for the blank

Figure 1 illustrates a sample analysis line along with the instrument calibration line. The extrapolated value for the sample analysis line (Zs) must be corrected for the background reading (Zb) since the instrument calibration line indicated the necessity of a blank correction. From the data of the instrument calibration line (Table I) extrapolated to the abscissa, a background reading of 0.559 ppm zinc was determined. It is this value which must be subtracted from the extrapolated sample analysis in order to obtain the net sample concentration. Since the extrapolated background value and the sample analysis value are both mean quantities and each has an estimated precision term, the difference between these means also will have an estimated uncertainty term. The variance of the difference between two independent means is the sum of their respective variances (i.e., V(Zs - Zb) = V(Zs) + V(Zb)). The variance for an extrapolated value, Z, is estimated (from equation 5) as follows:

$$V(Z) = \frac{(Sr)^2}{(M)^2} \quad (A + B) \tag{7}$$

When combining the variances of two means, a pooled standard error of regression Sr is used (4), obtained from the regression standard error for both the instrument calibration line and the sample analysis line.

Pooled standard error of regression,

$$Sp = \sqrt{\frac{(n_1 - 2)\ (Sr_s)^2 + (n_2 - 2)(Sr_b)^2}{n_s + n_b - 4}} \tag{8}$$

The estimated precision term Sd, for the difference between two independent means (Zs-Zb) is given by:

$$Sd = \pm\ (Sp) \cdot \sqrt{\frac{(A_s + B_s)}{(Ms)^2} + \frac{(A_b + B_b)}{(Mb)^2}} \tag{9}$$

Subscripts s and b refer to the sample and blank respectively. A confidence interval for equation (9) can be obtained by multiplying by the appropriate Student-t value, for $n_s + n_b - 4$ degrees of freedom.

Table III gives the net mean and estimated precision term as calculated from equation (9) for the values listed in Table III, corrected for the instrument background reading. It should be emphasized that the uncertainty interval may become increasingly large as the predicted value moves away from the mean ($\overline{X}$) of the standards, since estimates are expected to become poorer when extrapolating away from the range used in the original data (7). The error term, Sd, calculated from equation (9) provides an estimate of the variability encountered between samples as indicated by the standard error of difference for the twelve replicate samples.

Environmental Analysis

The previously described technique was applied to an environmental sample consisting of a quantity of dried orchard leaves obtained from the National Bureau of Standards (8) and containing certified concentrations of several elements. The zinc concentration itself was not certified but supporting information indicated a level to be expected of 28 ppm. The leaves were prepared for analysis and the zinc concentration determined by the method of standard additions. The amount of zinc determined in the samples was 31.0 ± 3.92 (95% C.L.) ppm, a range within the expected value.

ACKNOWLEDGMENTS

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Symbols Used in Text

X	= concentration of standard solutions
Y	= linear instrument response reading
$\overline{X}$	= average of concentration values = $(\Sigma X)/n$
$\overline{Y}$	= average of instrument response readings = $(\Sigma Y)/n$
n	= total number of readings made
M	= slope of regression line
I	= intercept of regression line with ordinate axis
Z	= $-I/M$, $\lvert Z \rvert$ = absolute value of Z
A	= $(n + 1)/n$
B	= $(Z - \overline{X})^2/\Sigma(X-\overline{X})^2$
t	= Student-t value for appropriate degrees of freedom
Sr	= standard error of regression (Eq. 4)
Sp	= pooled standard error of regression (Eq. 8)
Sz	= estimated error for the sample extrapolated value Z (Eq. 5)
Sb	= estimated error for the extrapolated background value (Eq. 5)
Sd	= estimated error term for the difference between two independent means (Eq. 9)
$(Sz_p)^2$	= pooled values for all sample information, Sz_1 to Sz_{12}
$V(Z)$	= variance of Z = $(Sz)^2$ (Eq. 7)
$S(Sz_p - Sb)$	= standard error of difference between two independent means for the pooled sample values and the background

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Table I. Example of data

Concentration of added standards (ppm Zn)	Instrument response readings (absorbance)
0 (untreated)	0.197, 0.195, 0.199, 0.195, 0.197, 0.195, 0.197
0.5	0.291, 0.289, 0.289, 0.287, 0.298, 0.288, 0.287
1.0	0.381, 0.384, 0.383, 0.382, 0.384, 0.380, 0.384
2.0	0.556, 0.553, 0.551, 0.561, 0.559, 0.551, 0.553

$n = 28$; $t_{95} = 2.056$; Slope (absorbance/ppm Zn), $Ms = 0.179$

Ordinate intercept (absorbance), $I_s = 0.199$

Standard error of regression, $(Sr)_s = \pm 4.14 \times 10^{-3}$

Predicted value, $|Zs| = 1.114 \pm 5.414 \times 10^{-2}$ @ 95% C. L.

Calibration line data:

$n = 217$; $t_{.95} = 1.960$; Slope (absorbance/ppm Zn), $Mb = 0.183$

Ordinate intercept (absorbance), $I_b = 0.102$

Standard error of regression, $(Sr)_b = \pm 4.16 \times 10^{-3}$

Predicted value, $|Z_b| = 0.559 \pm 4.49 \times 10^{-2}$ @ 95% C. L.

Table II. Results of 12 replicate analysis by the method of standard additions.

Analysis number	Extrapolated value, ppm Zn	Estimated Error, Sz (Eq. 5)
1	1.069	± 0.01921
2	1.107	± 0.01136
3	1.109	± 0.01403
4	1.091	± 0.01570
5	1.082	± 0.01269
6	1.094	± 0.01877
7	1.093	± 0.009664
8	1.114	± 0.02633
9	1.070	± 0.01459
10	1.079	± 0.01562
11	1.103	± 0.01848
12	1.104	± 0.02284

Mean = 1.093

Std. dev. = ± 0.01520

Table III. Net zinc concentration with estimated error

Analysis number	Net Zinc concentration, ppm	Estimated Error, Sd (Eq. 9)
1	0.510	± 0.0338
2	0.548	± 0.0334
3	0.550	± 0.0339
4	0.532	± 0.0335
5	0.523	± 0.0332
6	0.535	± 0.0338
7	0.534	± 0.0333
8	0.555	± 0.0350
9	0.511	± 0.0331
10	0.520	± 0.0333
11	0.544	± 0.0339
12	0.545	± 0.0344

Mean = 0.534

$^{*}S_{(Sz_p - Sb)} = \pm\ 0.0287$

"Known amount" = 0.50 ± 0.01 (Std. Dev.)

For several independent samples drawn from the same population with a given variance, the best estimate of the population variance is obtained from pooling all the sample information. Thus,

$^{*}S_{(Sz_p - Sb)} = \sqrt{(Sz_p)^2 + (Sb)^2}$, where (Sz) and (Sb) are calculated from equation (5) for the individual samples and the blank, and,

$$(Sz_p)^2 = \frac{(n_1 - 2)(Sz_1)^2 + (n_2 - 2)(Sz_2)^2 + \ldots + (n_{12} - 2)\ (Sz_{12})^2}{(n_1 - 2) + (n_2 - 2) + \ldots + (n_{12} - 2)}$$

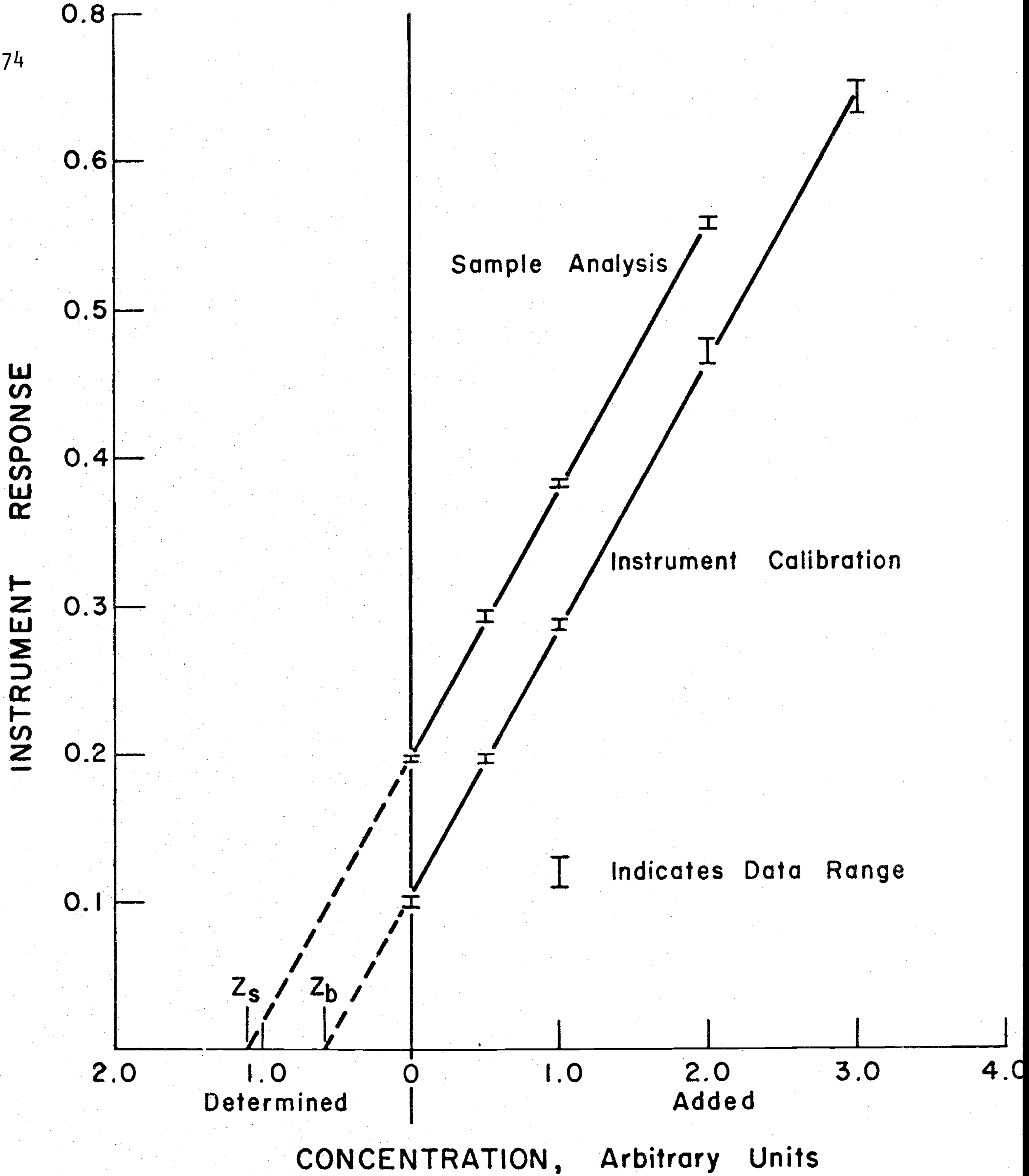

Figure 1. Instrument calibration line and sample analysis line for the Method of Standard Additions. Zs & Zb are the extrapolated values for the respective regression lines.

THREE SPECIMENS OF BATHYSAURUS MOLLIS GUNTHER, 1878 FROM THE NORTHEASTERN PACIFIC OCEAN.

by David Stein and John Butler

ABSTRACT

Three male Bathysaurus mollis Gunther, standard lengths 678 mm, 458 mm, and 440 mm, were captured 560 km off the coast of Oregon in 3358-3780 m. The 678 mm specimen is the largest reported individual of this species. Gill tooth plates alternate from side to side on the first gill arches of two specimens, but are paired on the first gill arches of the third. The largest specimen has irregular rather than oval orbits.

Three male Bathysaurus mollis Gunther, 1878, were taken in two bottom trawls on Tufts Abyssal Plain about 560 km off Oregon by R/V YAQUINA. Two individuals, 678 mm s.l. and 458 mm s.l., were captured on 31 May 1970 at 44° - 55.9°N, 131° - 25.6°W in 3358 m. The third individual, 440 mm s.l., was captured on 5 June 1970 at 44° - 32.0°N, 134° - 43.6°W in 3780 m. The gear used was a three meter beam trawl.

These specimens were compared with all known reports of B. mollis (Gunther, 1878; Vaillant, 1888; Vaillant, in Roule, 1919; Townsend and Nichols, 1925; Koefoed, 1927; Nybelin, 1957; and Mead, 1966). Morphometric and meristic counts generally agree, with the exception of gill tooth plate counts. Mead (1966) reported 6-15 gill tooth plates on the first gill arches of both his specimens (215 mm and 188 mm sl.). In our two largest specimens, the number of gill tooth plates on the outside first arch is 5-14. In our smallest specimen, there are 5-16 first gill arch tooth plates.

The positions of gill tooth plates in our specimens differ from those of Mead's 1966 specimens, which had one row of gill tooth plates located mesially on the first gill arches. In our smaller specimens, the position of these plates is irregular; they both alternate from side to side along the arch and are paired in other places. In our largest specimen, the plates alternate regularly. These differences in gill tooth plates position may represent a change with increasing size and age. Mead's (1966) small (215 mm and 188 mm) specimens had only one series of single plates; our smaller (410 mm and 458 mm) specimens had paired and alternating plates, and our largest (678 mm) specimen had alternating plates.

Our largest specimen (678 mm) is the largest reported in this species. It differs from all other known specimens in having very irregular orbits (Fig. 1). The two anterior extensions of the orbit are skin covered and are not immediately apparent. The larger of these extends forward from the anterior ventral quadrant, the smaller from the anterior dorsal quadrant.

The color of the fresh specimens was dirty white with a black patch of skin between the pectoral fins, extending forward to the isthmus. The few scales remaining were in the same location, suggesting that skin and scales are easily lost, and that adult coloration is dark, as it is in another member of the genus, _B. agassizii_ Goode and Bean, which is dark brown.

Bathysaurus mollis has been recorded throughout the Pacific Ocean; off Baja California in 3220 m, off Japan in 3429 m, in the South Pacific in 4361 m (Mead, 1966) and now in the Northeast Pacific in 3358-3780 m. It is also known from the Northeast Atlantic in 2615-4360 m, and the Gulf of Mexico in 3150-4700 m (Mead 1966). The established wide range in the Pacific Ocean suggests that more sampling will show this species to be present throughout the Pacific, Atlantic, and possibly the Indian Oceans between 2600-4700 m.

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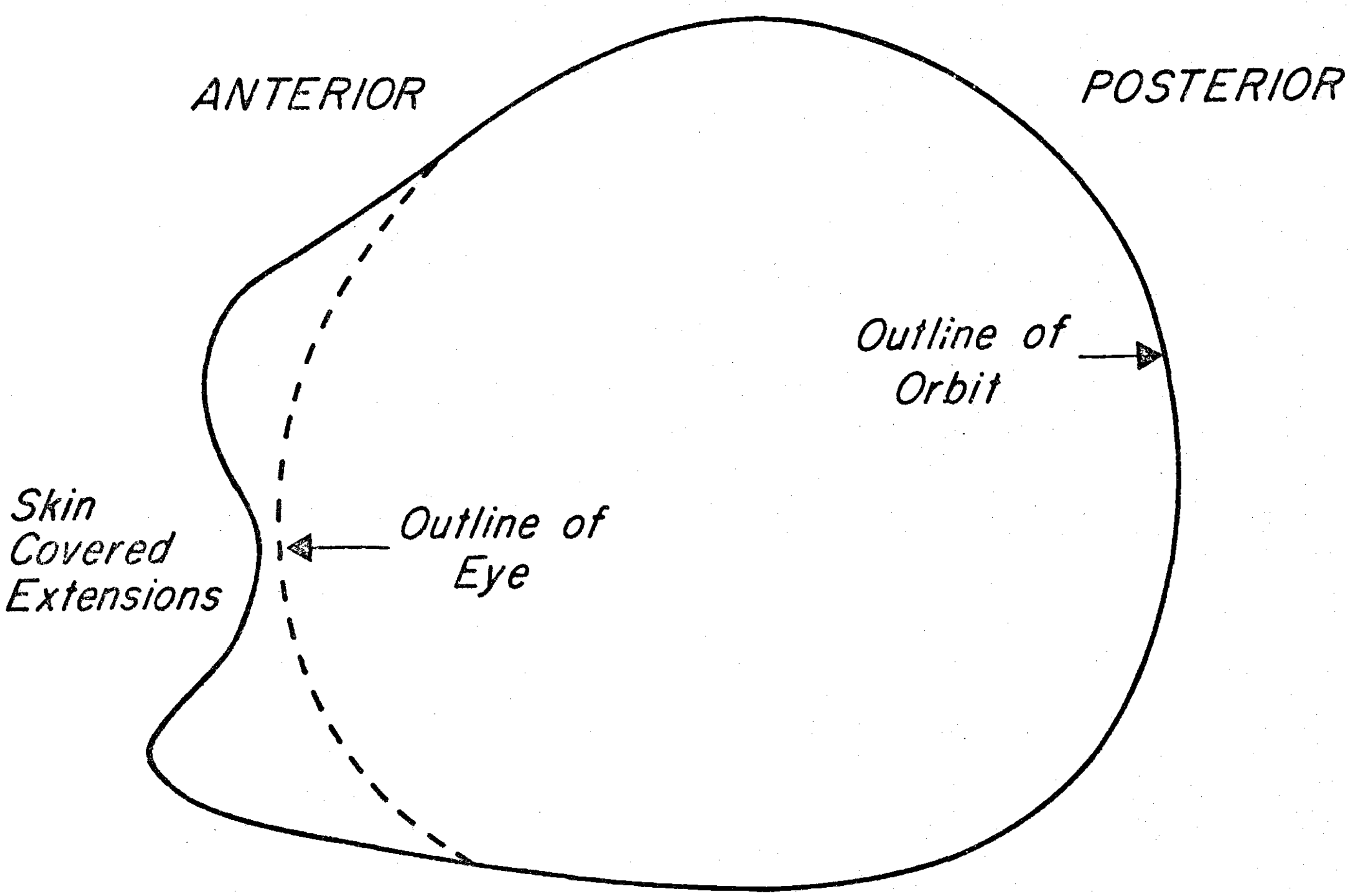

FIG. I Orbit of B. mollis Gunther, OSU 1904; 678 mm s.l.

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Revised Abstract

IAEA/SM-158/17

ZINC-65 SPECIFIC ACTIVITIES FROM OREGON AND WASHINGTON (U.S.A.) CONTINENTAL SHELF SEDIMENTS AND BENTHIC INVERTEBRATE FAUNA

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Abstract

The relationships between the benthic fauna and sediments on the continental shelf of Oregon and Washington have been investigated by determining specific activities of ^{65}Zn, a radionuclide present in the Northeast Pacific Ocean. Zinc-65, induced by neutron activation in Columbia River water used to cool plutonium production reactors at Richland, Washington, was carried down the river and into the marine environment.

Sediment from the Columbia River moves northward. Zinc-65 specific activities in sediment and benthic invertebrates decrease northward with distance from the river and westward with both distance and depth. Many organisms to the south of the river mouth and westward with depth have higher ^{65}Zn specific activities than the sediments in, or on, which they live. Other sources of ^{65}Zn via the food web are suspected as the cause for the differential in specific activity between the sediment and benthic fauna. Long-term declines in ^{65}Zn specific activities have been noted. A wide range of ecological and systematic forms have been included in the study.

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INTRODUCTION

The behavior and fate of radionuclides in the oceanic environment are the result of a complex of processes that includes the active concentration by organisms as well as physical and chemical processes. Particularly for biologically active elements the effects of marine animals and plants must be considered. The sea floor as the lower boundary of the ocean is the site for many physical, chemical, and biological processes; it is a sink for many elements in the ocean. Therefore, the sediments and associated organisms are portions of the marine ecosystem that play an important role in the fate of radionuclides in the oceans. The objective of this paper is to compare and contrast the distribution and concentration of ^{65}Zn in the sedimentary environment and in the benthic fauna on the Oregon and Washington continental shelf. We consider the specific activity of ^{65}Zn (nCi ^{65}Zn/gZn) in sediments to determine if the benthic invertebrate fauna living in, on or associated with the sea floor reflect the elemental composition of their sedimentary environment or whether other portions of the environment must be considered in the determination of their source of ^{65}Zn.

The largest source of ^{65}Zn to the area of the Northeast Pacific Ocean adjacent to the coasts of Oregon, Washington, and British Columbia has been until recently the U.S.A.E.C. plutonium production reactors at Hanford, Washington [1] [2]. These reactors operated with a cooling system that resulted in the neutron activation of trace elements in Columbia River water passed through the reactors. Longer-lived radio-nuclides, including ^{65}Zn (245 day half life), were carried down the river and eventually into the Northeast Pacific Ocean. Some radionuclides were in particulate form or sorbed onto silt and clay particles and settled out in depositional areas in the river during their 600 km journey down the river [3].

Since 1967 a plutonium production reactor has been permanently shut down each year; a total of eight have been phased out of operation since 1964. The last reactor utilizing the single-pass cooling system stopped operation in January 1971. Because of the steady decrease in the number of reactors in operation, the input of ^{65}Zn to the marine environment has been steadily decreasing during the course of the research to be reported.

The outflow of the Columbia River into the ocean with its load of dissolved and particulate radionuclides reacts to seasonal wind stress. Under the influence of northerly winds in the summer (approximately May through September), the river discharge flows to the southwest as a distinct lens-like plume of low-salinity water. During the winter period (approximately October through April) predominantly southerly winds push the Columbia River outflow to the north where it lies parallel and close to shore as a low-salinity surface layer which mixes with other sources of freshwater run-off. [4].

Zinc-65 from the Columbia River has been detected in all phases of the marine environment and in all ecological groups of marine biota. Radiozinc has been detected in phytoplankton, zooplankton, nekton, and benthos to depths of 2860 meters and to distances 490 km off the central Oregon coast

[5] [6] [7] [8]. It has been reported in sediment and water of the Northeast Pacific Ocean [4] [9] [10].

