CENTER FOR ESTUARINE AND MENHADEN RESEARCH

ANNUAL REPORT
TO THE
ATOMIC ENERGY COMMISSION

A COOPERATIVE AGREEMENT BETWEEN
THE NATIONAL MARINE FISHERIES SERVICE AND
THE ATOMIC ENERGY COMMISSION

JULY 1, 1971

U. S. Department of Commerce

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National Marine Fisheries Service

Beaufort, North Carolina

U. S. DEPARTMENT OF COMMERCE

National Oceanic and Atmospheric Administration

National Marine Fisheries Service

Beaufort, N. C.

ANNUAL REPORT
TO THE
ATOMIC ENERGY COMMISSION

By

The Staff

CENTER FOR

ESTUARINE AND MENHADEN RESEARCH

T. R. Rice, Director

For Administrative Use Only

July 1, 1971

EDITORIAL COMMENT

This report contains research results in various forms, ranging from preliminary progress reports to manuscripts prepared for scientific publication. The reader is therefore cautioned that any of the material which follows is subject to revision before formal publication. Reprints of published information and preliminary results, properly qualified, may be available from the individual authors at the Center for Estuarine and Menhaden Research.

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INTRODUCTION

During fiscal year 1971, President Nixon reorganized parts of the Executive Branch of the Federal Government, and the Bureau of Commercial Fisheries was transferred from the Department of the Interior to the National Oceanic and Atmospheric Administration (NOAA) in the Department of Commerce, and was renamed the National Marine Fishereies Service (NMFS). The Center for Estuarine and Menhaden Research (CEMR) lost its major field station at Gulf Breeze, Florida to the newly formed Environmental Protection Agency in this maneuver, but was otherwise unaffected by the change. In the meantime, we have continued the consolidation and intensification of our research efforts on ecological energetics and elemental cycling in estuarine environments and on the interaction of environmental stresses on estuarine organisms.

This consolidation began after the formation of CEMR by the recombination in July 1969 of the former Radiobiological and Biological Laboratories at Beaufort.

The research facilities of the entire station are now more readily available to all staff members, as a result of improved administrative coordination. Important equipment and facilities more readily accessible to personnel on AEC-supported research include several boats for field sampling, a temperature and salinity-controlled flowing sea water system for experimental use and an IBM 1130 computer with a line to an IBM 360 computer in the Interior Department. The computer facility is operated by a competent staff under the direction of a biometrician, whose services are utilized by the entire staff of CEMR. In addition, certain aspects of menhaden research require field sampling and data processing very similar to those used in our general ecological research. We are striving to achieve an effective coalition of our CEMR research objectives in order to increase operational efficiency in all programs. Thus, work on the physiology and environmental requirements of menhaden during their estuarine phase is coordinated with other research on the physiology, feeding, and ecological relationships of estuarine fishes and on the standing crop and species composition of fishes in the Newport River estuary, and both programs benefit from the resultant information.

During FY 1971, 11 staff members presented or co-authored 19 distinct papers presented at eight major international, national, or regional scientific meetings (page 6). These papers described original research concerned with various aspects of ecological energetics, elemental cycling, physiological ecology, and radioecology in estuarine/marine environments. Many of these presentations will result in publications (See "Publications in Press", page 20). In addition, several publications of the staff appeared in print during FY 1971---ranging from abstracts through research papers to review articles (page 16). We have included, as a supplement to this report, copies of all available publications not previously submitted.

In this report, research is described under three headings: (1) Distribution and cycling of elements, (2) Energy relations in estuarine ecosystems, and (3) Interaction of environmental stresses on estuarine organisms. Represented under these headings is a diverse assortment of laboratory and field research work which, with very few exceptions, is designed to provide a data base for the development of a system of mathematical models describing the flows and cycles of energy and trace elements (or radionuclides) in the estuarine ecosystems near Beaufort, N.C. We believe it is feasible for a small organization such as ours to undertake a comprehensive study of an ecosystem by attacking the research in small parts over an extended period of time. Most ecosystems appear much the same from year to year and remain recognizably the same system. During the period of our research the estuarine ecosystem will change in many ways such as species composition and abundance, but the same general principles should continue to govern its operation. Prediction of the responses of an ecosystem to stresses placed upon it requires knowledge of its principles of operation. From the results of the studies presented in this report and in our ongoing research, we are endeavoring to deduce these principles of operation.