Many radionuclides in aquatic ecosystems become associated with sediments. Much of the Columbia River ^{65}Zn appears in the sediments in the river and at sea [2] [3]. This paper explores relationships between the behavior of ^{65}Zn in the sedimentary reservoir and the bottom-living organisms. As many of the benthic fauna significantly rework sediments in their search for food, their effect on the fate of ^{65}Zn on the continental shelf will be considered. Benthos may be important in resuspending radionuclides in the water or introducing them into the oceanic food web. The results reported are part of a time series study of the decline of ^{65}Zn in the marine environment of Oregon and Washington.

METHODS

Sediments and benthic invertebrate animals were collected during 1970-71 on the Oregon continental shelf adjacent to the Columbia River. The stations (Fig. 1) were patterned to sample a range of depths across the shelf at varying distances north and south of the river mouth. The trawling stations (Table I) were arranged in a series of transects normal to the coastline. Integrated cruises to sample both sediments and benthic fauna were scheduled in winter and summer to allow study of the effects of season and elapsed time on ^{65}Zn specific activities.

The fauna was sampled by 7 meter semi-balloon shrimp trawl with ½" (3.8 cm) stretch mesh. The more abundant epibenthic invertebrates were sorted to species on the ship and deep-frozen in plastic bags. Care was taken to minimize trace metal contamination. The organisms were later dried for two weeks to constant weight in a forced draft drying oven at 65°C. For further concentration of the samples, the samples were ashed in a muffle furnace at 450°C for 48 hours. The ash was ground to a fine powder in a SPEX mixer-mill and packed in 15 cm^3 plastic tubes for gamma-ray analysis. Except for the larger organisms, several to several hundred organisms from one trawl were pooled to obtain enough ash. The samples were counted for gamma-emmissions for 400 or 800 minutes, depending on the radioactivity of the sample, in the well of a 12.7 x 12.7 cm sodium iodide (Tl) crystal attached to a 512-channel pulse height analyzer. The radionuclide data were reduced by a least squares computer program and reported as pCi/g ash-free dry weight. Data were corrected for decay during the time between collection and analysis.

Total zinc was analyzed by atomic absorption spectrophotometry using a Perkin-Elmer Model 303. An aliquot of ash from each sample was prepared for element analysis by dissolving in concentrated HNO_3 and then diluting with 0.36N HCl.

Sediment samples were obtained with a 0.1m^2 spring-loaded Smith-McIntyre bottom grab [11]. The upper 1.0 cm (approximately 250 cm^2) of the relatively undisturbed sections of the sediment sample was lifted off. The sediment was immediately placed in 500 ml of 0.05 M $CuSO_4$ for 1-3 weeks to extract

^{65}Zn and stable Zn. The suspension was then filtered; the filtrate was analyzed for ^{65}Zn by gamma-ray spectrometry and for Zn by atomic absorption spectrophotometry. Specific activities appear to be constant during the period of extraction and are not affected by uncertainties of extraction yields [2].

RESULTS

Generals Trends in Faunal ^{65}Zn Specific Activities

Zinc-65 specific activities (nCi ^{65}Zn/gZn) exhibit a general pattern associated with distance from the Columbia River mouth and with depth. Specific activities at station transect lines further from the river at a distance of 160-180 km north and south are low (Fig. 2), while those from stations adjacent to the river are highest. Less radiozinc has decayed during the short transit time to nearby sites and there is less chance for isotopic dilution. Specific activities for ^{65}Zn generally decrease with depth because of increased transport time from shore and from the surface through the water column to the benthic boundary. These results have been noted elsewhere for ^{65}Zn concentrations and specific activities in benthic invertebrates in the Northeast Pacific Ocean [5] [8]. No general trend with season and year has been detected for these data.

The data in Fig. 2 are derived from carnivorous echinoderms. Trophic level can affect the levels of ^{65}Zn and consequently the specific activities. There is an inverse relationship between trophic level and ^{65}Zn specific activities [5] [7] [8] [12]. Data from organisms at one trophic level have been utilized in this analysis to demonstrate general trends in the faunal specific activities within the study area. Predatory asteroids are ubiquitous on the continental shelf in the Northeast Pacific Ocean [14], and their food source is generally known [13]. They prey upon sediment-detrital feeding organisms and can be placed in the same trophic level.

Effect of Depth on ^{65}Zn Specific Activities

Specific activities for ^{65}Zn in sediments and benthic epifauna change markedly with increasing depth and distance from The Columbia River (Fig. 3). Though the general trend is a decrease in specific activity with depth, the ^{65}Zn concentrations in the benthos and in their sedimentary environment differ over a large portion of the continental shelf. The specific activity in surface sediments are at intermediate levels at 25-50 m depth, increase to a maximum at 80-100 m, and then decline with depth. Zinc-65 cannot be detected in sediments on the Tillamook Head transect on the continental slope at 950 m depth or below.

Benthic organisms contain the most ^{65}Zn inshore at the shallowest stations sampled (25-30 m). Animals collected on the same dates as the sediment samples in December 1970 and March 1971 have higher ^{65}Zn specific activities at these inshore stations than does their sedimentary environment. The sedimentary ^{65}Zn has higher specific activities at mid-shelf depths (60-100 m), but from 150 m down to 2370 m depth (station THB 19 on the

Tillamook Head transect), the benthic invertebrates consistently have higher specific activities for zinc-65 than do the sediments. Zinc-65 can be detected in bottom-dwelling organisms beyond 2000 m whereas in the sediments it is absent or at extremely low levels beyond the threshold of the analyzer.

These data indicate that ^{65}Zn reaches the benthic fauna along other pathways instead of, or in addition to, the sedimentary source. Low levels of ^{65}Zn have been reported for Willapa Bay sediments [10], while oysters have accumulated higher concentrations [9]. These filter-feeding members of the benthos probably obtain ^{65}Zn from particles in the water rather than from bottom sediments. Zinc-65 is at low levels in the nearshore sediments where there are significant tidal and wave generated bottom currents to keep the finer particles in suspension. As ^{65}Zn can be detected in bathyal and abyssal benthic fauna [5] [8] while not in the surrounding sediments (Fig. 3) [2], it is evident that the fauna is concentrating zinc. The detrital food web in the food-poor abyssal environment may be the primary pathway of zinc-65 to the benthic fauna.

Effect of Distance on ^{65}Zn Specific Activities

The highest ^{65}Zn specific activities are found in benthic organisms and sediments in the depositional area directly west of the river (Fig. 2 and Fig. 4) on the inner continental shelf. The levels decrease to the north and south of the river mouth. This pattern is damped with increasing depth and distance from the river. The specific activities in sediments at 100 m depth west of the river mouth are about one half those at 50 m depth, while benthos specific activities decrease only slightly. Further west at the edge of the continental shelf at 200 m depth, sediment specific activities are again significantly decreased while the faunal specific activities are much less so.

At the mid and outer shelf environments, the ^{65}Zn in the sediments to the south of the river have low to zero specific activites. The distribution of ^{65}Zn predominantly to the north of the Columbia River is caused by the long duration of northerly flowing surface currents during the fall, winter and early spring months [10].

Effect of Time on ^{65}Zn Specific Activity

The decreasing input since December 1964 of ^{65}Zn into the marine environment is reflected in specific activity levels in the sediments [2] and in the benthic fauna [12] [15]. Continental shelf benthic fauna, as exemplified by the holothurian, <u>Parastichopus californicus</u>, have decreased about five-fold at the edge of the continental shelf west of Tillamook Head and Newport (Fig. 5). The specific activity is lower off Newport, 179 km south of the Columbia River mouth, and the decline is more regular. The large fluctuations of ^{65}Zn specific activity in the organism off Tillamook Head is thought to be caused by marked seasonal changes in the position of the Columbia River plume. <u>Parastichopus</u> is an efficient detritus feeder; it sweeps the sediment surface with mucous-covered tentacles [16].

CONCLUSIONS AND SUMMARY

1. Zinc-65 specific activities are highest in benthic fauna and sediments on the inner continental shelf directly west of the Columbia River mouth.

2. Beyond the depositional area at the river mouth zinc-65 specific activities in sediments reach a maximum on the mid continental shelf at depths of 60-100 m.

3. Zinc-65 specific activities in fauna and sediment generally decrease with depth (and transport time), though the specific activities are higher in fauna than in the sediments on the continental slope and deeper environments beyond.

4. Specific activity for ^{65}Zn in benthic fauna and sediments decreases with distance (and transport time) from the Columbia River. Specific activities in sediment reach zero about 80 km south of the river while organisms 100 km further to the south off Newport still contain significant amounts of ^{65}Zn.

5. The Columbia River plume transports zinc-65 to benthic organisms to the south of the river and probably to the north also.

6. Specific activities for ^{65}Zn have declined five-fold in five years. The specific activities in fauna off Tillamook Head close to the river have significant seasonal variations in levels.

7. Benthic organisms are often not in equilibrium with the ^{65}Zn specific activities of their sedimentary environment. They probably acquire ^{65}Zn with differing specific activities from other sources such as the detutal food web.

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Table 1. Station locations and sampling data for benthic Fauna

	Station	Depth (m)	Location Lat.	Location Long	Distance From River (km)	Collection Dates Jan 70	Mar 70	Sep 70	Dec 70	Feb 71	Mar 71	June 71	Oct 71
DESTRUCTION ISLAND TRANSECT													
	DIB 2	50	47° 39.0' N	124° 40.0' W	162.1-N							X	X
	DIB 4	100	47° 39.0' N	124° 50.0' W	166.1-N							X	X
	DIB 6	150	47° 29.0' N	125° 00.0' W	170.4-N							X	X
	DIB 8	200	47° 39.0' N	125° 05,5' W	173.7-N							X	X
RAFT RIVER TRANSECT													
	RRB 4	100	47° 27.0' N	124° 37.6' W	143.5-N						X		X
	RRB 6	150	47° 27.0' N	124° 45.8' W	143.9-N						X		
GRAYS HARBOR TRANSECT													
	GHB 2	50	47° 08.0' N	124° 20.0' W	101.9-N								
	GHB 4	100	47° 08.0' N	124° 32.0' W	103.3-N						X		X
	GHB 6	150	47° 08.0' N	124° 45.0' W	110.7-N						X		X
	GHB 8	200	47° 08.0' N	125° 05.0' W	124.3-N						X		
WILLAPA BAY TRANSECT	WBB 1	30	46° 38.0' N	124° 10.0' W	43.5-N		X		X				
	WBB 2	50	46° 38.0' N	124° 15.0' W	44.3-N						X	X	X
	WBB 3	75	46° 38.0' N	124° 18.2' W	42.2-N				X				
	WBB 4	100	46° 38.0' N	124° 25.0' W	50.0-N						X	X	X
	WBB 6	150	46° 38.0' N	124° 31.0' W	54.4-N				X		X		X
	WBB 8	200	46° 38.0' N	124° 38.0' W	60.2-N						X	X	X
TILLAMOOK HEAD TRANSECT													
	THB 2	50	45° 56.0' N	124° 02.1' W	35.4-S			X					
	THB 3	75	45° 56.0' N	124° 06.0' W	35.2-S						X	X	
	THB 4	100	45° 56.0' N	124° 12.2' W	36.7-S						X		
	THB 6	150	45° 56.0' N	124° 28.0' W	45.2-S				X		X	X	X
	THB 8	200	45° 56.0' N	124° 38.7' W	55.0-S	X	X		X	X			X
	THB 19	2370	45° 57.0' N	124° 44.5' W	73.5-S								X
NEWPORT TRANSECT													
	NAD 2	50	44° 39.1' N	124° 09.8' W	175.0-S			X					
	NAD 8	200	44° 39.1' N	124° 36.0' W	179.3-S	X	X	X					

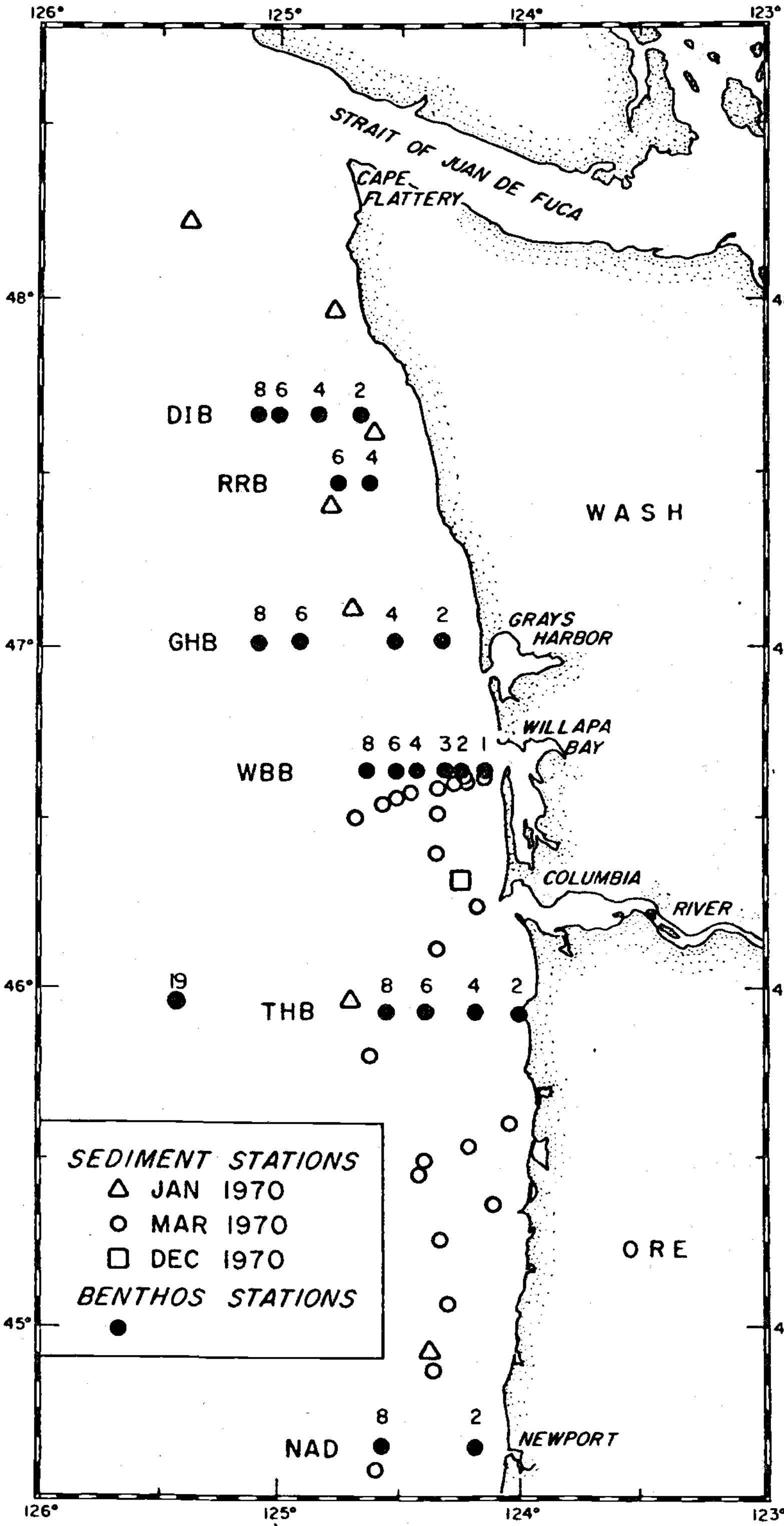

Fig. 1. Map showing sediment and benthic fauna station locations. The sampling date is indicated for each sediment sample; the standard trawling stations are indicated on the sampling transects (DIB, Destruction Island Benthos; RRB, Raft River Benthos. GHB, Grays Harbor Benthos; WBB, Willapa Bay Benthos; THB, Tillamook Head Benthos and NAD, Newport Anchor Dredge).

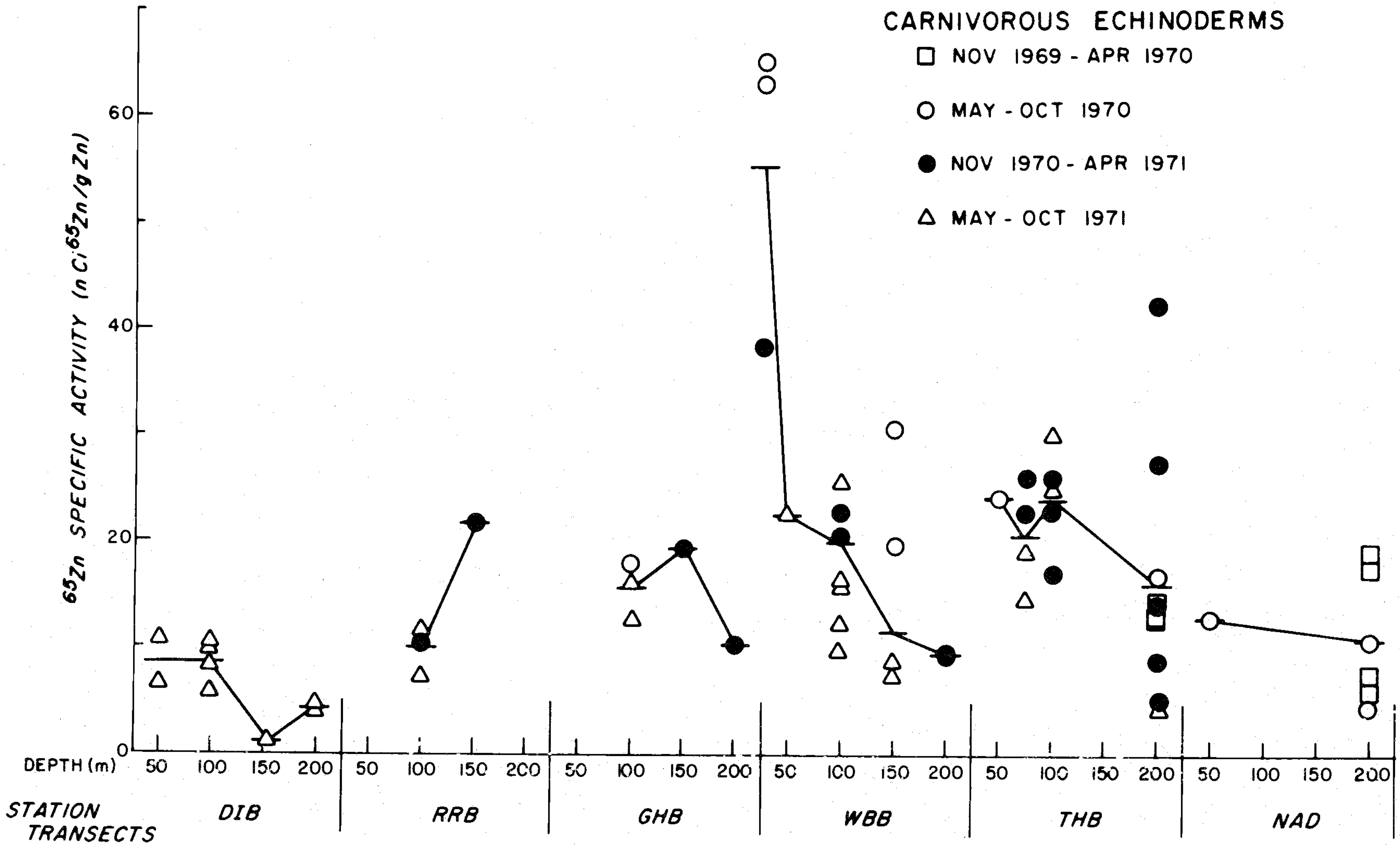

Fig. 2. Zinc-65 specific activities for carnivorous echinoderms at depths of 25-200 meters on the benthos station transects (DIB, Destruction Island Benthos; RRB, Raft River Benthos; GHB, Grays Harbor Benthos, WBB, Willapa Bay Benthos; THB, Tillamook Head Benthos; NAD Newport Anchor Dredge). Data points are for individual determinations with the period of collection indicated. Means for each station are plotted.

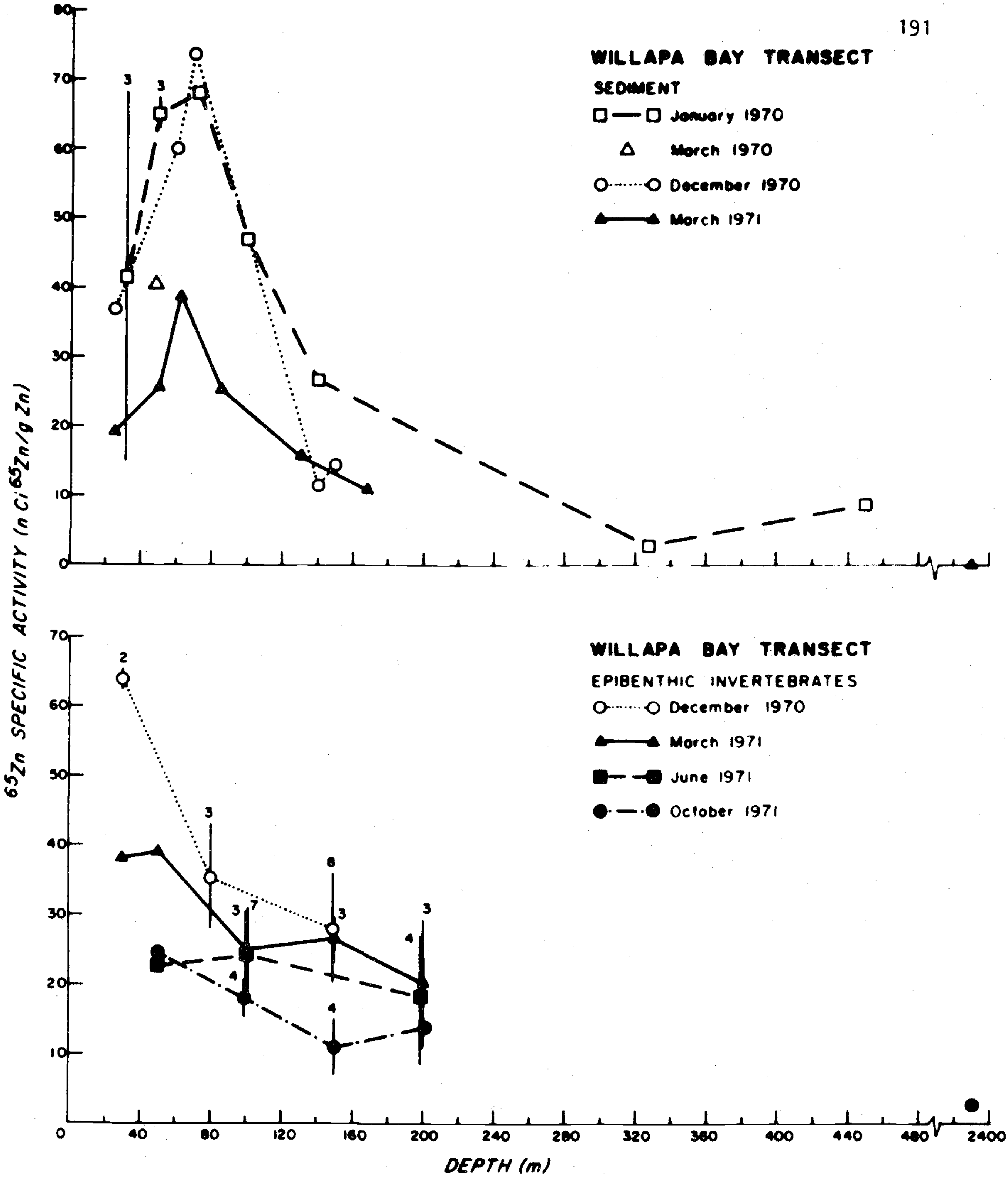

Fig. 3. Zinc-65 specific activities for benthic epifaunal invertebrates and for sediment from the Willapa Bay transect (WBB). Means ± 1 sample standard deviation are plotted. The number of observations is indicated above each point. The station at 2370 m depth is THB 19 on the Tillamook Head transect (45° 56.8'-N, 125° 29'-W). Animals analyzed include a broad range of taxa and ecological types.

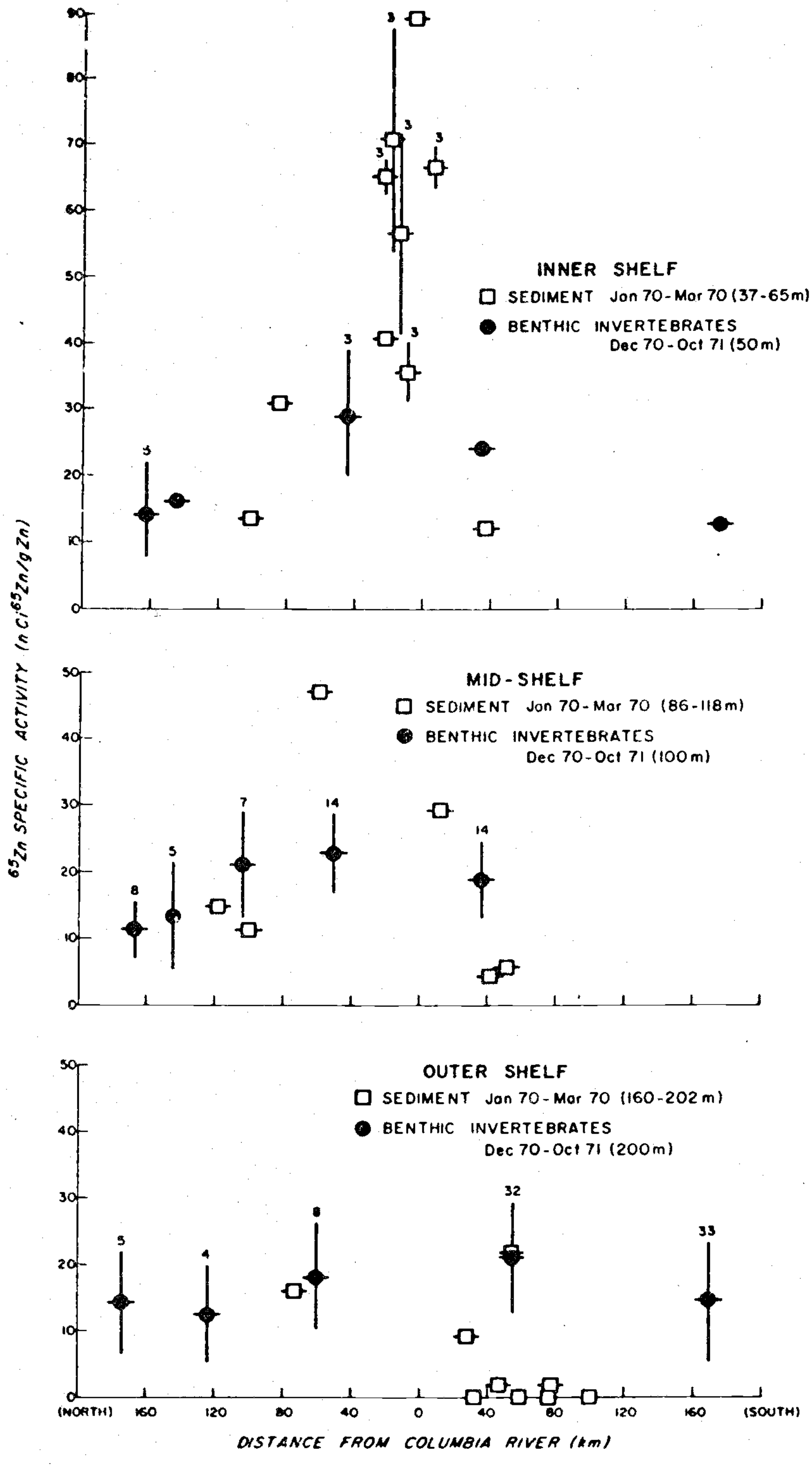

Fig. 4. Zinc-65 specific activities for sediment and epibenthic fauna along 3 depth contours: inner continental shelf, mid-shelf, and outer shelf from the Destruction Island Transect (DIB) to the Newport Transect (NAD). Means ± 1 sample standard deviation are plotted. When more than one observation was made, the number is indicated. Animals analyzed include a broad range of taxa and ecological types.

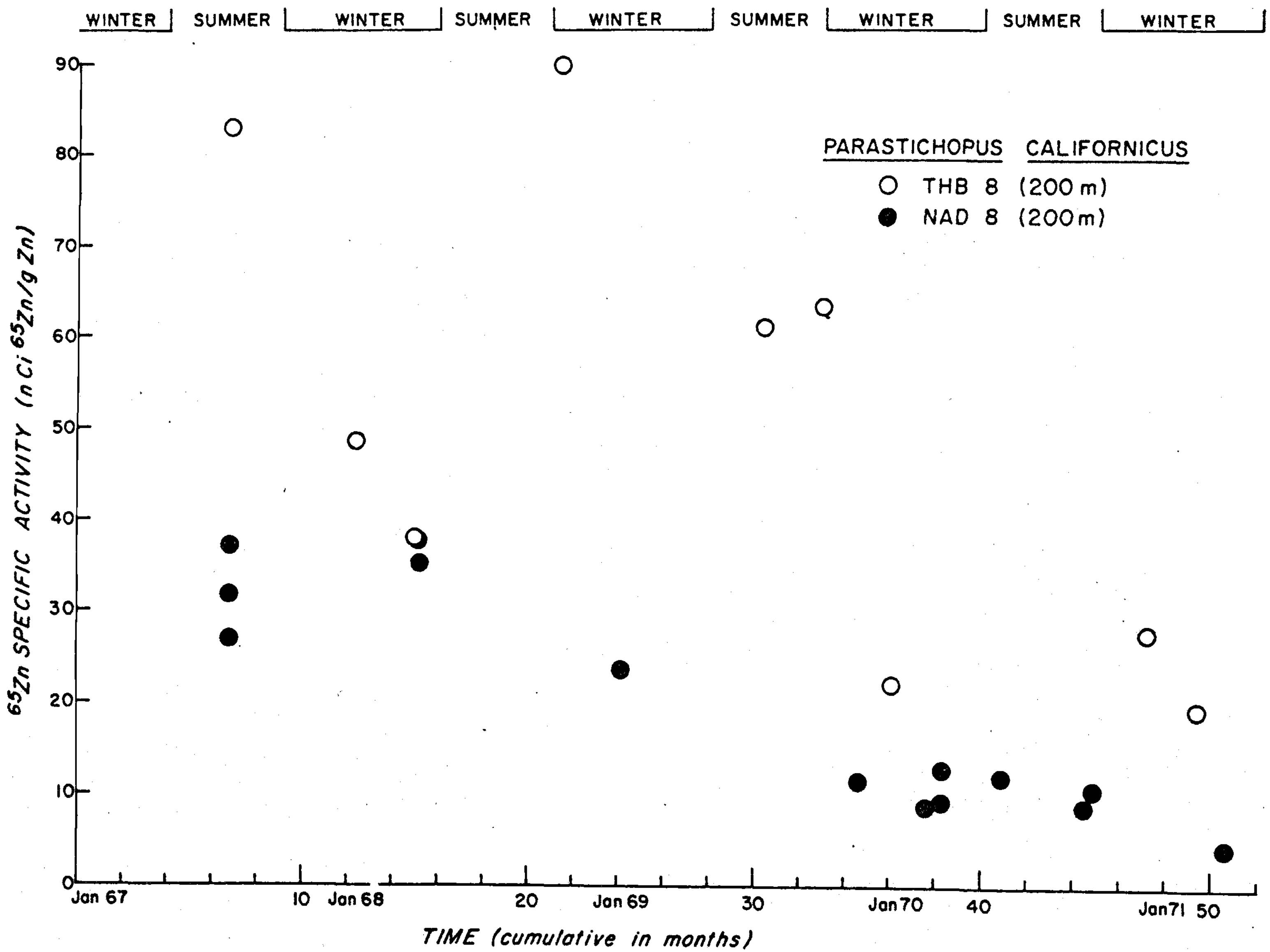

Fig. 5. Zinc-65 specific activities for the holothurian, Parastichopus californicus from April 1967 to February 1971 from 200 meters depth on the Tillamook Head Transect (THB) and Newport Transect (NAD).

Radioecology of Benthic Fishes off Oregon, U.S.A.

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Abstract

Gamma-emitting radionuclides were found in benthic fishes from depths of 50-2800 m off the Oregon coast from 1964-1971. ^{65}Zn, ^{60}Co, ^{54}Mn, ^{144}Ce, ^{137}Cs and ^{40}K were present. Zinc-65, originating mainly from the nuclear reactors on the Columbia River, was the predominant artifically-induced radionuclide. Levels of ^{65}Zn per g and specific activities of ^{65}Zn decreased markedly in several species of fishes between 1965 and 1971 because of the shutdown of reactors. This decrease was greater for small than large _Lyopsetta exilis_ during 1970-1971. Specific activities decreased with increasing depth, both for individual species inhabiting broad depth ranges and for different species inhabiting different depths. Specific activities of ^{65}Zn were inversely related to body size for _L. exilis_ and _Sebastolobus_. Other variations of ^{65}Zn were related to trophic position. Fishes that preyed on low trophic level pelagic animals had higher specific activities than fishes that preyed on benthic invertebrates. Such pelagic feeders may play an important role in accelerating the transport of some radionuclides or elements to the sea floor.

INTRODUCTION

This paper examines the artificial radioactivity of benthic fishes off Oregon and, more specifically, how the specific activity of zinc-65 (nCi ^{65}Zn/g total Zn) varies among species, size of fishes, depth of capture, years and seasons, and feeding habits. Differences may be useful for identifying pathways of zinc accumulation from a surface input and may provide information on the ecology of this important group of animals which comprises a significant portion of the biomass of benthic communities.

Until recently the most important source of artificial radionuclides in the ocean off Oregon was the Columbia River [1][2]. Radionuclides were mainly induced by neutron-activation of elements in river water used to cool "single-pass", plutonium-production reactors at Hanford, Washington. Most of the radionuclides produced had a short half-life and decayed to undetectable levels during the 370 mile trip down the Columbia River to the Pacific Ocean. Starting in 1964 reactors at Hanford were sequentially shut down, and in January 1971 the last reactor inducing radioactivity of coolant water was deactivated. This study encompasses the years when radioactivity introduced into the Pacific Ocean was declining.

The distribution of Columbia River water in the ocean depends largely on seasonal wind patterns and ocean circulation. During the summer, when winds are usually from the north, the Columbia River waters are pushed to the south off Oregon, often as a distinct plume of low-salinity water. During the winter, when southerly winds prevail, the river waters are found to the north largely along the coast of Washington [3] . Radioactivity introduced by the Columbia River has been traced in surface water by chromium-51 content [3][4] and in sediments by zinc-65 and cobalt-60 [3] [5].

Of the radionuclides introduced into the Pacific Ocean by the Columbia River, zinc-65 is the most common in marine organisms. ^{65}Zn, with a 245 day half-life, has been reported in many species of plankton, nekton and benthos off Oregon [6] [7] [8] [9] [10].

METHODS

Fishes were collected with a 7-m semi-balloon shrimp trawl or a 3-m beam trawl on the continental shelf, slope and abyssal plain off Oregon from 1964-1971.

Fishes were sorted from the trawl samples and frozen in plastic bags at sea taking caution to prevent trace-metal contamination. In the laboratory ashore they were identified, measured (standard length), weighed and dried to a constant weight at 65°C. To provide enough material for radioanalysis, several individuals of a species often constituted one sample. After drying, samples were weighed, ashed at 450°C in a muffle furnace, ground to a fine powder with a mortar and pestle, and packed in $15 cm^3$ plastic counting tubes for gamma-ray counting.

Samples were radioanalyzed in the well of a 12.7 x 12.7-cm sodium iodide (Tl) crystal with a 512 channel pulse-height analyzer. Counting time was 100 or 400 minutes, depending on the radioactivity of the sample. Readout information was stored on paper punch tape, transferred to computer cards and analyzed by a least squares program to give radioactivity per gram ash, corrected for decay.

Zinc concentrations were determined on subsamples of ash using an atomic absorption spectrophotometer (Perkin-Elmer Model 303). These samples were first digested in concentrated HNO_3 and diluted with 0.37N HCl.

RESULTS

Gamma-ray Spectra

Zinc-65 was the predominant artificial gamma-emitting radionuclide in all benthic fishes. It produced a prominent photopeak and was present above minimum detectable activity[1] in virtually all samples. Besides ^{65}Zn and naturally-occuring ^{40}K, other radionuclides were occasionally evident above background. Distinct photopeaks of ^{54}Mn and ^{137}Cs were sometimes present in the spectra (Fig. 1); they occurred most often in *Anoplopoma fimbria*, *Merluccius productus* and *Atheresthes stomias*, all large carnivores. ^{60}Co and ^{144}Ce were recorded rarely but no clear photopeaks were evident.

^{65}Zn and Size of Fishes

Fish of the same species but of different size sometimes had values of ^{65}Zn radioactivity per gram that were inversely related to body weight or length. Table I shows the amount of total zinc, ^{65}Zn radioactivity and specific activity for different sizes of two species of *Sebastolobus* caught at one station. With order of magnitude increase in weight of each species, the concentration of Zn and ^{65}Zn both decreased. Specific activity

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[1]Minimum detectable activity, $3(N)^{1/2}$, where N = the background count, was 5 pCi for a 100-minute count and 2 pCi for a 400-minute count for ^{65}Zn.

of ^{65}Zn also decreased significantly, indicating that the relative decrease in ^{65}Zn was greater than that for Zn. The specific activities of *Lyopsetta exilis*, a common flounder, were also inversely correlated with body size. Fig. 2 shows the regression lines between size and specific activities for 14 different collection periods in 1970 and 1971. The slopes of all but two of these individual regression lines are significant ($P < 0.05$). Therefore the effect of size must be considered when comparing spatial or temporal variations of specific activity of these species.

Unlike *Sebastolobus* and *L. exilis*, the ^{65}Zn specific activity of another flounder, *Microstomus pacificus*, was relatively independent of size. The slope of the linear regression between specific activity and weight was not significant for fish ranging between 96 and 846 g during April-May 1970 ($P > 0.5$, $n = 27$), 42 and 318 g during June 1970 ($P > 0.2$, $n = 11$), and 200 and 1050 g during July-October 1970 ($P > 0.5$, $n = 40$). To understand this inconsistency we must examine the reasons for expecting lowered specific activity with increased weight.

The model of Vanderploeg [11] helps to explain these specific activity-weight relationships. His model assumes zinc input is proportional to feeding intensity and that α, the rate of zinc input per body burden of zinc, will decrease with weight, W, as will feeding intensity per unit weight. Using the respiratory and weight relationships of Winberg [12] and the stable zinc-size relationship for *M. pacificus*, α decreases with W according to

$$\alpha \approx CW^{-0.3}$$

where C is a constant for a given temperature. It can be shown that in the steady state, this relationship implies that smaller fishes will have a higher specific activity than larger fishes, assuming similar diets. From equation 9 given by Vanderploeg [11] , the specific activity of a fish, S, under equilibrium conditions is given by

$$S = \frac{\alpha F}{\alpha + \lambda}$$

where F = the equilibrium or constant specific activity of the prey, and $\lambda = 2.83 \times 10^{-3}$, the physical decay constant for zinc-65. If, for example, $\alpha = 1 \times 10^{-3}$, a value obtained for *M. pacificus* [11] , then $S = 0.26F$. If α is doubled, then $S = 0.41F$. Moreover, rapid growth, a concomitant of increased feeding intensity, implies increased α and thus higher specific activity. Since rapid growth characteristically occurs when fish are small relative to asymptotic size, the growth effect would tend to augment the size effect in a given species.

The conflicting results of the specific activity - weight regressions among the above species are clarified using the model. First, the _relative_ size ranges of _M. pacificus_ were smaller than those of the other two species. The sizes of _Sebastolobus_ spp. and _L. exilis_ ranged over more than two and one orders of magnitude respectively. In contrast, the size ranges of _M. pacificus_ were less than an order of magnitude. Because α is halved with each order of magnitude increase in weight, a specific activity - weight effect would not be strongly defined for _M. pacificus._ Second, these fishes were not in equilibrium with their food during this period of reactor shutdown. Under certain nonequilibrium conditions, the inverse relation between specific activity and size could diminish.

Long-Term Declines

Short-term decline of radioactivity after temporary shutdown of Hanford reactors has been reported by Watson et al. [13] for freshwater animals and by Renfro and Osterberg [14] for ^{65}Zn specific activities of the flounder _Platichthys stellatus_ in the Columbia River estuary. Our study shows long-term decreases of ^{65}Zn in marine fishes attributable to the reduced operations of reactors at the Hanford Plant on the Columbia River. Eight "single-pass" reactors were phased-out between December 1964 and January 1971.

The average specific activity of _Microstomus pacificus_ decreased by an order of magnitude between 1965 and 1970 (Fig. 3), as the number of reactors decreased from five to one. Two other species of large flounders _Glyptocephalus zachirus_ and _Atheresthes stomias_, showed similar decreases of specific activity over this same interval (Fig. 4).

The specific activity of _Lyopsetta exilis_ also decreased significantly during 1970-1971. This is shown by plotting the ^{65}Zn specific activity for two size groups, 5-20 mm and 45-60 mm fish, in Fig. 5A. The significant slope of the least squares fit to these points ($P < 0.001$ and $P < 0.01$ for the small and large fish respectively) substantiates the decline of radioactivity associated with reactor shutdowns.

Fig. 2 shows that both the slopes and the Y - intercepts of the regression lines for _L. exilis_ usually decreased with time. The regression line of these slopes vs. time is significant ($P < 0.05$; Fig. 5B). These trends, and the significantly ($P < 0.01$) larger slope of the regression line for small than for large fish in Fig. 5A, indicate that small _L. exilis_ responded more rapidly to decreased levels of ^{65}Zn in the environment than large _L. exilis._ The Zn turnover of small fish was faster and/or the specific activity of their prey decreased more rapidly.

Seasonal Variations

Although seasonal variations are not apparent in the data for *L. exilis* from 1970 and 1971 in Fig. 5, 22 analyses of earlier collections, when ^{65}Zn radioactivity levels were higher, demonstrate that specific activities were indeed higher during May-September, the time of year when the plume is usually located off Oregon, than during October-April, when most Columbia River flows north along the Washington coast (Table II).

Depth of Capture

The average specific activities of benthic fishes are listed according to depth of capture in Table III for 1964-1967, the period before rapid decreases of specific activities (Figs. 3 and 4). Specific activities generally decreased with depth. This trend is evident despite the large variability listed for individual species. Variation is due to aforementioned factors and those cited by Renfro and Osterberg [14] .

Specific activities of deep-sea macrourids on the abyssal plain (2700-2900m) are between one and two orders of magnitude lower than values for fishes from the upper continental shelf (50-100m). This general trend for decreasing specific activities with depth is believed to be mainly caused by the increased time required for vertical transport of ^{65}Zn from surface waters into the deep-sea. The difference in average specific activities between fishes on the upper shelf and the abyssal plain is equivalent to 4.3 half-lives of ^{65}Zn or about 3 years. Larger ^{65}Zn input into surface waters on the shelf is a possibility but the geographic location of the Columbia River plume based on salinity and radioisotopes [3] [4] [15] and echinoids [9] all show that the plume commonly is found intermediate distances off Central Oregon during the summer and usually is not confined to shallow water over the inner shelf where upwelling is prominent.

Specific activities of individual species captured over a wide depth range also decreased with increased depth of water (Fig. 6). *Microstomus pacificus* had highest specific activities in shallow water (less than 200m depth) and values were lower by 10 times in deep water (800 m). Note that larger fish were usually captured in deep water, a factor that could confound interpretation of specific activities were it not for the relative independence of specific activities and size for large fish of this species over moderate size ranges. The ^{65}Zn specific activities of *Sebastalobus* spp. also decreased in deeper water during 1965-1967 but not in 1970 when only one reactor was in operation. Data on hagfishes (*Eptatretus* spp.) suggest a change of specific activity with depth in 1966 but not in 1970 when all had low specific activities.