STAFF

Theodore R. Rice, Director

RESEARCH STAFF

*Mary T. Boyd	Biological Aid
Ford A. Cross	Oceanographer
Edna M. Davis	Biological Technician
David W. Engel	Fishery Biologist
Larry H. Hardy	Biological Technician
*William F. Hettler, Jr.	Fishery Biologist
Donald E. Hoss	Fishery Biologist
Charles D. Jennings	Oceanographer (Resigned 8-28-70)
Neysa Y. Jones	Biological Aid
Michael W. LaCroix	Biological Aid
Curtis W. Lewis	Biological Technician
Jo-Ann M. Lewis	Biological Aid
Marianne B. Murdoch	Biological Technician
*David S. Peters	Fishery Biologist
Thomas J. Price	Fishery Biologist
Thomas G. Roberts	Biological Technician
Gordon W. Thayer	Fishery Biologist
*William R. Turner	Fishery Biologist
Richard B. Williams	Fishery Biologist
James N. Willis III	Chemist
Douglas A. Wolfe	Research Chemist

STAFF SERVICES

John P. Baptist	Fishery Biologist
Rebecca S. Clarke	Fishery Biologist
Irene D. Huff	Secretary
Peggy M. Keney	Fishery Biologist
Margaret L. Rose	Clerk-Stenographer

*Personnel not supported by the Atomic Energy Commission, but whose work has had direct applicability also to the research objectives of this contract.

STAFF ACTIVITIES

Meetings Attended and Papers Presented

American Institute of Biological Sciences, Bloomington, Ind., August 23-29, 1970.

G. W. Thayer - Identity and regulation of nutrients limiting phytoplankton photosynthesis in an estuarine system.

American Society of Limnology and Oceanography, Kingston, R.I., August 25-28, 1970.

F. A. Cross - Distribution of radioactive and stable zinc in an experimental marine ecosystem.

Atlantic Estuarine Research Society, Easton, Md., October 23-24, 1970.

T. J. Price - Quantitative sampling of benthos in estuarine areas near Beaufort, N.C.

G. W. Thayer

R. B. Williams

D. A. Wolfe

FAO Technical Conference on Marine Pollution and Its Effects on Living Resources, Rome, Italy, December 9-18, 1970.

T. R. Rice - Potential hazards from radioactive pollution of the estuary.

Association of Southeastern Biologists, Richmond, Va., April 15-17, 1971.

W. F. Hettler Jr. - A comparison of two flowing respirometers for measuring fish oxygen consumption.

D. S. Peters - Planktonic copepods (Crustacea: Harpacticoida) distribution and regulating factors in the Pamlico River estuary.

T. J. Price - The organic content of shells, tissues, and extrapallial fluid of some estuarine pelecypods and its ecological implications.

G. W. Thayer - Standing crop, biomass, and respiration of the epibenthic invertebrate community of an eelgrass bed.

Atlantic Estuarine Research Society, Atlantic Beach, N.C., April 16-17, 1971.

Professional personnel of the Center.

Third National Symposium on Radioecology, Ann Arbor, Mich., May 10-12, 1971.

J. W. Angelovic - Influence of ionizing radiation, salinigy, and temperature on the osmotic regulation of the mummichog, Fundulus heteroclitus.

J. P. Baptist

F. A. Cross - Concentrations of Mn, Fe, and Zn in estuarine fish.

D. W. Engel - The effect of radiation, salinity, and temperature on the ionic regulation of the blue crab, Callinectes sapidus.

D. E. Hoss - Accumulation of soluble and particulate radionuclides by estuarine fish.

D. S. Peters - The effect of temperature, salinity, and food availability on the growth rate and growth efficiency of juvenile flounder, Paralichthys dentatus and P. lethostigma.