Even fishes from deep water had specific activities that varied with depth. A comparison of specific activities of Macrouridae collected in 1965 and 1966 from 1250-1600 m on the continental slope and from 2800m on the abyssal plain showed that the fishes from slope waters had highest specific activities ($P < 0.05$, $n = 19$).

Food Habits

Within the depth intervals listed in Table III, specific activities of some fishes are clearly related to feeding habits. Stomach contents of Pleuronectiformes (flatfishes) were analyzed and species with highest specific activities were found to feed largely on pelagic prey such as euphausiids, pandalid shrimp, and fishes, whereas species with low specific activity fed on benthic prey such as polychaetes, ophiuroids, mollusks and amphipods (Table IV). This trend is also illustrated in Fig. 7 which shows the ^{65}Zn specific activities of several species from one collection. Specific activities were highest for L. exilis and A. stomias, pelagic feeders, and lowest for M. pacificus and G. zachirus, benthic feeders. The ^{65}Zn specific activities of the stomach contents of L. exilis and A. stomias from this collection were 40 nCi/g; they were 22 nCi/g for M. pacificus. In all instances specific activities of the prey were considerably higher than the fishes themselves. This decrease in specific activity follows from radioactive decay in passage up the food chain [16].

Based on this relationship between ^{65}Zn specific activities and food habits we thought that Isopsetta isolepis, a flounder with a low ^{65}Zn specific activity (Table III) and for which we could find no information on feeding habits, would be a benthic feeder. Subsequent examination of stomachs proved this to be the case (Table IV). Thus specific activity, in this instance, was used to predict feeding habits.

Apparently some species of fishes captured in bottom trawls are more closely linked with the pelagic than the benthic food web. Some species are pelagic and reside at times just above the bottom. Some undertake diel vertical migrations swimming off the bottom at night, as reported for other species [17]. Others may reside on the sea floor but feed on pelagic animals that migrate close to the bottom during the day. Pandalid shrimp and euphausiids are vertical migrants [18] [19] that are important food for several benthic fishes off Oregon (Table IV) and for Atheresthes stomias and Merluccius productus from northern California [20].

Pelagic feeders have higher ^{65}Zn specific activities than benthic feeders because less time is evidently required for atoms of ^{65}Zn to be passed to fishes through the pelagic food chain than through the benthic food chain and relatively less physical decays occurs. This lag explains why surface-living or predatory benthic invertebrates have higher ^{65}Zn

content than deposit-feeding infauna [6] [9]. The fact that euphausiids have relatively high concentrations of ^{65}Zn compared to other animals [7] [Pearcy, unpubl.] also supports this contention. Therefore pelagic-feeding benthic animals may accelerate the transport of elements and energy from surface waters to the sea floor just as vertically migrating organisms may accelerate transport into the deep sea [8].

The relationship between specific activity and weight for Lyopsetta exilis shown in Figs. 2 and 5 may in part be owing to the feeding habits of different size classes of this species [21]. The size of ingested organisms was positively correlated with size of fish examined during some months. The small prey consisted of small pelagic crustaceans such as euphausiids and decapod larvae. The large prey were shrimps and fishes that often had lower specific activities than the small crustaceans they consumed [18] [21]. Assuming L. exilis accumulates zinc through the food chain, small fish would be expected to have the highest specific activities. Diet may also be responsible, in part, for the more rapid decline of specific activity in the smaller L. exilis (Fig. 2). Possibly small pelagic crustaceans respond more quickly to decreasing environmental radioactivity causing, in turn, a more rapid decrease in smaller L. exilis.

SUMMARY AND CONCLUSIONS

1. Although other radionuclides were present, ^{65}Zn was the most conspicuous gamma emitter found in benthic fishes off Oregon.

2. The relationship between specific activities of ^{65}Zn and size of individuals was investigated for three species. A significant inverse relationship was found for two of these species.

3. Long-term decreases of ^{65}Zn specific activities, illustrated for several species, were correlated with the shutdown of nuclear reactors on the Columbia River between 1964 and 1971.

4. Both the slope and the Y-intercept of the regressions of ^{65}Zn specific activity on _Lyopsetta exilis_ weight decreased with time during 1970 and 1971. This indicates that small _L. exilis_ responded more rapidly to the decline of ^{65}Zn in the environment than large _L. exilis_. The faster decrease of zinc-65 in small fish is related to their size and the specific activity of their prey.

5. Seasonal variations of ^{65}Zn specific activities in _L. exilis_ were observed that correlated with known seasonal changes in the location of the Columbia River plume.

6. Specific activities of ^{65}Zn decreased with increasing depth and were at least 10 times lower in fishes captured at depths of 2800m than 100m. Individuals of species collected over a wide depth range displayed similar trends.

7. The fact that benthic fishes feeding on pelagic prey generally had higher ^{65}Zn specific activities than fishes feeding on benthic invertebrates suggests that these pelagic feeders are more closely coupled with the source of ^{65}Zn and accelerate its transport to the sea floor.

ACKNOWLEDGMENTS

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FIGURE LEGENDS

Fig. 1. Gamma-ray spectrum of a 440 mm Merluccius productus (Pacific hake) collected at a depth of 311 m, March 1966.

Fig. 2. Regression lines of the ^{65}Zn specific activities vs. wet weight of Lyopsetta exilis for 14 collection dates in 1970 and 1971.

Fig. 3. Specific activity of ^{65}Zn for Microstomus pacificus collected off Central Oregon, 180-270m, 1965 to 1971. The lower figure shows the number of Hanford nuclear reactors in operation during this period.

Fig. 4. Specific activity of ^{65}Zn for two flounders, 1965-1970. Solid symbols denote fish <200 mm, half-solid symbols fish between 200 and 300 mm, and open symbols fish >300 mm.

Fig. 5A (below) Specific activities of ^{65}Zn for Lyopsetta exilis during 1970 and 1971. Each point represents a sample. Lines are least squares fits to the points. Upper regression line is for fish 5-20 g wet weight; lower line for fish 45-60 g wet weight.
B. (above) The slope of the specific activity vs. weight relationships of Fig. 2 plotted for different collections during 1970 and 1971. Slopes and their standard errors are shown. For the least squares fit, each point was weighted by the inverse of its standard error.

Fig. 6. Specific activity of ^{65}Zn at different depths for several benthic fishes. Symbols indicate different collection times and size of fishes. The symbols for Microstomus pacificus: solid <200 mm, half-solid 200-300 mm, open >300 mm; for Sebastalobus spp.: solid < 100 mm, half-solid 100-200 mm, open >200 mm; for Eptatretus spp. all individuals were between 310-510 mm.

Fig. 7. Specific activity vs. wet weight of five species of benthic fishes all collected at one station on 10 May 1970. All weights less than 100g are averages of more than one individual per sample.

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Table I. Zinc, Zinc-65 radioactivity and specific activity for different sizes of Sebastolobus spp. caught at the 800 m depth of Tillamook Head, Oregon, 13 July 1969.

Species	Number in Sample	Average wet wt. of fish in sample (g)	μg Zn/g wet weight	pCi ^{65}Zn/g wet weight	Specific Activity nCi/gZn
S. altivelis	42	5	10.4	0.161	15.4
S. altivelis	23	16	9.6	0.109	11.3
S. altivelis	10	48	8.6	0.082	9.5
S. altivelis	5	112	8.3	0.080	9.6
S. altivelis	2	167	7.7	0.070	9.1
S. altivelis	2	249	5.4	0.053	9.7
S. alascanus	1	573	6.6	0.036	4.6
S. alascanus	1	761	6.6	0.027	4.0
S. alascanus	1	983	6.3	0.026	4.1

Table II. Zinc and Zinc-65 in <u>Lyopsetta exilis</u> collected from June 1964 to January 1967, 200m depth off Newport, Oregon. All fish were between 100 and 200 mm in length.

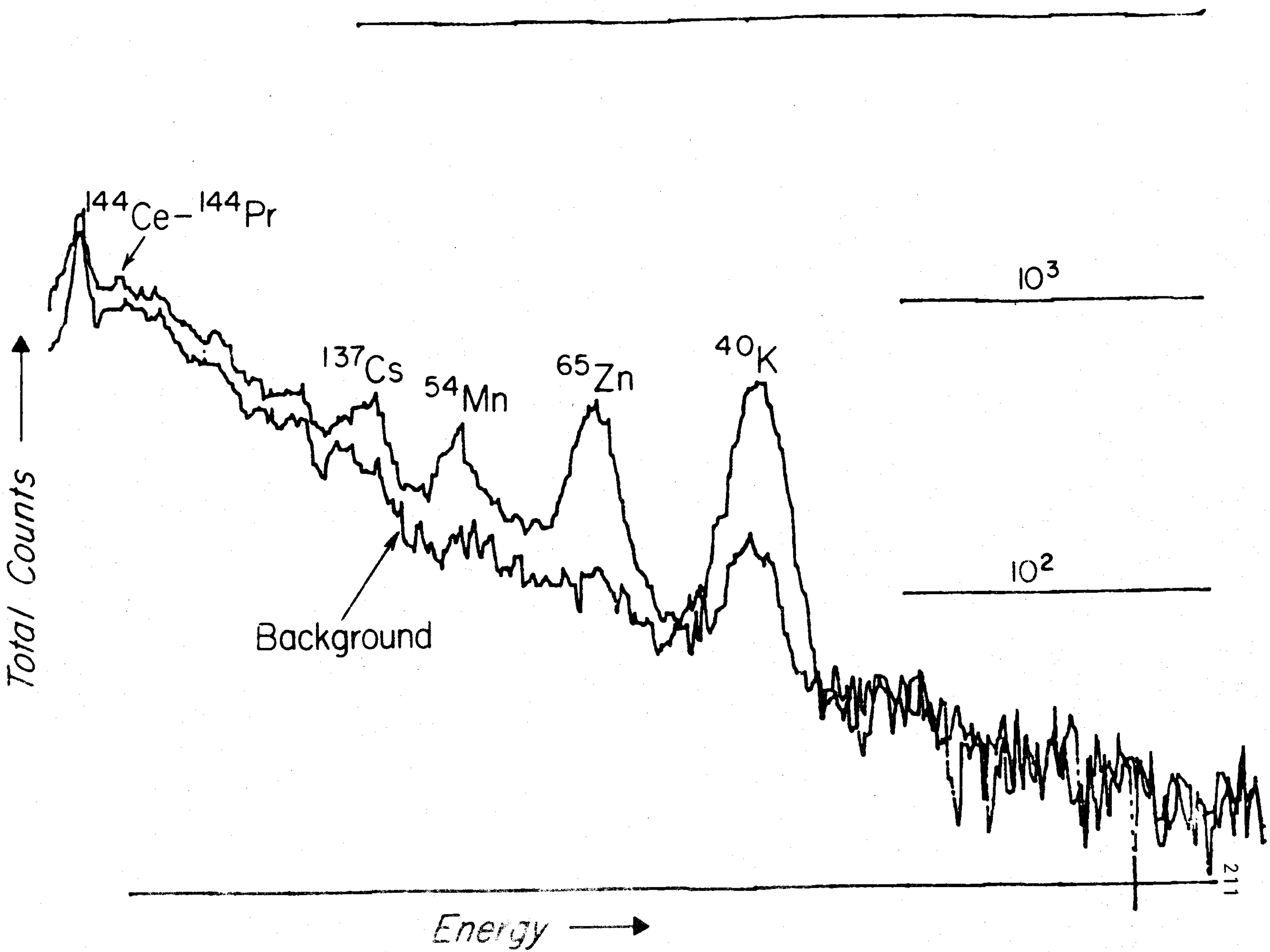
	May-September	October-April	P
pCi ^{65}Zn/g ash-free dry wt.	12.6	8.21	>0.1
µg total Zn/g ash-free dry wt.	63.9	72.1	>0.3
nCi ^{65}Zn/g Zn	224	110	<0.02*

Table III. Specific Activity of Zinc-65 in species of benthic fishes collected on the Continental Shelf and slope and the abyssal plain off Oregon, 1964-1967.

Depth (m)	Species	Length Range	No. of Analyses	Specific Activity $nCi\,^{65}Zn/gZn$ mean	std. dev.
50- 100	*Citharichthys sordidus*	125-210	4	560	90
	Cymatogaster aggregata	85-110	3	370	280
	Eopsetta jordani	115-235	4	220	120
	Isopsetta isolepis	135-250	4	80	10
	Parophrys vetulus	190-300	7	130	60
100- 200	*Microgadus proximus*	150-190	3	170	120
	Sebastes spp.	160-250	6	140	90
	Atheresthes stomias	260-380	4	170	110
	Anoplopoma fimbria	160-450	7	90	60
	Xenopyxis latifrons	90-160	6	120	20
	Lyopsetta exilis	70-200	33	140	110
	Sebastalobus altivelis	125-200	6	100	20
	Sebastes elongatus	170-250	5	80	20
	Microstomus pacificus	245-360	14	70	60
	Glyptocephalus zachirus	225-285	16	70	40
200- 400	*Merluccius productus*	420-530	3	50	30
	Eptatretus spp.	300-460	8	30	10
400- 800	*Sebastalobus alascanus*	55-245	14	40	20
	Anoplopoma fimbria	400-470	5	30	20
	Microstomus pacificus	130-360	9	30	30
800-1300	Macrouridae	260-250	5	30	30
1600-2300	*Antimora rostrata*	310-470	4	20	20
2700-2900	Macrouridae	200-570	25	10	10

Table IV. Feeding Habits and ^{65}Zn specific activities of Pleuronectiformes (flatfishes) collected at two depth ranges off Oregon, 1964-1967.

50-100m	nCi ^{65}Zn/gZn Specific Activity	Food Habits
Citharichthys sordidus	560	euphausiids, shrimps, amphipods crab larvae
Eopsetta jordani	220	shrimps, pelagic fishes, euphausiids
Isopsetta isolepis	80	gastropods, polychaetes, pelecypods
Parophrys vetulus	130	polychaetes, amphipods, pelecypods
100-200m		
Atheresthes stomias	170	fishes, shrimps, euphausiids
Lyopsetta exilis	140	euphausiids, shrimps
Microstomus pacificus	70	polychaetes, ophiuroids, pelecypods
Glypotocephalus zachirus	70	polychaetes, amphipods



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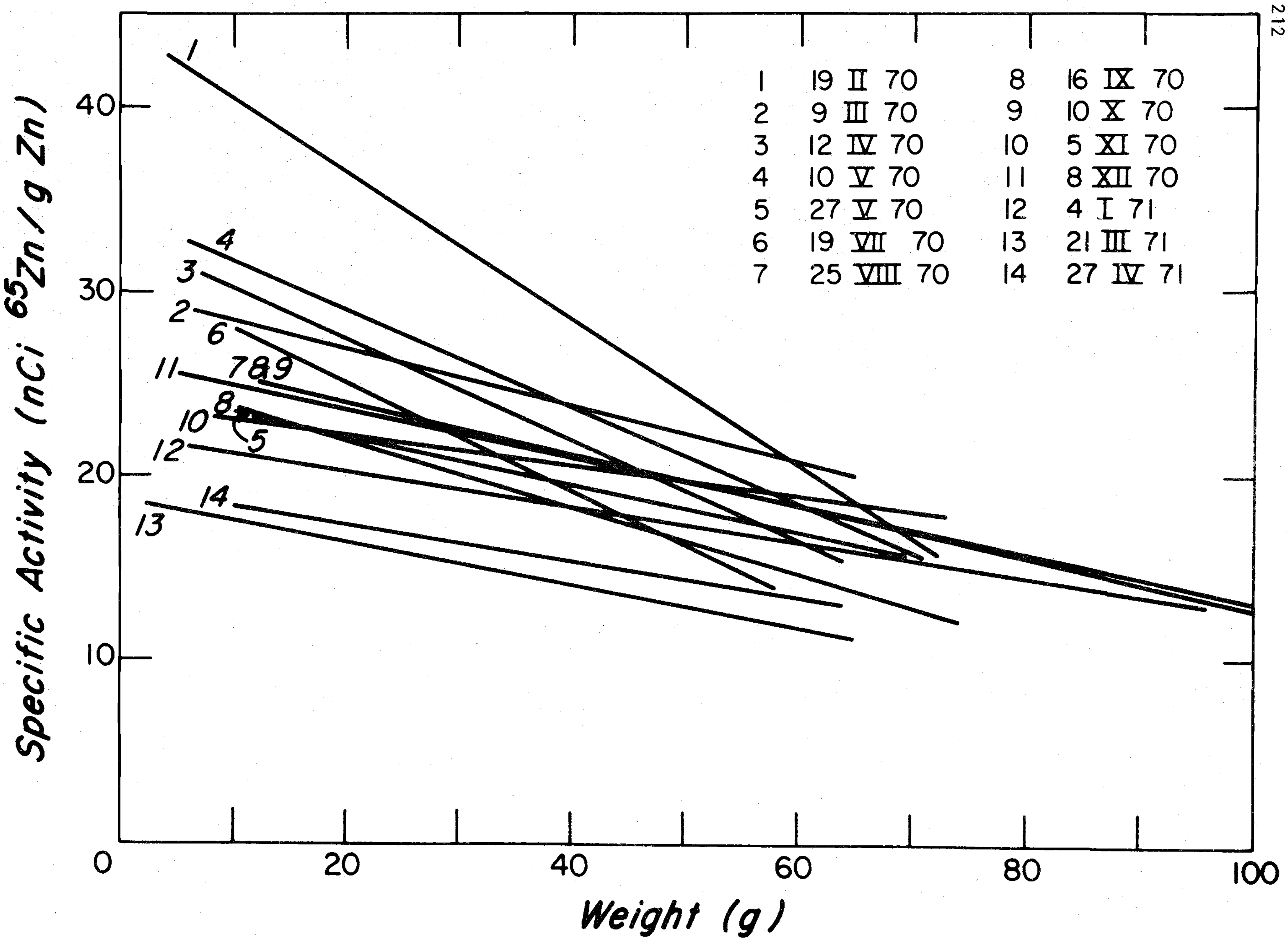

Fig. 2. Regression lines of the ^{65}Zn specific activities vs. wet weight of

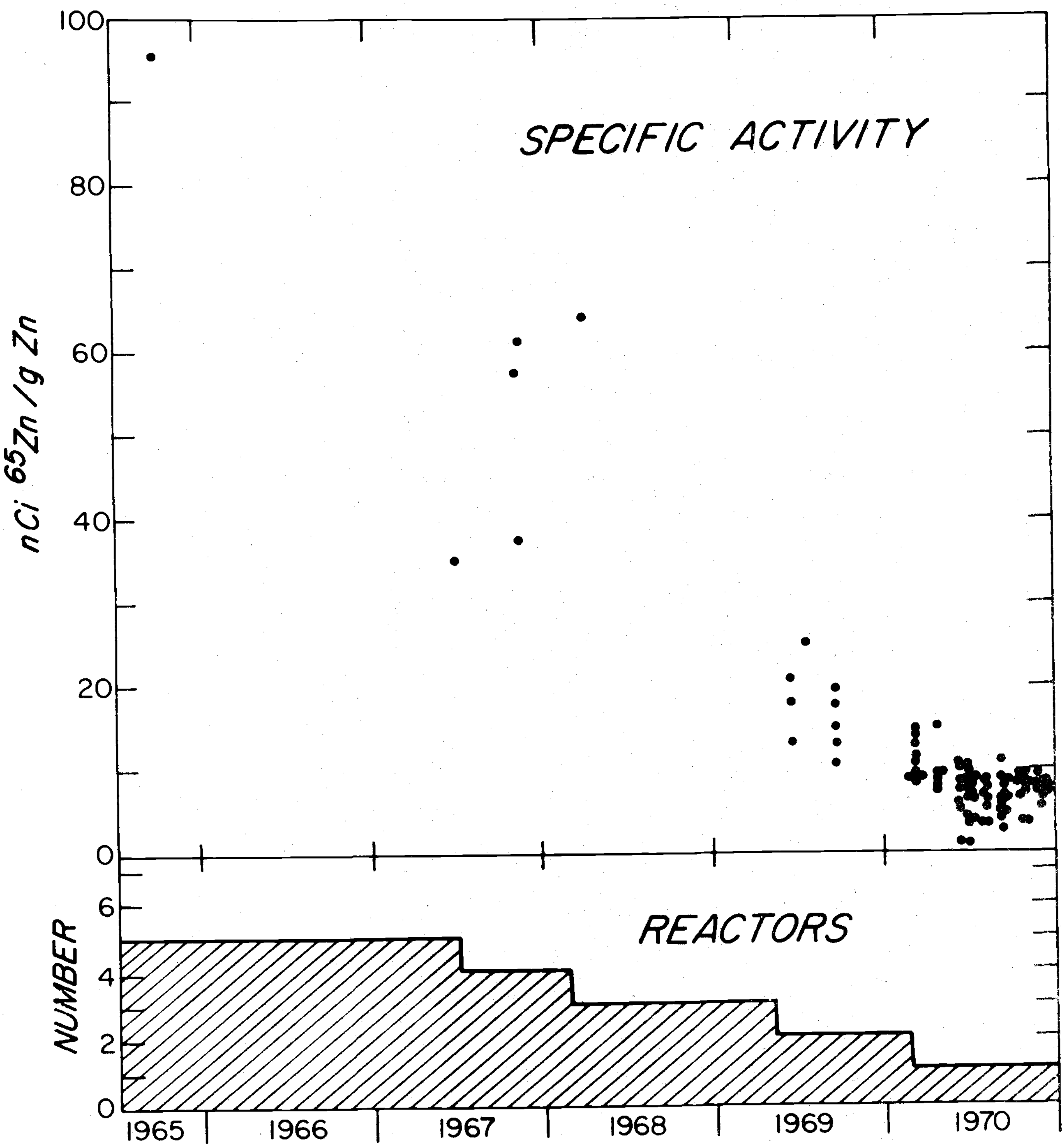

Fig. 3. Specific activity of ^{65}Zn for Microstomus pacificus collected off Central Oregon, 180-270m, 1965 to 1971. The lower figure shows the number of Hanford nuclear reactors in operation during this period.

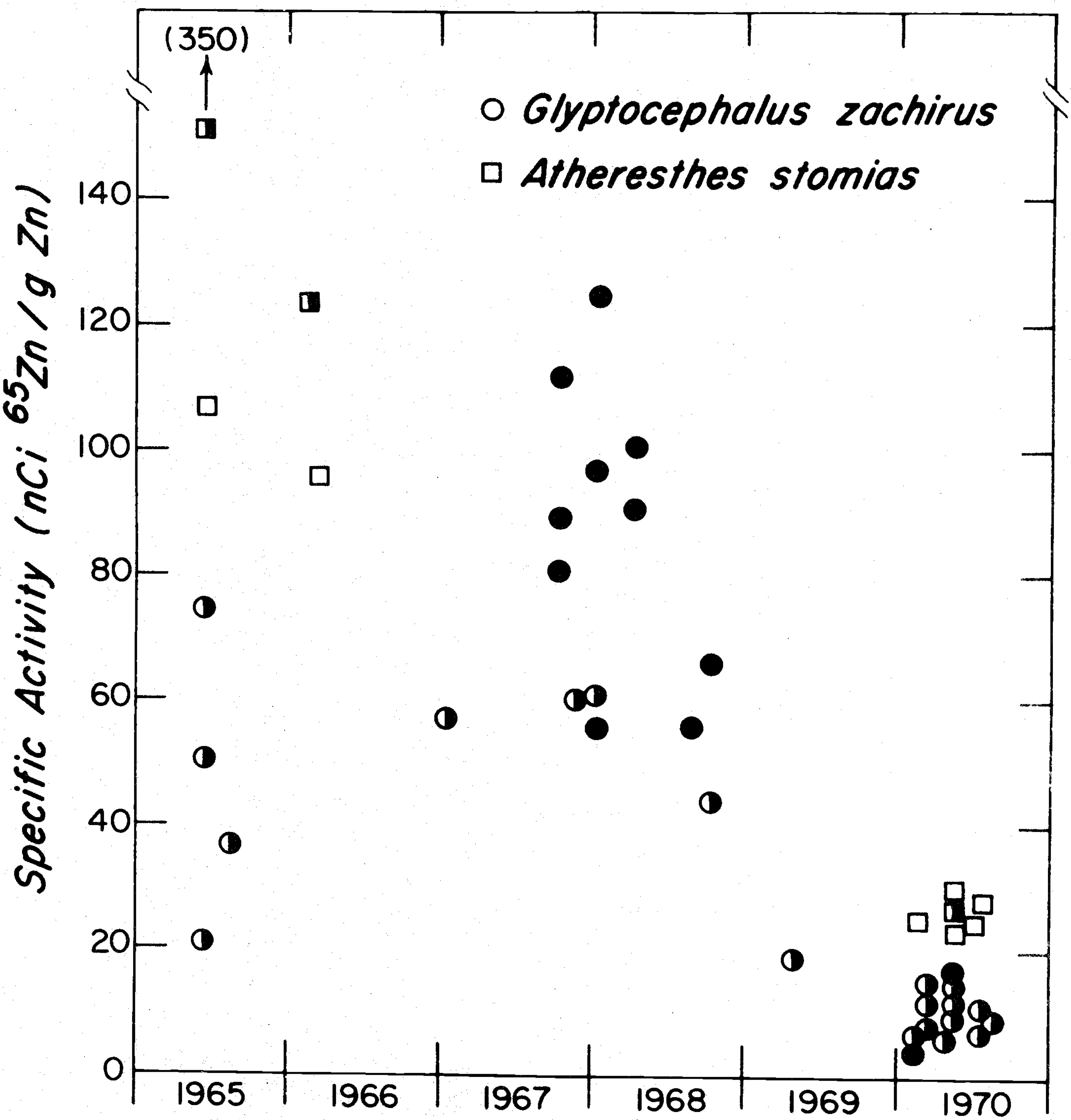

Fig. 4 Specific activity of ^{65}Zn for two flounders, 1965-1970. Solid symbols denote fish < 200 mm, half-solid symbols fish between 200 and 300 mm, and open symbols fish > 300 mm.

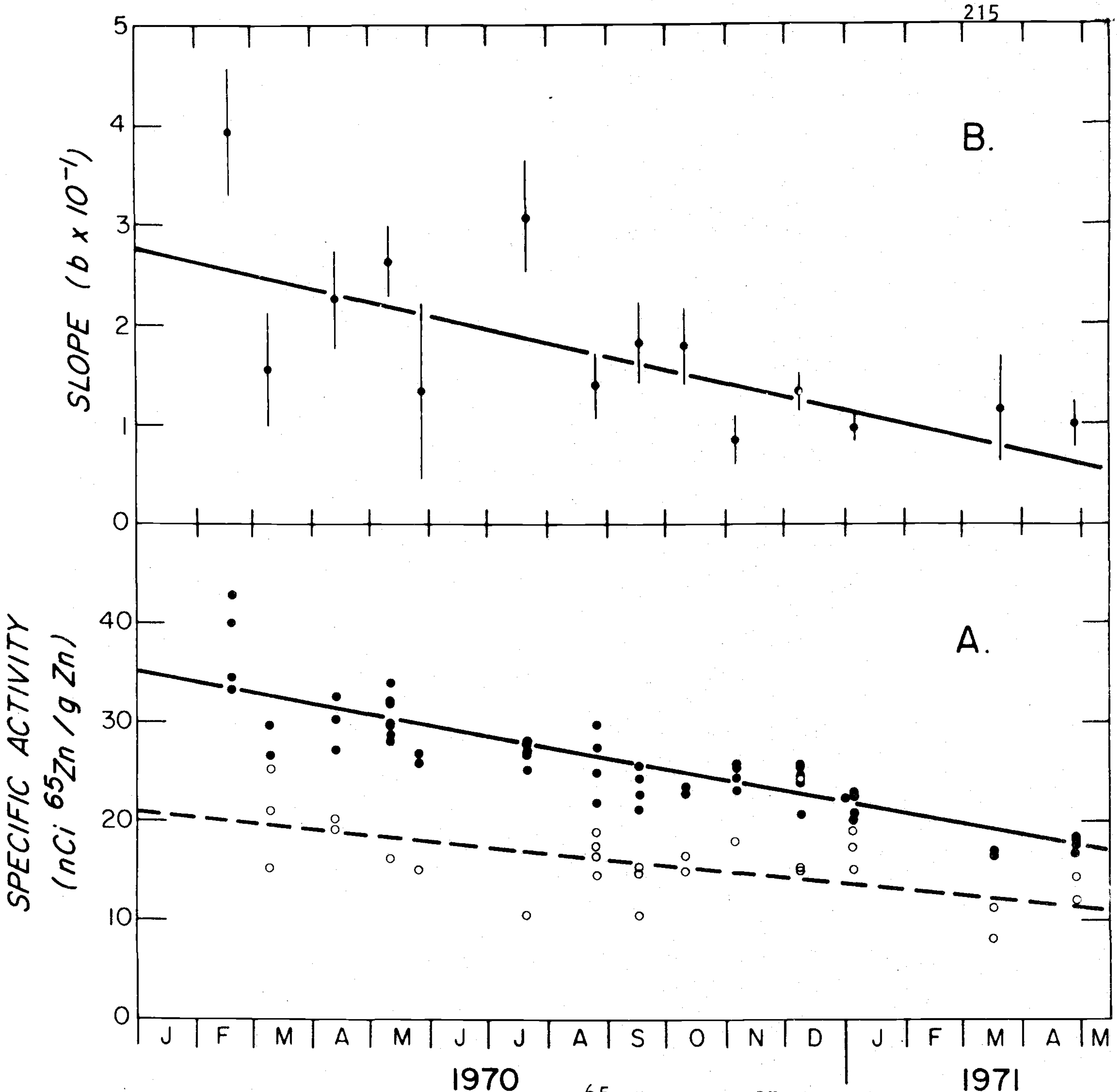

Fig. 5A (below) Specific activities of ^{65}Zn for Lyopsetta exilis during 1970 and 1971. Each point represents a sample. Lines are least squares fits to the points. Upper regression line is for fish 5-20 g wet weight; lower line for fish 45-60 g wet weight.
B. (above) The slope of the specific activity vs. weight relationships of Fig. 2 plotted for different collections during 1970 and 1971. Slopes and their standard errors are shown. For the least squares fit, each point was weighted by the inverse of its standard error.

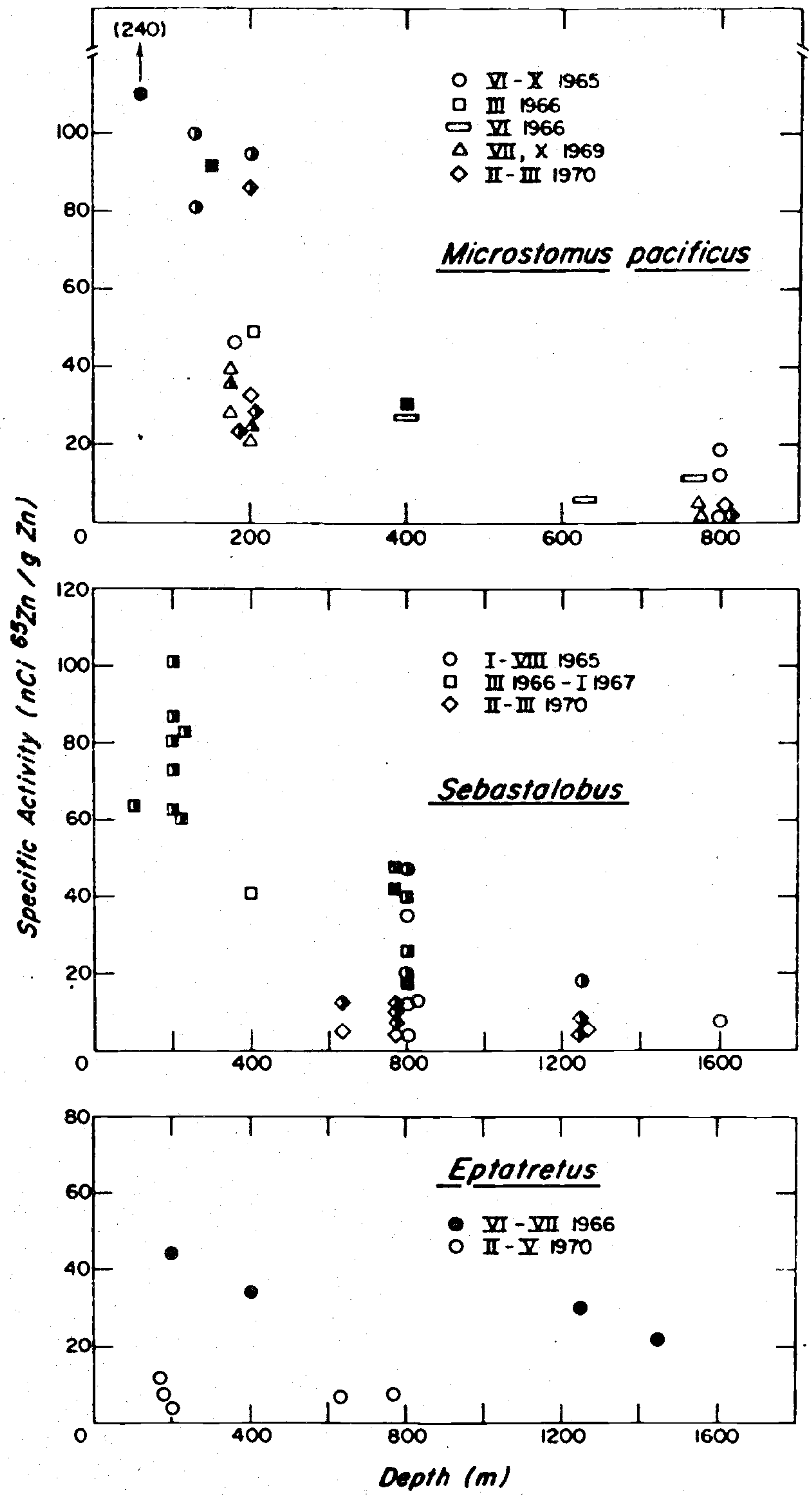

Fig. 6. Specific activity of ^{65}Zn at different depths for several benthic fishes. Symbols indicate different collection times and size of fishes. The symbols for Microstomus pacificus: solid < 200 mm, half-solid 200-300 mm, open >300 mm; for Sebastalobus spp.: solid < 100 mm, half-solid 100-200 mm, open > 200 mm; for Eptatretus spp. all individuals were between 310-510 mm.

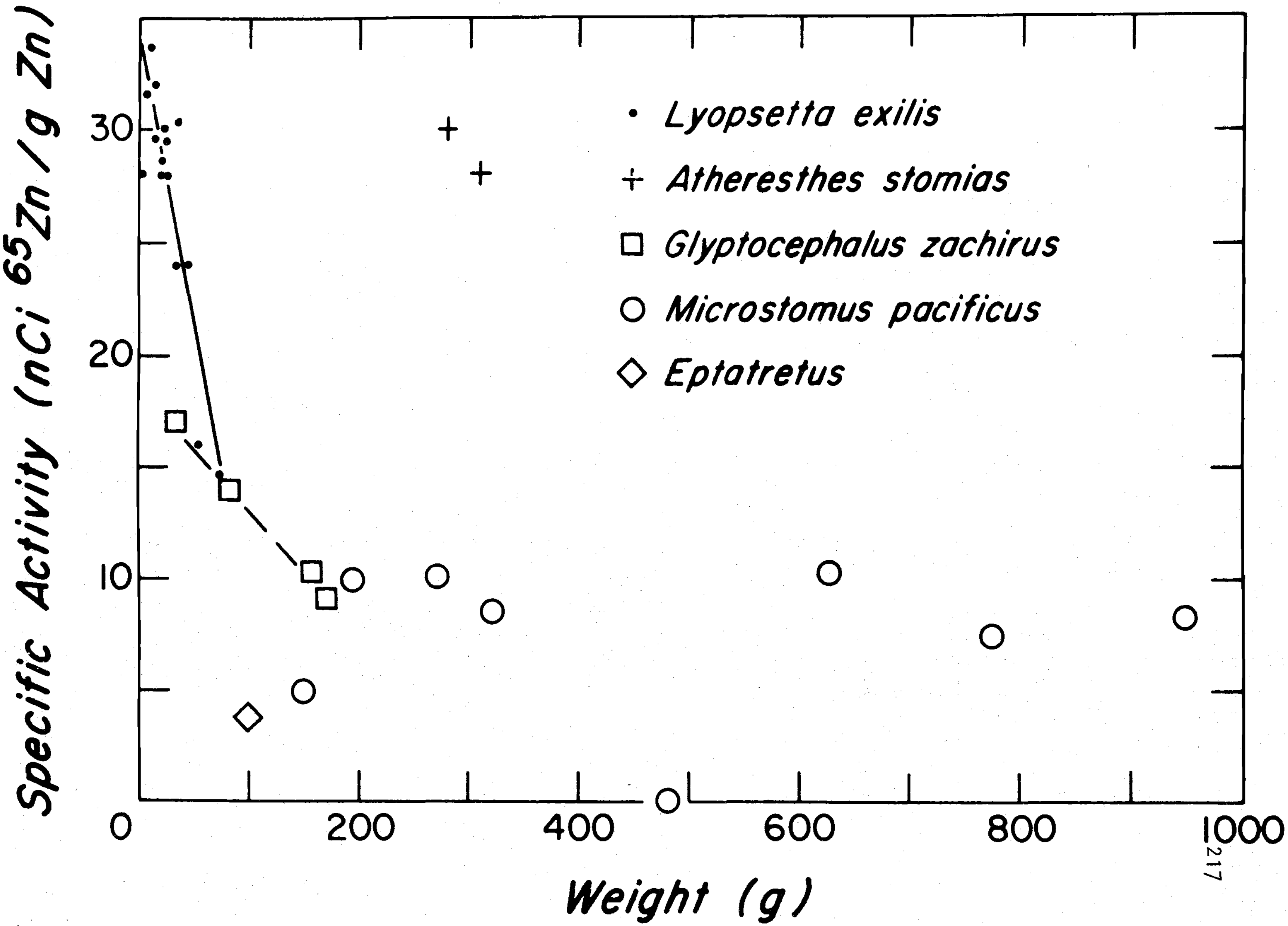

Fig. 7. Specific activity vs. wet weight of five species of benthic fishes all collected at one station on 10 May 1970. All weights less than 100 g are averages of more than one individual per sample.

EFFECTS OF OCEAN WATER ON THE SOLUBLE-SUSPENDED DISTRIBUTION OF COLUMBIA RIVER RADIONUCLIDES*

by D. W. Evans and N. H. Cutshall

REVISED ABSTRACT

The relationship of dissolved concentrations of Hanford radionuclides with salinity in the Columbia River estuary were interpreted in terms of the exchange of the radionuclides between dissolved and suspended particulate phases. Both ^{65}Zn and ^{54}Mn carried by the Columbia River were partially desorbed from suspended particulate matter upon mixing with ocean water in the estuary. Experiments in which ocean water was added to Columbia River water and to suspended particulate matter collected on filters confirmed the partial desorption of ^{65}Zn and ^{54}Mn from the particulate phase.

The percentage of ^{65}Zn and ^{54}Mn desorbed varied with experimental approach but desorption of ^{65}Zn seemed to lie in the range 15% - 45% and ^{54}Mn in the range 30%-60%.

None of the experiments revealed any effect of salinity upon the soluble-suspended particle distribution of ^{51}Cr, ^{124}Sb or ^{46}Sc. Dissolved concentrations of these nuclides varied inversely with salinity. There was no evidence that any of the radionuclides studied was removed from solution by flocculation, precipitation or adsorption as the result of mixing with ocean water.

Ocean water contact partially removed ^{54}Mn but not ^{65}Zn, ^{46}Sc or ^{60}Co from Columbia River bottom sediments transferred to the marine environment. The inability of ocean water to desorb ^{65}Zn from bottom sediment contrasts with its action with suspended particulate ^{65}Zn.

The distribution of radionuclides between dissolved and particulate phases is important in determining their modes of physical transport and biological uptake in aquatic environments. Changes in environmental conditions can alter this distribution. For radionuclides introduced into rivers, the most extreme change in conditions probably takes place where rivers enter the ocean. In estuaries major redistributions of radionuclides might occur because of gradients in salinity and chemical composition, and possibly in temperature and biological activity as well.

Laboratory studies with radioactive tracers adsorbed on a variety of artificial and natural substrates have simulated estuarine mixing. Fukai [1] and Kharkar et al. [2] reported partial desorption of several radionuclides from various substrates upon contact with sea water.

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Studies of the behavior of trace metals under more natural conditions have allowed inference of the behavior of their analogous radioisotopes. De Groot et al. [3] reported the "solubilization" from fluvial sediments of a number of heavy metals in the Rhine and Ems estuaries. Conversely, Lowman et al. [4] have noted the flocculation and precipitation of several trace elements dissolved in river water after mixing with seawater.

Conclusions about the behavior of radionuclides in estuaries appear to depend not only on the properties of the radionuclides of interest, but also on the experimental approach. We report results of some experiments aimed at detecting the exchange of some Columbia River radionuclides between suspended particulate matter and solution consequent on mixing with seawater.

The Columbia River is unique in having had, until recently, a nearly continuous input of radioactive substances at relatively high activity levels. These radionuclides were formed by neutron activation of corrosion products and dissolved trace elements in the coolant waters of Hanford plutonium production reactors. These radionuclides enter the river largely in dissolved form in coolant water [5]. During downstream flow, many radionuclides become increasingly associated with suspended matter and bottom sediments. At Vancouver, Washington, 425 km. downstream (See Fig. 1), more than 80% of ^{65}Zn, ^{60}Co, ^{46}Sc, and ^{54}Mn can be removed from river water by filtration. The radionuclides ^{51}Cr and ^{124}Sb remain largely in dissolved form (greater than 90%) although significant fractions have been deposited with bottom sediments along the intervening stretch of the river [5].

Johnson et al. [6] leached bottom sediments collected from the Columbia River with seawater. Between 16% and 74% of the associated ^{54}Mn was eluted during the nominal one hour contact periods. Less than 3% of the ^{65}Zn and negligible percentages of the ^{51}Cr and ^{46}Sc were removed. To the degree that bottom sediments represent suspended sediments, these studies simulate the behavior of radionuclides associated with suspended matter in the Columbia River estuary. The possibility of adsorptive uptake by sediments was not examined.

Radionuclide - Salinity relations in the Columbia River estuary

Dissolved and suspended particulate gamma emitting radionuclides ^{51}Cr, ^{65}Zn, ^{46}Sc, and ^{124}Sb were sampled at locations of different salinities in the Columbia River estuary. Surface water was collected at mid-channel during a three hour period, July 30, 1970, by centrifugal pump on board R/V SACAJAWEA (See Fig. 2 for locations). Duplicate 50-liter filtrate samples were obtained by pressure filtering 100 liters of water through a single 265 mm diameter, 0.45-micron pore size, membrane filter (Gelman Type GA-6) sandwiched between two glass fiber prefilters (Gelman Type E) held in a specially constructed polyvinyl chloride support structure. The filtrates were contained in 8-mil polyethylene bags supported by 70 liter plastic barrels.

Water samples for salinity determination were collected simultaneously and analyzed in the laboratory using an inductive salinometer.

Coprecipitation with $Fe(OH)_3$ was used to concentrate the dissolved radionuclides from the filtrate. Ten ml of carrier solution (0.193M $K_2Cr_2O_7$, 0.306M $ZnSO_4$ and 0.368M $MnSO_4$) was added and mixed with the filtered water. Thirty minutes was allowed for isotopic equilibration, and 25 ml of 0.7M $FeSO_4$ was added and mixed to reduce ^{51}Cr and stable chromium from the +6 to the more readily adsorbed +3 oxidation state [7]. After a second 30 minute period, 25 ml of 2M $FeCl_3$ was added and mixed. After a final 30 minute period, 25 ml of concentrated NH_4OH was added and mixed to raise the pH, precipitate $Fe(OH)_3$, and coprecipitate the radionuclides and stable carriers. One hundred ml of 0.05% Dow Separan NP10 was added and mixed to promote flocculation and settling of the precipitate. The supernatant was siphoned off, and the precipitate slurry drained of water by filtration and dried.