T. R. Rice - Chaired session on Radionuclides in Marine Ecosystems.

R. B. Williams - The effects of continuous low level gamma radiation on estuarine microcosms.

D. A. Wolfe - ^{55}Fe and ^{103,106}Ru in the brackish-water clam Rangia cuneata.

In addition to the above presentations, the following two papers presented at this symposium also described research of Center staff members:

C. L. Schelske, D. A. Wolfe, and D. E. Hoss - Ecological implications of fallout radioactivity accumulated by estuarine mollusks and fishes.

W. O. Forster, D. A. Wolfe, F. G. Lowman, and R. McClin - Trace element interactions between river water and seawater.

Radiation Research Society, Boston, Mass., May 12-13, 1971

D. W. Engel - The radiation sensitivities of selected estuarine Crustacea.

American Nuclear Society, Boston, Mass., June 14-17, 1971.

T. R. Rice - Ocean use planning.

Appointments, Committees, Conferences, and Seminars

W. R. Turner - Conference, Field survey, South Carolina Estuarine Environmental Studies, Beaufort, S.C., July 14-24, October 13-20, 1970; Columbia, S.C., January 6-9, 1971.

C. D. Jennings - Conference, BCF Pesticide Field Station, Gulf Breeze, Fla., July 20-24, 1970.

T. R. Rice - Conference, Governor's public hearing on "Interstate Environmental Problems," Raleigh, N.C., July 22, 1970.

T. R. Rice - Conference, NMFS Regional Office, St. Petersburg, Fla., July 27-28, August 3-5, November 17-18, 1970; May 6, May 26-28, 1971.

D. E. Hoss - Conference, Biological-Technical Committee of the Charleston Ad Hoc Group, Charleston, S.C., August 12, October 28, 1970; November 10, 1970; February 18, 1971, Columbia, S.C.

T. R. Rice - Conferences, Biology Departments, various Colleges and Universities, North Carolina and South Carolina, September 9-11, 1970.

D. E. Hoss - Conferences, Radioecology groups, Oregon State University, Corvallis, Newport, and Astoria, Ore., September 30 - October 2, 1970.

F. A. Cross - Conference, "Environmental Mercury Contamination," Ann Arbor, Mich., September 30 - October 2, 1970.

D. W. Engel, G. W. Thayer - Conference, NASA representatives, Langley Research Center, Norfolk, Va., October 13, 1970.

T. R. Rice - Conferences and visits - Center of Fontenay-aux-Roses, Paris, France; Institute National D'Hygiene, D'Oceanographic Medicale, Nice, France; Commissariat a l'Energie Atomique, Villefranche-sur-Mer, France; International Atomic Energy Agency, Monaco; CNEN-EURATOM, Fiascherino, La Spezia, Italy, November 30 - December 8, 1970.

W. F. Hettler, Jr., D. E. Hoss - Workshop, "Rearing, Physiology, and Behavior of Larval Fish and Invertebrates" and World Mariculture Society Meeting, Galveston, Tex., January 26-29, 1971.

T. R. Rice - Conference, Marine Technology Advisory Committee, Cape Fear Technical Institute, Wilmington, N.C., February 5, 1971.

J. N. Willis - Conference, Division of Ecosystem Quality personnel, NMFS, Washington, D.C., February 9, 1971.

T. R. Rice - Panel member, NSF Sea Grant Program Site Visit, Raleigh, N.C., February 10-11, 1971.

T. R. Rice - Conference, Game Fish Research Orientation, NMFS Regional Office, St. Petersburg, Fla., February 16-17, 1971.

D. A. Wolfe - Conference, "Ecological Survey of Oceanic Waste Disposal Sites," NMFS Technology Laboratory, Ann Arbor, Mich., February 18-19, 1971.

W. R. Turner - Conference, South Carolina Water Resources Commission, Federal, and State representatives, Columbia, S.C., March 2-4, March 19, Charleston, S.C., April 5-7, April 22-27, 1971.

T. R. Rice - Panel member, Marine Aquatic Life and Wildlife of the Water Quality Criteria Committee, National Academy of Sciences, Washington, D.C., March 5, March 26, May 20-21, June 23, 1971.

T. R. Rice - Conference, "MARMAP," NMFS Regional Office, St. Petersburg, Fla., March 15-17, 1971.

D. A. Wolfe - Member, AEC review team, University of Miami's research program, NMFS Tropical Atlantic Biological Laboratory, Miami, Fla., April 1-3, 1971.