The dry precipitate was ground to a powder, and a 1% subsample weighed out and dissolved in 0.36N HCl for analysis of Zn and Cr by atomic absorption spectrophotometry. The efficiency of recovery of ^{51}Cr and ^{65}Zn was estimated from the recovery the stable carriers, since the amount of Cr and Zn added was known. Chromium recoveries ranged from 76% - 95% with mean 87%. Zinc recoveries ranged from 75% to 91% with mean 83%.

The remaining 99% of the precipitate was packed into a 12 ml plastic counting tube and radioanalyzed using a 5" by 5" NaI(Tl) well-crystal coupled to a Nuclear Data 512-channel analyzer. The output is a composite spectrum of the individual gamma spectra of the radionuclides present. After subtraction of background, the activities of the individual radionuclides was determined by a least squares fit of the individual spectra of radionuclide standards. Corrections for decay were made and the standard error of estimate of the activity of each radionuclide was calculated.

Filters and suspended matter were digested for three hours in 200 ml of a 1:1 mixture of concentrated HCl and concentrated HNO_3 at 100°C. After cooling, the liquid was filtered from the solid residuum. The residuum was washed three times with 0.36N HCl and the washings added to the filtered liquid. This mixture was then evaporated to dryness under a heat lamp. The resultant dry froth was ground to a powder and packed in a counting tube for radioanalysis, effecting a significant reduction in volume with greater than 95% recovery of the radionculides of interest.

The dissolved concentrations of ^{51}Cr, ^{65}Zn, ^{46}Sc, and ^{124}Sb have been plotted versus salinity in Fig. 3. Corrections for recovery efficiency have been made for ^{51}Cr and ^{65}Zn. Total recovery has been assumed for ^{46}Sc and ^{124}Sb. Particulate radionuclide concentrations are plotted in Fig. 4.

If dilution by seawater were the only cause of changes in radionuclide concentrations in the estuary, a plot of dissolved concentration versus salinity should be linear for each radionuclide. The dissolved concentrations of the radionuclides of interest are negligibly small in the undiluted seawater mixing in the estuary; therefore, such a linear plot should have a salinity intercept equal to the salinity of the mixing seawater. This salinity should be between 32.6°/oo and 33.4°/oo [8] [9]. The least squares salinity intercept and linear correlation coefficients are shown in Table I.

The concentrations of ^{124}Sb, ^{46}Sc, and ^{51}Cr have significant linear relationships with salinity at the 95% confidence level as determined by the F test using the duplicate data values to estimate pure error [10]. Both ^{124}Sb and ^{46}Sc have salinity intercepts very close to that of the mixing seawater. That of ^{51}Cr is unexpectedly high, possibly indicating changing input concentrations from the river during the mixing period of the waters in the estuary. It could not be due to desorption from suspended particles because the concentrations of this possible source are too low to account for the increase.

In contrast, ^{65}Zn does not fit the linear model. Dissolved ^{65}Zn concentration reaches a maximum at salinity, 4.98 °/oo, rather than at 0 °/oo. At salinities above 4.98 °/oo, the dissolved ^{65}Zn concentration:salinity relation is highly linear, with a correlation coefficient of 0.971 and a salinity intercept of 32.6 °/oo, suggesting that only dilution by seawater acts to change dissolved ^{65}Zn concentrations in this salinity range. The dissolved ^{65}Zn concentrations at salinity 1.12 °/oo and 2.75 °/oo are significantly less than that predicted by the linear regression curve through the data points at salinity 4.98 °/oo and above. The difference between observed and predicted values can be explained if dissolved ^{65}Zn was added between salinity 1.12 °/oo and 4.98 °/oo. The only source of this added ^{65}Zn must be ^{65}Zn associated with particulate phases. At salinity 1.12 °/oo the difference that must have been added is about 0.15 pCi/l. The suspended ^{65}Zn concentration at salinity 1.12 °/oo was 0.46 pCi/l. Therefore, about 33% (= 0.15 pCi/l divided by 0.46 pCi/l times 100%) of the suspended ^{65}Zn would have been desorbed. Nothing can be said about possible desorption at salinities less than 1.12°/oo.

The linear dilution model cannot be applied in the same way to the suspended particulate radionuclide concentrations because settling out or resuspension of particulate phases in the water column can alter the concentration of suspended radionuclides without requiring exchange with the dissolved phase.

Data collected by Hanson [11] show more dramatically the contrasting behavior of ^{51}Cr and ^{65}Zn. Water samples were collected during a 25-hour period, May 21-22, 1966, along a vertical profile from the Point Adams Coast Guard Station pier (See Fig. 2 for location). Samples were processed and analyzed much as described above with the exception that recovery efficiencies were not determined and are assumed to be 100%. The radionuclide ^{46}Sc was relatively less abundant at this time, making possible the determination of ^{54}Mn, with which it interfered. The original data reduction did not include ^{124}Sb; rather, it was later determined from the residuals.

Consequently ^{124}Sb is reported in cpm rather than pCi because counting efficiency was not known. Dissolved radionuclide concentrations are plotted versus salinity in Fig. 5. Both ^{51}Cr and ^{124}Sb show strong linear relations with salinity, with correlation coefficients of 0.936 and 0.830 respectively. The salinity intercepts were 31.7 °/oo and 38.4 °/oo respectively. The latter is higher than expected largely as a result of two outlying high salinity data points. These radionuclides appear to be conservative in the estuary, exhibiting no net exchange between soluble and particulate phases.

Neither ^{65}Zn nor ^{54}Mn shows a strong linear relation with salinity. They appear to be non-conservative; their concentrations at salinities above 5 °/oo are greater than would be predicted by simple dilution with seawater. An estimate of how much greater can be obtained by plotting the concentrations on a seawater free basis versus salinity. Measured concentrations were divided by the fraction of fresh (Columbia River) water present to obtain these adjusted concentrations (fraction freshwater equals 1 - where S is the measured salinity and 33.0 is the salinity of the mixing seawater). Dissolved concentrations plotted on this basis are shown in Fig. 6. There does not appear to be a minimum salinity above which only dilution takes place.

It appears that ^{51}Cr and ^{124}Sb are constant with salinity, whereas ^{65}Zn and ^{54}Mn tend to increase with increasing salinity. This increase results from addition of dissolved ^{65}Zn and ^{54}Mn, probably by desorption from suspended or bottom sediments. Using the mean of the adjusted concentrations of the five samples with salinities less than 1°/oo as the best estimate of the dissolved concentrations of inflowing Columbia River water, the concentration (on a seawater free basis) added by desorption at each salinity sampled can be calculated. The mean of these five samples is 2.6 pCi/l for ^{65}Zn and 0.24pCi/l for ^{54}Mn. The adjusted ^{65}Zn concentration shows a plateau in the salinity range 6°/oo to 15°/oo, with mean 4.9 pCi/l, a difference of 2.3 pCi/l from the inflowing concentration. Adjusted concentrations at salinities greater than 20°/oo have mean 12.6 pCi/l, a difference of 10.0 pCi/l.

If these differences were supplied by desorption from incoming suspended particulate ^{65}Zn, knowledge of the concentration of the latter would permit calculation of the percentage desorption. Using the mean adjusted suspended ^{65}Zn concentrations at salinities less than 1°/oo, (12.7 pCi/l), to represent this, one finds 19% desorption (2.3/12.7 times 100%) in the salinity range 6°/oo to 15°/oo and an average of 79% desorption (10/12.7 times 100%) at salinities greater than 20 °/oo. While only little ^{65}Zn has been found to be desorbed from bottom sediments [6], diffusion from the large reservoir of ^{65}Zn in bottom sediments in the estuary and desorption from resuspended bottom sediments might serve as partial sources of the observed difference. This is probably most important in the near bottom (high salinity) water samples. Therefore, 79% is probably an inflated estimate of the desorption of ^{65}Zn from incoming suspended matter.

Desorption from bottom sediments, either in place or temporarily resuspended, must contribute to the increase in dissolved ^{54}Mn found at higher salinities. The difference between the adjusted mean dissolved ^{54}Mn concentration of samples with salinity greater than 20°/₀₀ and the estimated adjusted input concentration is 1.22 pCi/l (= 1.46 - 0.24). The incoming adjusted suspended particulate concentration is 0.74pCi/l. The percentage desorbed would have been 165%, obviously impossible.

An experimental approach which eliminates the ambiguity in the contribution of the sources to the increase in dissolved radionuclide concentrations is desirable.

Seawater Mixing Experiments

Estuarine mixing was simulated by mixing seawater with Columbia River water in large containers. Seawater and river water were mixed in equal volumes, resulting in a final mixed salinity of about 16°/₀₀. A practical upper limit for experimental contact times is set by the need to minimize chemical and biological reactions on the container surfaces. This sets an upper limit of several days, after which periphytic biological uptake or sorption of radionuclides on the container walls would probably be important. This seems sufficient to allow for ion exchange reactions [12] or flocculation reactions [13] to take place as they operate on the time scale of minutes or hours.

The first mixing experiments were made with Columbia River water collected October 31, 1969 from behind McNary Dam (see Fig. 1) 125 km. downstream from the Hanford reactors. Fifty liters of river water were transported to Corvallis in polypropylene carboys. Twenty-five liters were added without filtration to twenty-five liters of filtered seawater (salinity about 32 °/₀₀).* The remaining twenty-five liters was left unmixed as a control. After four hours, the mixed and control samples were filtered and the soluble and particulate fractions analyzed for gamma emitting radionuclides. The analytical procedure was as described above except that no stable carriers were added to the filtrates, and the recovery of the dissolved radionuclides was assumed to be complete. The results are shown in Table II.

There was no significant difference in the distribution of ^{51}Cr and ^{46}Sc between the seawater mixed and control samples. ^{51}Cr remains mostly dissolved (about 95%) while ^{46}Sc remains mostly particulate (about 75%). In contrast to this conservative behavior, ^{65}Zn is relatively more soluble in the seawater mixed sample (68%) than in the control sample (43%). This suggests that contact with seawater has caused the release of a significant

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* In this and all other samples of seawater used in the mixing experiments negligible concentrations of the radionuclides of interest were found.

fraction of the particulate associated ^{65}Zn. The fraction of the ^{65}Zn desorbed can be calculated: fraction "desorbed" = (57% - 32%)/57% = 0.44.

Counting errors make the apparent 25% desorption of ^{54}Mn insignificant at the 95% confidence level, as determined by a t-test.

A second mixing experiment of this type was performed in the field on July 30, 1970. Surface water was pumped from the Columbia River in the main channel, opposite Harrington Point (See Fig. 2) and upstream of the limit of intrusion of salt water into the estuary. Duplicate samples of fifty liters each were filtered and mixed with an equal volume of filtered seawater in 55 gallon barrels lined with polyethylene bags. Duplicate samples of unfiltered water were similarly mixed with filtered seawater. Duplicate control samples of unfiltered river water were collected but not mixed with seawater. All samples were allowed to stand for 24 hours reaction time and then filtered. Analysis for the radionuclides present in each phase was as before; stable carriers of zinc, chromium, and manganese were added this time. The radionuclides ^{65}Zn, ^{51}Cr, ^{46}Sc, and ^{124}Sb were in quantitatively measurable concentrations.

The mixing of filtered river water with filtered seawater was designed to test the possibility of flocculation or precipitation from solution of radionuclides in the Columbia River estuary. Because both river water and seawater samples had been filtered prior to mixing, the detection of any radionuclides on filters after subsequent filtration could be attributed to the formation of new particulate phases.

No significant concentrations of any radionuclide were found on the filters after this second filtration, indicating the absence of flocculation or precipitation. It was felt, however, that the centrifugal pump used to force the samples through the filters might have broken apart flocculant aggregates, allowing them to pass through the filters and thus go undetected. Therefore, this experiment was repeated with samples collected August 26, 1971 using air pressure (3 atm) to force the water sample through the filters. Again, no significant activity was found on the filters, confirming the earlier result.

The mixing of unfiltered river water samples with filtered seawater had the same goal as the earlier mixing experiment of October 31, 1969. The results are shown in Table III.

There was little change in the distribution of ^{51}Cr, ^{46}Sc, and ^{124}Sb between the soluble and particulate phases when compared to the control. These radionuclides would appear to be conservative.

In contrast, ^{65}Zn was markedly more soluble in the mixed system (54%) than in the control (17%). It would appear that about 45% of the ^{65}Zn associated with the particulate phase was transferred to solution. This conclusion is clouded by the lack of a constant total of ^{65}Zn activity among the systems. The lower total ^{65}Zn activity of the control could be due to sorption of soluble ^{65}Zn on the polyethylene container surface, thus biasing the result to indicate an apparent "desorption" from particles.

Seawater Leaching of Suspended Matter:

Seawater leaching of Columbia River suspended matter separated from river water allows a more sensitive determination of the percentage desorption of the radionculides. Suspended matter collected on filters as before was placed in one liter polyethylene containers to which 0.5-liter of filtered seawater was added. The seawater was filtered from individual sample containers after progressively longer contact times. The solutions were evaporated to dryness, and the sea salts packed in counting tubes for analysis. The leached suspended matter and accompanying filters were digested and analyzed as before. Table IV shows the percentage of the total activity of individual radionuclides found in the seawater fraction for samples collected July 30, 1970 and a single sample collected January 6, 1970. Included are uncertainty estimates calculated from the one standard error counting errors.

Again ^{65}Zn and ^{54}Mn contrast with ^{51}Cr and ^{46}Sc. No significant ^{65}Zn was desorbed. It is of interest that very little ^{65}Zn was desorbed within four hours contact time, suggesting that ion exchange, which is rapid, is not the cause of ^{65}Zn desorption. An odor of decay in the one and three week samples suggests the possible role of microbial degradation.

Seawater Leaching of Bottom Sediments

The observed desorption of ^{65}Zn from suspended sediments stands in contrast to the results of Johnson et al. [6] who found little desorption of ^{65}Zn from bottom sediments in the Columbia River. One possible explanation for these differences might be that the one hour seawater contact time used was too short.

To determine if longer contact times might result in increased desorption of ^{65}Zn from bottom sediments, samples of bottom sediments (silty-sand) were collected from behind McNary Dam and transferred to Yaquina Bay. About five kilograms of sediment were placed in a plastic basin to a depth of about 8 cm, covered with a plastic screen to exclude larger organisms, and suspended in the water column from the OSU Marine Science Center dock. Sediment was also sealed in 25 cm lengths of dialysis tubing and submerged along with the sediments in the plastic basin. Samples were recovered at intervals over an eleven-week period, dried, weighed, packed into counting tubes, and radioanalyzed. Salinity of the bay water was determined from surface samples collected on days 12 and 26; it was 33.7 ‰ and 31.5 ‰ respectively.

Table V shows the results of these analyses, corrected for decay to the date of submersion. ^{65}Zn and all other radionuclides except ^{54}Mn remained essentially unchanged in concentration. About half of the ^{54}Mn was lost by the eleventh week, confirming the results of Johnson et al. [7]. It appears that the reaction with seawater differs for suspended sediment and bottom sediment, at least for ^{65}Zn.

Summary and Conclusions

1. The radionuclides ^{65}Zn and ^{54}Mn in the Columbia River are partially desorbed from suspended particulate matter during estuarine mixing. The calculated estimates of percentage suspended ^{54}Mn and ^{65}Zn desorbed varied over a wide range. This is probably the result of analytical uncertainties, the experimental procedures used, and temporal variations in the chemical and biological character of seawater and Columbia River water. The percentage desorption of ^{65}Zn is in the range 15% to 45% while that of ^{54}Mn is higher, 30% to 60%.

2. There was no evidence of desorption of ^{51}Cr, ^{46}Sc, and ^{124}Sb.

3. None of the above radionuclides showed any evidence of removal from solution as the result of flocculation, precipitation, or absorption consequent on mixing with seawater within the estuary.

4. Desorption of ^{65}Zn from suspended particles by seawater is greater than desorption of ^{65}Zn from riverbed sediments.

The differing behavior of the radionuclides studied may be related to their ionic states in solution in the Columbia River. Nelson _et al_. [14]

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Figure 1. The Columbia River from Hanford to the Pacific Ocean.

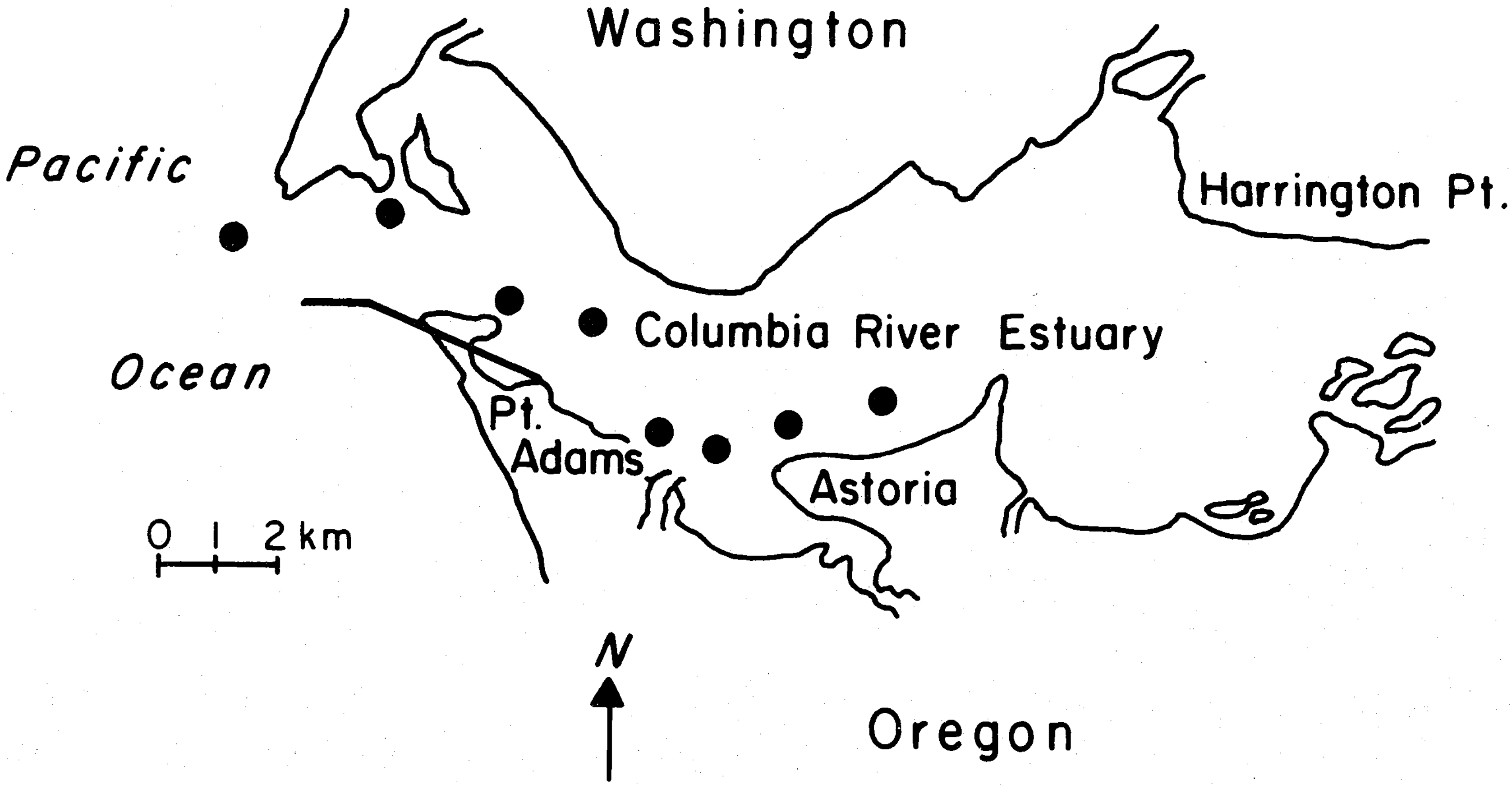

Figure 2. The Columbia River estuary showing sampling locations, July 30, 1970.

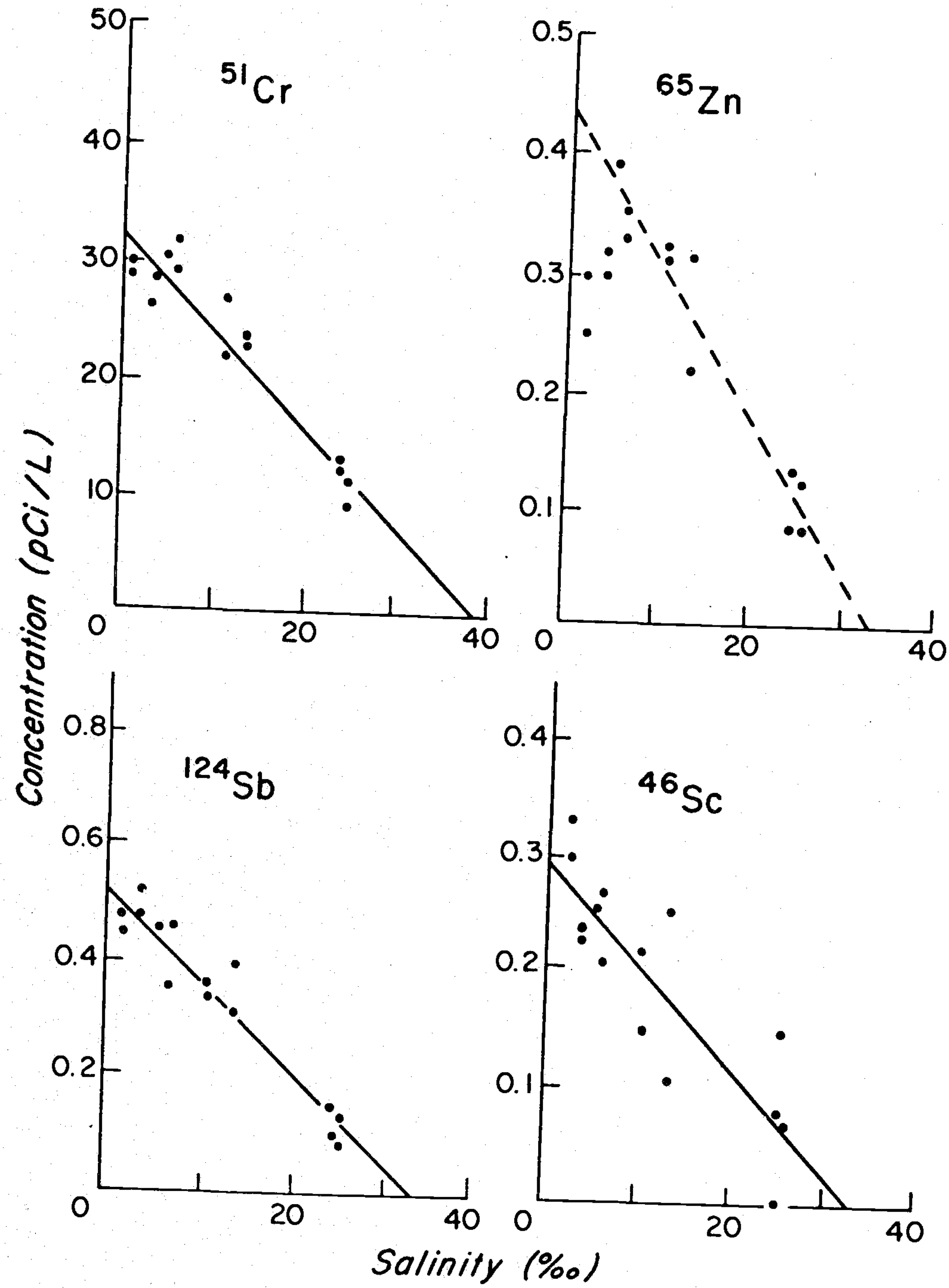

Figure 3. Concentrations of dissolved radionuclides in the Columbia River estuary, July 30, 1970. Solid lines represent least squares fit to all data points. Dashed line is least squares fit to data points at salinities 4.98‰ and above only.

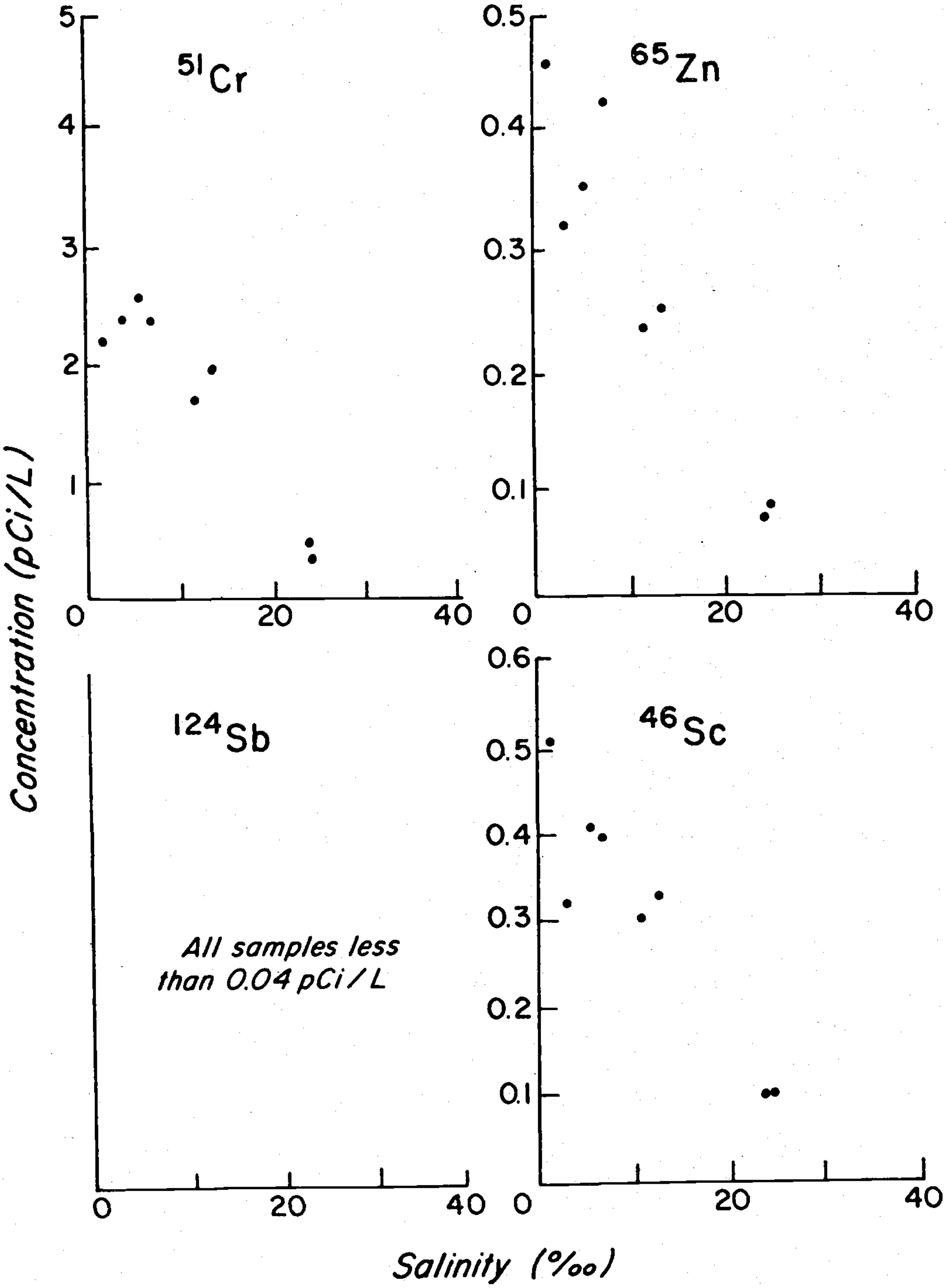

Figure 4. Concentrations of suspended particulate radionuclides in the Columbia River estuary, July 30, 1970.

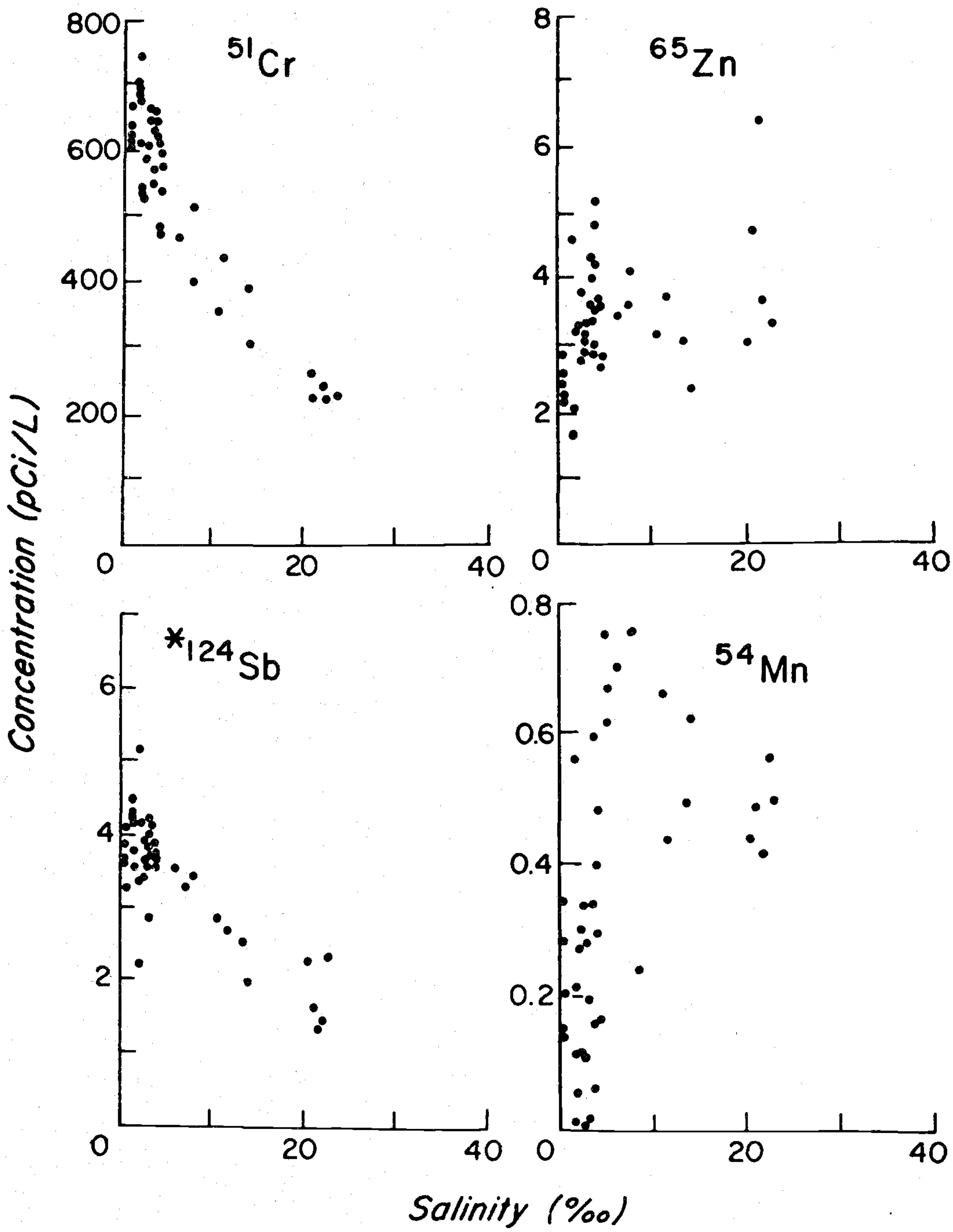

Figure 5. Concentrations of dissolved radionuclides at Point Adams Coast Guard Station, May 21-22, 1966. *^{124}Sb is reported in units of cpm/L.

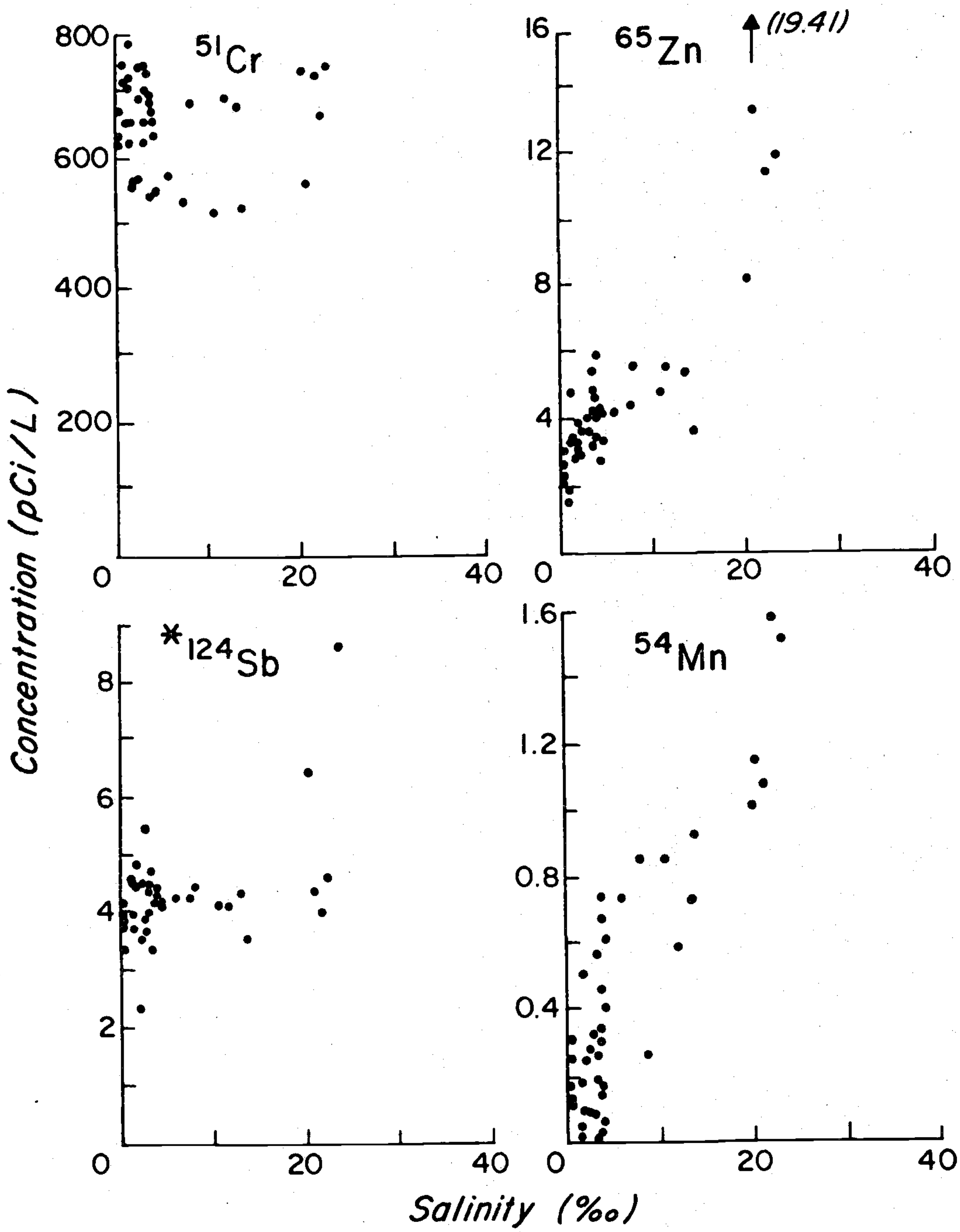

Figure 6. Concentrations of dissolved radionuclides, on a seawater free basis, at Point Adams Coast Guard Station, May 21-22, 1966. *^{124}Sb is reported in units of cpm/L.

Calcium - Magnesium Ratios in the Test Plates of *Allocentrotus fragilis*

by James L. Sumich and James E. McCauley

ABSTRACT

Calcium - Magnesium ratios in test plates of the sea urchin *Allocentrotus fragilis* (Jackson) are age dependent and not temperature dependent.

The skeletal material of echinoderms is composed primarily of $CaCO_3$ with lesser amounts (usually less than 15%) of $MgCO_3$. The variation of the Mg concentration in echinoderm skeletons has been studied for over a half century, yet the underlying causes of these variations are still not understood. In a recent review, Dodd (1967) listed six factors which he believed to be important in determining the skeletal Mg composition of marine organisms: 1) the amount of Mg relative to Ca in sea water and in body fluids, 2) spatial isolation of the calcification site from sea water, 3) taxonomic level of the organism, 4) ontogeny of the organism, 5) growth rate of the organism, and 6) other environmental factors such as water temperature and salinity. The difficulty in obtaining complete and precise information concerning some or all of these conditions at the time and site of collection has been the major drawback of previous studies of skeletal Mg.

To minimize or eliminate some of these variables, the skeletal Mg content of a single species of echinoid, *Allocentrotus fragilis* (Jackson), was studied. This species has a narrow temperature range and its age can be determined accurately. It occurs along the Pacific Coast of North America in depths of 50 to 1260 m, spanning a temperature range of 10.5C to 3.5C. Seasonal temperature fluctuations are small, less than 2°C at 200m, and almost non-existent below 400m. These temperatures have been inferred from hydrographic data of the Oregon State University Department of Oceanography and verified by direct measurements by Dr. A.G. Carey, Jr. (unpublished).

We recently reported a simple age determination method for *A. fragilis*, using visible growth zones in test plates (Sumich and McCauley, *mss.*). Growth rates at 800 and 1260 m were noticeably less than at 200m. Clarke (1911) and Clarke and Wheeler (1917) were the first to report a positive correlation between the Mg concentration of echinoderm calcite and environmental water temperature. In 1922, Clarke and Wheeler demonstrated a relationship between skeletal composition (especially Mg concentration) and the taxonomy of certain invertebrate groups. Eighty-two echinoderms were analyzed, of which only 14 were echinoids. Chave (1954) reviewed the literature on magnesium in calcareous marine organisms.

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Pilkey and Hower (1960) studied the intraspecific variation of skeletal Mg in Dendraster excentricus (Eschscholtz), a Pacific Coast sand dollar. Again, a direct correlation between water temperature and skeletal Mg concentration was found. At least for D. excentricus, the variation of skeletal Mg concentration was much less at the intraspecific level than at the interspecific or class level.

Variations of echinoderm skeletal Mg concentration have been reported at many levels of systematic organization. They have been shown to exist within a single skeletal unit (tooth), between different skeletal parts of the same specimen, and between homologous skeletal components of different echinoid species from the same marine community (Raup, 1966; Weber, 1969).

Raup (1966) confirmed the correlation between skeletal Mg concentration and environmental water temperature, but stressed that the large variations observed could not be explained by water temperature fluctuations alone. The skeletal Mg variation between different parts of an individual is often as great as the class-level variations attributed by other workers to temperature effects.

Allocentrotus fragilis was collected from depths of 200, 800, and 1260 m. The tests were cleaned, then dissolved in 5% HCl. The Mg concentrations were determined using atomic absorption spectrophotometry (Perkin-Elmer Corp., 1968). Perivisceral fluids of specimens from 200 and 800m were frozen at the time of collection and later analyzed for Ca and Mg. Perivisceral fluids of specimens from 1260 m were not available. The skeletal $MgCO_3$ content of one trawl collection of A. fragilis from each depth is shown in Table 1.

No correlation between the skeletal Mg content and environmental water temperature is apparent from the data presented in Table 1. However, when the skeletal Mg values of A. fragilis at each depth are plotted against the urchin's age, a definite trend develops (Fig. 1). The regression lines of skeletal Mg content for each depth indicate that either the amount of Mg incorporated into newly formed skeletal calcite decreases as the urchins grow older; or that Ca ions gradually replace Mg ions after the calcite is formed. If the former were true, older skeletal test plates near the peristome (Sumich and McCauley mss.) should contain more Mg than the newer plates which are near the apical area. However, if Ca was gradually substituted for Mg in the calcite lattice, older plates should contain equal or lesser amounts of Mg than younger plates.

That older A. fragilis incorporate less Mg into the new skeletal calcite was shown by a series of Mg determinations along the length of complete interambulacral test plate columns (Table 2). Test plates of a 66mm specimen (6 years old) from 200m and of a 27mm specimen (2 years old) from 1260 were used.

A definite decrease in Mg content from the oldest to the newest plates in conjunction with data shown in Figure 1 indicates that, as A. fragilis ages and the growth rate decreases, less Mg is incorporated into the skeletal material being formed. Dodd (1967) and Weber (1969) have shown that echinoids

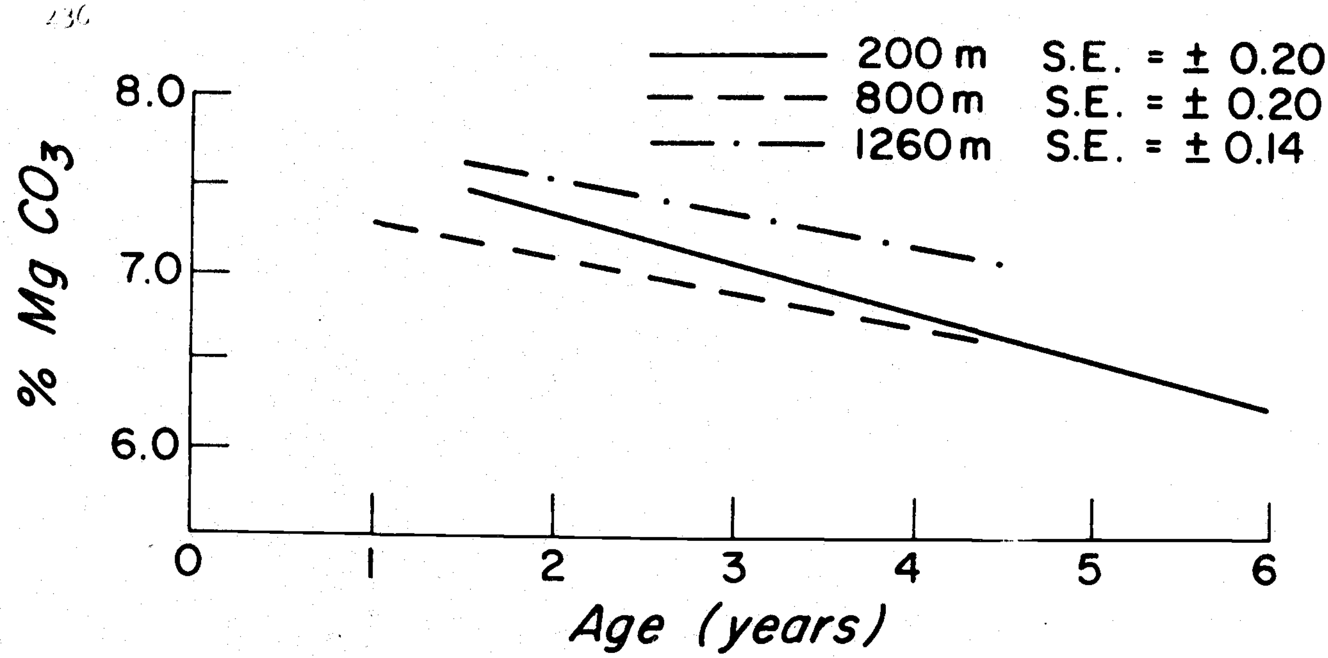

Fig. 1. Variation of A. fragilis skeletal $MgCO_3$ with age at 200, 800, and 1260 m depths.

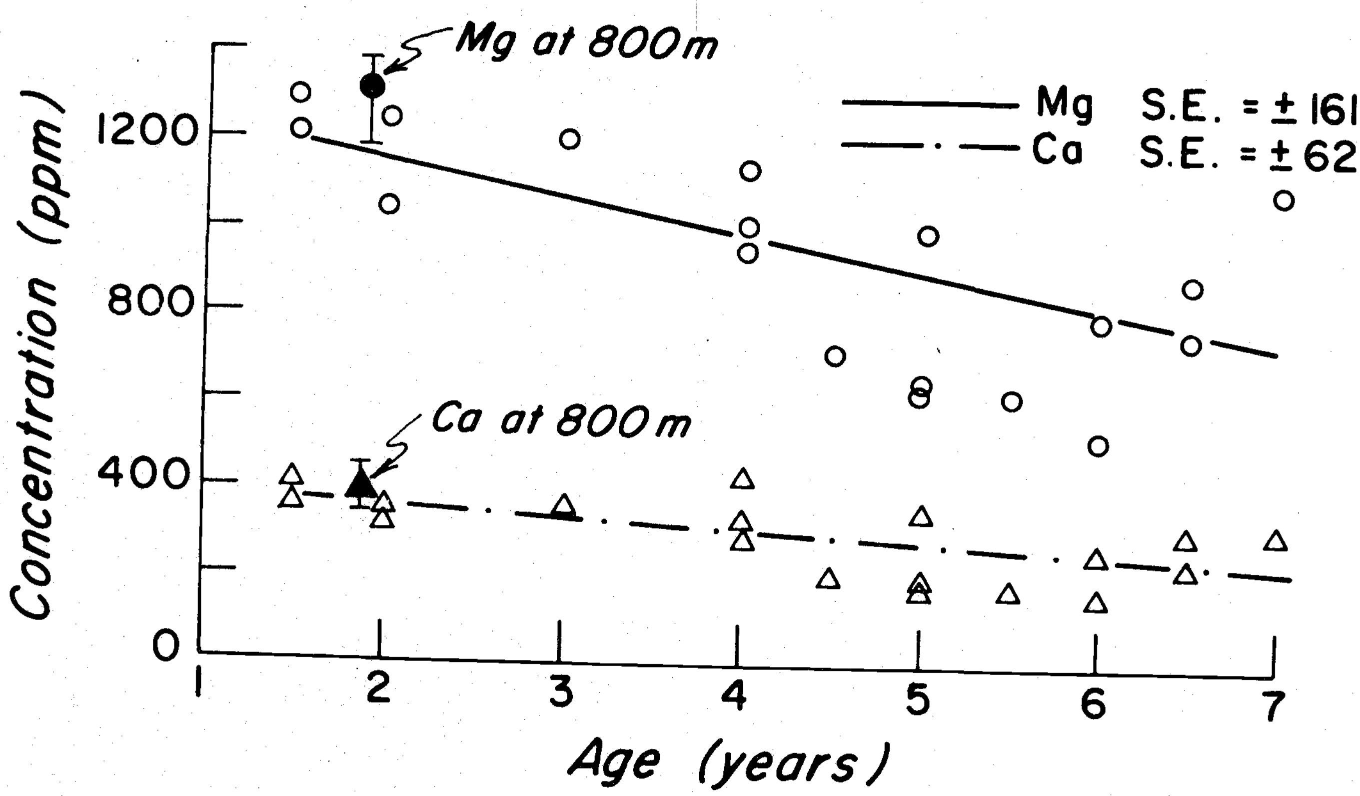

Fig. 2. Mg and Ca concentrations in perivisceral fluids of A. fragilis from 200m. Mean values and ranges of Ca and Mg at 800 m are also shown.

with slower growth rates generally have smaller amounts of skeletal Mg. Weber (1969) proposed that Mg is incorporated into the calcite lattice by random substitution for Ca at the site of calcification. The Mg ion, however, is less stable than the Ca ion in the crystal lattice. Thus, in slowly forming calcite (viz., slowly growing urchins) more Mg may be excluded from the calcification site by the more stable Ca ion prior to actual calcite formation. Conversely, in rapidly forming calcite more Mg may be incorporated into the calcite lattice.

Preliminary Mg and Ca analyses of the perivisceral fluids of A. fragilis suggest an additional mechanism for the formation of high Mg calcites in younger urchins. The Mg and Ca concentrations in the perivisceral fluids of 18 A. fragilis from 200m exhibit a negative correlation with the urchin's age (fig. 2). Analyses of the perivisceral fluids of 15 A. fragilis from 800m were also made. However, all these urchins were young and near the same age (2 years old). The range of perivisceral fluid Mg and Ca concentrations from 800m are also shown in Figure 2. These values are only slightly greater than the Mg and Ca values of A. fragilis of the same age from 200m. The Mg and Ca concentrations in the body fluids of the youngest urchins were very similar to values reported by Sverdrup, Johnson, and Fleming, 1942, for sea water (1278 ppm and 400 ppm, respectively). The greater Mg concentration in the perivisceral fluids of young urchins may, in part, account for the high Mg concentrations found in the test plates of these urchins. Although echinoids are known to vary the Ca content of their perivisceral fluids by over 50% with respect to sea water (Binyon, 1966), no mechanisms have been proposed to explain age variations of Mg and Ca in the perivisceral fluids of A. fragilis.

The deposition of magnesium in the calcite of the regular sea urchin, Allocentrotus fragilis, is age dependent rather than temperature dependent.

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A REPORT TO THE OCEANOGRAPHER OF THE NAVY

by Andrew G. Carey, Jr.[1], Danil R. Hancock[1] and Roger R. Paul[1]

ABSTRACT

Ten quantitative beam trawl samples and twenty-three Smith-McIntyre 0.1 m^2 grab samples were collected from five stations near the Deep-Water Dump Site G in the Northeast Pacific Ocean. The research is a portion of an ecological survey conducted by the U. S. Navy during September 1971. Macro-epifaunal and macro-infaunal organisms were identified. Numerical abundance/m^2 and biomass (grams wet preserved weight)/m^2 were determined. This report presents and summarizes these data.

The dump site lies at the base of the continental slope on northern Cascadia Abyssal Plain 95 nautical miles west of the Straits of Juan de Fuca. It is an area previously not sampled for benthic organisms and consequently a number of them may be unknown.

The beam trawl was found to be sensitive enough to detect major changes in the benthic environment. Station 5 was found to have a different faunal composition than the other stations sampled; it was not located along the depth contour originally designated. The average numerical abundance of the macro-infauna ranged from 74/m^2 to 128/m^2 while the highest values occurred at Station 1. The biomass of the macro-infauna reflected little difference between stations. Based on ranges, the between-sample variations were as large or larger than the between-station variations. The macro-epifauna was more diverse in terms of number of species present than the macro-infauna. Total biomass of macro-epifauna was higher at stations near the dump site (Stations 1,2). Several suggestions as to possible reasons for this are discussed. However, because no pre-site investigation of the area prior to dumping was undertaken, we do not know previous conditions or natural variations for the organisms for this region, therefore no definite conclusions as to the effects of the disposal of munitions ships on the benthic communities can be made.

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CHAPTERS IN
THE COLUMBIA RIVER AND ADJACENT OCEAN WATERS

OSU authors have contributed substantially to the recently published, AEC-sponsored book The Columbia River and Adjacent Ocean Waters. Fifteen chapters comprising 315 pages of the book involve OSU authors. Because of the total quantity of material, we have not reproduced each chapter here. Titles and abstracts are included below. The degree to which each chapter was supported by our AEC contract varies widely. For example, Chapter 2 was supported only during the drafting of the manuscript while the work discussed in Chapter 30 was entirely supported by AEC and is still continuing.

CHAPTER 2 RLO-1750-40

PHYSICAL ASPECTS OF THE COLUMBIA RIVER AND ITS ESTUARY

Victor T. Neal

ABSTRACT

The Columbia River drops from an elevation of over 2600 ft to below sea level (near Bonneville Dam) on its 1210-mile course to the Pacific Ocean from its headwaters in Canada. The combined drainage area of the Columbia and its tributaries is about 1/4 million square miles. Flow of the Columbia is affected by precipitation, runoff, and dams. Precipitation is highest in winter, but flow is highest during the period May through July owing to melting snows in the high headwaters. Estimated average flows for the period prior to construction of the series of dams on the Columbia River were 660,000 cu ft/sec from May through July and 70,000 cu ft/sec from September through March. Completion of the scheduled 13 dams on the main stream of the Columbia and over 100 dams on its tributaries will provide for controlling future flows within a range of about 150,000 to 600,000 cu ft/sec. For purposes of this study, the Columbia River estuary was considered as that part of the river that is subjected to salinity intrusion, namely, from the mouth to 1 or 2 miles above Harrington Point, or a total distance of about 23 miles from the ocean. Factors affecting the estuary which were considered here included geomorphology and influences of tides on water level and salinity. Salinities, river flow, and tidal data were used according to four different methods to calculate flushing times and probable distributions of pollutants in the estuary.

CHAPTER 5 RLO-1750-41

CHEMICAL BUDGET OF THE COLUMBIA RIVER

P. Kilho Park, Charles L. Osterberg, William O. Forster

ABSTRACT

The average annual chemical inputs from the Columbia River into the Pacific Ocean during 1966 and 1967 are 2.1×10^{14} liters of water, 10^8 moles of phosphate, 2.6×10^9 moles of nitrate, 3.4×10^{10} moles of silicate, 2.2×10^{11} equivalents of alkalinity, 2.2×10^{11} moles of total carbon dioxide, and 1.6×10^9 liters of oxygen.

CHAPTER 9

RLO-1750-51

EFFECTS OF COLUMBIA RIVER DISCHARGE ON CHLOROPHYLL a AND LIGHT ATTENUATION IN THE SEA

Lawrence F. Small, Herbert Curl, Jr.

ABSTRACT

The effects of Columbia River discharge on chlorophyll *a* concentration and light attenuation in the sea off Oregon were examined in relation to effects of upwelling, coastal runoff other than that from the Columbia River, and oceanic water.

Chlorophyll a concentration and light attenuation within about 45 miles of the Columbia River mouth are statistically different than they are in other areas off Oregon in spring and summer, and possibly in winter though not enough data were available for analysis. Nutrient depletion with increasing distance from the Columbia mouth is probably the major factor controlling chlorophyll concentration. Although the Columbia River plume extends southward off Oregon in summer, there are large inshore-offshore chlorophyll and light-extinction gradients at right angles to the plume axis. These gradients mask any possible differences created solely by water from the Columbia beyond 45 miles from the river mouth. Nutrient-rich water upwelled along the coast is largely responsible for the inshore-offshore gradients.

Mean chlorophyll *a* and mean light-extinction values in Columbia River discharge, from data combined for all seasons and distances from shore, were predicted well by an equation developed by Riley for Long Island Sound waters, even though water 45 miles from the river mouth deviated from the Riley curve when analyzed separately. Mean values from coastal runoff and oceanic water also were predicted well by the Riley equation. The medians from upwelled water were very different from the Riley prediction, however, a fact which might be explained by the low frequency of sampling and by the spatial heterogeneity of chlorophyll *a* in upwelled water.

CHAPTER 12 RLO-1750-27

DISTRIBUTION OF ORGANIC CARBON IN SURFACE SEDIMENT, NORTHEAST PACIFIC OCEAN

M. Grant Gross, Andrew G. Carey, Jr., Gerald A. Fowler, and L. D. Kulm

ABSTRACT

Organic carbon in surface sediment is most abundant on the continental slope and on Cascadia Basin near the edge of the continent; it is least abundant in the coarse-grained sediment on the inner continental shelf (<90m) and on the deep-ocean floor, seaward of Juan de Fuca and Gorda ridges. Factors controlling organic-carbon concentrations include grain size, dissolved-oxygen concentrations in near-bottom water, and rates of sediment accumulation. Surface and subsurface currents, the submarine ridge system, and seachannels on the ocean bottom are all more or less parallel to the coast. These processes apparently restrict the seaward movements of sediment-associated organic carbon and cause the observed zoned distribution parallel to the coast. Terrigenous organic matter derived from rivers, especially from the Columbia River, contributes organic carbon to sediments on the continental shelf near the river mouths and to sediment in the seavalleys and seachannels on the ocean bottom.

CHAPTER 16 RLO-1750-42

EFFECTS OF THE COLUMBIA RIVER PLUME ON TWO COPEPOD SPECIES

Lawrence F. Small and Ford A. Cross

ABSTRACT

The distribution of two small copepods, _Acartia danae_ and _Centropages mcmurrichi_, was examined in relation to seasonal changes in the location of Columbia River plume waters. Net tows made in surface waters along four parallels of latitude between the Columbia River mouth and the Oregon - California border demonstrated that _A. danae_ was a good negative indicator of the offshore and southern limits of Columbia River plume waters; _C. mcmurrichi_ showed no distributional relation to plume waters.

CHAPTER 17 RLO-1750-45

DISTRIBUTION AND ECOLOGY OF OCEANIC ANIMALS OFF OREGON

William G. Pearcy

ABSTRACT

Mid-water trawl and plankton-net collections from 1961 to 1968 off the Oregon coast provided data on the species composition, seasonal and annual occurrences, inshore-offshore distributions, and vertical distributions of oceanic animals. Species lists of pelagic animals that were collected or observed are included. The fauna is mainly associated with subarctic and transitional water.

A few species of animals usually dominated catches. The abundance of individual species, however, varied among seasons and years. Seasonal variations were often accompanied by inshore-offshore changes of abundance. These variations were frequently correlated with seasonal changes in prevailing currents and upwelling.

Opening-closing nets caught the largest numbers of common mesopelagic fishes and a sergestid shrimp at depths of 0 to 150 m at night and 150 to 500 m during the day. These trends are evidence for diel vertical migrations of small nektonic animals off Oregon.

CHAPTER 18 RLO-1750-58

TECHNIQUES AND EQUIPMENT FOR SAMPLING BENTHIC ORGANISMS

Andrew G. Carey, Jr. and H. Heyamoto

ABSTRACT

The sampling gear and the field methods used by Oregon State University and the Bureau of Commercial Fisheries to gather benthic samples and oceanographic data are described. Among the types of gear described are an anchor-box dredge, a Smith-McIntyre grab, otter trawls, a new beam trawl with odometer wheels, shrimp trawls, corers, and screening devices. The procedures used by these two research groups with the various types of gear and the techniques used to recover, identify, and weigh the catches are outlined. Numerous innovations to adapt existing gear to differing conditions are presented.

CHAPTER 19 RLO-1750-39

A PRELIMINARY CHECKLIST OF SELECTED GROUPS OF INVERTEBRATES FROM OTTER-TRAWL AND DREDGE COLLECTIONS OFF OREGON

James E. McCauley

ABSTRACT

A checklist is provided for epifaunal species of nine phyla taken in otter-trawl and biological-dredge hauls by personnel from Oregon State University, Department of Oceanography. Species within each phylum are listed from observed depth of shallowest to deepest occurrence.

CHAPTER 20 RLO-1750-57

ECOLOGICAL OBSERVATIONS ON THE BENTHIC INVERTEBRATES FROM THE CENTRAL OREGON CONTINENTAL SHELF

Andrew G. Carey, Jr.

ABSTRACT

The distribution and abundance of benthic invertebrates on the continental shelf west of Newport, Oreg., are characterized. The infauna was collected by deep-sea anchor dredge and by anchor-box dredge from a transect of six stations across the shelf, and the macroepifauna, by quantitative 3-m beam trawl from four stations. The composition and abundance of the fauna change with increasing depth and distance from the shore. The macroepifauna is composed of a sparse molluscan assemblage inshore, whereas at the shelf edge it consists of numerous echinoderms and crustacea. The infaunal composition exhibits a seaward trend from a nearshore filter-feeding arthropod assemblage to an offshore assemblage dominated by burrowing polychaetes. Abundance increases seaward, the largest numerical density and biomass occurring at the outer edge of the continental shelf. Polychaete worms are shown to form closely associated species groups at the inner, middle, and outer portions of the continental shelf. These faunal trends can be correlated with various aspects of the benthic environment which change with increasing depth and distance from shore. Sediment may play a major role in determining the distribution and abundance of fauna; it is, however, but one of an interacting complex of environmental features that affect the fauna.

CHAPTER 25 RLO-1750-70

METHODS FOR THE MEASUREMENT OF HANFORD-INDUCED GAMMA RADIOACTIVITY IN THE OCEAN

Charles L. Osterberg and Richard W. Perkins

ABSTRACT

Radioactivity in the Columbia River resulting from the operation of the nulcear reactors at Hanford Laboratories, Richland, Wash., provides a unique tracer of the river water at sea. Several of the radionuclides can be most easily measured in sediments and biota, with measurements in the water proving more difficult. Although organisms concentrate certain radionuclides, not all plants and animals have equal affinities for the same radionuclides. It therefore is desirable to sort the samples prior to analysis. Even this time-consuming practice has difficulties - sample size is often limiting, there may be cycles in abundance and seasonal

variations in concentration due to metabolic differences, and organisms tend to reflect the average of their past environments.

It seems best, therefore, to measure the radioactivity directly in the water. Sample size is a restriction if seawater must be returned to the laboratory for analysis. This has led to the use of in situ gamma detectors, but here again limitations in sensitivity arise. To counter these limitations, large samples of water have been processed at sea, with relatively small concentrates (containing the bulk of the artificial radioactivity) being analyzed after return to the laboratory. In one series of experiments the concentrates were analyzed aboard ship to obtain a live-time distribution of Columbia River plume waters at sea.

The most recent and most sensitive technique employs sorption beds, which remove radionuclides from many gallons of seawater. The concentrate, when analyzed with multiparameter gamma-ray spectrometry, reveals a number of radionuclides present in the sea. However, levels are so low that measurement remains a challenge to oceanographers interested in using these radionuclides as tracers of water motion.

CHAPTER 26

RLO-1750-60

RADIOACTIVE AND STABLE NUCLIDES IN THE COLUMBIA RIVER AND ADJACENT NORTHEAST PACIFIC OCEAN

William O. Forster

ABSTRACT

This chapter presents the results of detailed studies of the downstream fate of radionuclides introduced at the Hanford site. Radionuclides associated with particulate matter or found in solution decrease in specific activity as the result of their physical decay rate, biogeochemical removal from the ecosystem, dilution by tributaries, and holdup by dams. The change in the concentration level and in the specific activities for the two forms, soluble and particulate, is not necessarily similarly influenced by downstream factors.

CHAPTER 27

RLO-1750-49

RADIONUCLIDE DISTRIBUTION IN COLUMBIA RIVER AND ADJACENT PACIFIC SHELF SEDIMENTS

William O. Forster

ABSTRACT

The distribution of several natural radionuclides and those from the Hanford nuclear reactors is described. Removal of these radionuclides from

the water by suspended and stream-bed sediments creates a major reservoir of radioactivity in this ecosystem. Redistribution of particulate isotopes on the various sediment size fractions in the different environments illustrates the strength of bonding between the particles and the radionuclides. Significant changes in the activity levels of individual radionuclides were found to be dependent on local rainfall and spring floods as well as the oxidation potentials of particular sites in the estuary. Major changes in activities due to the Hanford reactor shutdown of 1966 were found. Paired radionuclides of different decay constants were used to determine the transport rate of fractionated surficial sediments as they move out from the estuary and across the shelf. Deposition rates were also calculated by this paired-tracer technique. The advantages of the specific-activity approach in determining sediment transport rates were briefly illustrated. Natural radioactivity of ^{40}K and ^{214}Bi was stripped from the gamma spectra of nearshore sediments, and the ^{65}Zn in the plume was found to change with depth, season, organic content, and particle-size distribution.

CHAPTER 29 RLO-1750-46

RADIOECOLOGY OF ZINC-65 IN ALDER SLOUGH, AN ARM OF THE COLUMBIA RIVER ESTUARY

William C. Renfro

ABSTRACT

This chapter gives the results of an investigation of the transfer of ^{65}Zn through Alder Slough, a small, discrete segment of the Columbia River estuary located some 600 km downstream from Hanford, Wash. Zinc-65 activity levels were measured in water, sediments, algae, emergent vegetation, and in animals. The activity level increased in the spring, fell in midsummer, and continued at low level throughout the remainder of the year, even when concentrations of radionuclides in Columbia River organisms near Hanford were increasing. Organisms in the lowest trophic levels had the shortest ecological half-life, and each succeeding trophic level showed a longer ecological half-life (i.e., time required to reduce radionuclide specific activity by one-half by radioactive decay and biological turnover in spite of continued uptake of the radionuclide through the food web).

CHAPTER 30

RLO-1750-61

SEASONAL AND AREAL DISTRIBUTIONS OF RADIONUCLIDES IN THE BIOTA OF THE COLUMBIA RIVER ESTUARY

William C. Renfro, William O. Forster, and Charles L. Osterberg

ABSTRACT

This chapter describes the distribution of some radionuclides in organisms of the Columbia River estuary. Because zinc is of importance in the biological system and can be readily measured, ^{65}Zn was studied most intensively. Other radionuclides measured at least once in the biota were ^{60}Co, ^{54}Mn, ^{51}Cr, ^{46}Sc, ^{32}P, and some fallout fission products. Phytoplankton and zooplankton had relatively high but variable amounts of ^{65}Zn and ^{51}Cr with no apparent seasonal or areal trends. The specific activity of ^{65}Zn varied seasonally in fish and shrimp and generally reached a maximum in spring or summer. Starry flounders (Platichthys stellatus) and staghorn sculpins (Leptocottus armatus) from upstream locations exhibited higher radioactivity levels than those from stations farther downstream. During the period of this study (1964-1968), there was an obvious decline in ^{65}Zn specific activities of organisms. At the same time the number of reactors in operation at Hanford was reduced from eight to three.

CHAPTER 33

RLO-1750-55

ZINC-65 IN BENTHIC INVERTEBRATES OFF THE OREGON COAST

Andrew G. Carey, Jr.

ABSTRACT

Radioecological studies of benthic invertebrate fauna off central and northern Oregon demonstrate that ^{65}Zn entering the northeast Pacific Ocean via the Columbia River is concentrated by the sublittoral, bathyal, and abyssal fauna. The ^{65}Zn (picocuries per gram ash-free dry weight) and specific activity (microcuries of ^{65}Zn per gram of zinc) in the fauna decrease fairly regularly with distance from the river and markedly with depth within the first 400 m. The major route of the isotope to the fauna appears to be through the food web. The radioecology of the benthic organisms differs from that of the pelagic fauna.