G. W. Thayer - Conference, "The Role of Detritus in Ecosystems," University of Georgia, Athens, Ga., April 1-3, 1971.

D. W. Engel - Conference, "Remote Sensing of the Chesapeake Bay," NASA Wallops Station, Wallops Island, Va., April 5-7, 1971.

D. A. Wolfe - Conference, NMFS Physiological Task Force, Baltimore, Md., April 13, 1971.

F. A. Cross, T. R. Rice - Conference, Division of Ecosystem Quality personnel, NMFS, Washington, D.C., April 20, 1971.

T. R. Rice - Marine fisheries seminar presentation, "Radioactive Pollution in the marine environment," Texas A & M University, College Station, Tex., April 30, 1971.

W. F. Hettler, Jr. - Conference, NMFS Central Office, Washington, D.C., May 11-13, 1971.

D. A. Wolfe - Conference, Task force to evaluate future analytical plans for analyses of heavy metals, NMFS Center for Fish Protein Concentrate, College Park, Md., May 25-26, 1971.

G. W. Thayer - Symposium, "Microbiological Processes in Estuarine Ecosystems," Columbia, S.C., June 8-9, 1971.

R. B. Williams - Conference, International Field Year for the Great Lakes Planning Staff, NOAA, Washington, D.C., June 9-10, 1971.

D. E. Hoss - Symposium, "River Ecology and the Impact of Man," University of Massachusetts, Amherst, Mass., June 21-23, 1971.

T. R. Rice - Member, Editorial Committee of the Fishery Bulletin.

F. A. Cross, T. R. Rice, R. B. Williams, D. A. Wolfe - Adjunct appointments, Graduate Faculty, Department of Zoology, North Carolina State University, Raleigh, N.C.

R. B. Williams - President, Atlantic Estuarine Research Society.

P. M. Keney - Secretary-Treasurer, Atlantic Estuarine Research Society.

RADIOLOGICAL CONSULTING ACTIVITIES

J. P. Baptist and T. R. Rice

As a result of a rapidly expanding technology, the nation's need for more sources of power is being met by the construction of nuclear power plants. It is likely that nuclear reactors will eventually produce most of the nation's electric power including that now being produced by fossil fuels, partly because of the campaign against air pollution and partly because of economic considerations. Nuclear reactors, however, produce large quantities of radioactive wastes that must be disposed of in a safe manner. Since it is not economically feasible to store all wastes, those liquids having low concentrations of radioactivity are discharged into the aquatic environment where they are diluted and dispersed.

Even though the radioactivity discharged to the aquatic environment is reduced to low levels by dilution, organisms concentrate certain radionuclides many times the levels in the water. At present, it is not known whether the concentrations of radionuclides accumulated in organisms from water containing legal limits of radioactivity (Maximum Permissible Concentrations) will have harmful effects upon the organisms. Consequently, each reactor location must be studied individually and a radiological monitoring program must be designed to ensure that organisms will not be exposed to enough radioactivity to harm them or cause them to become unfit for use as food by man.

As radiological consultants for the U. S. Fish and Wildlife Service and The National Marine Fisheries Service, we review the Safety Analysis Reports for each nuclear power plant before construction begins. After making a careful study of the reactor site, radioactive waste disposal system, cooling water intakes and outlets, and the applicant's radiological monitoring program, we make recommendations based on sound principles of radioecology. These recommendations vary among nuclear power stations because of variation in physical features of the environment and differences among the proposed radiological surveys. In general, however, our minimum recommendations may be summarized as follows:

1. Make at least one preoperational radiological survey of the aquatic environment to establish background levels of radioactivity.
2. Make radiological surveys of the aquatic environment every 6 months after reactor operation has begun.
3. Analyze samples for contained radioactivity as follows.
    - A. Water and sediment samples within 500 feet of the reactor effluent outfall.
    - B. Aquatic plants and animals (crustaceans, mollusks, and fish) collected as near as possible to the effluent outfall and at stations upstream and downstream from the reactor site.
    - C. Gross beta and gamma radioactivity. If significant levels occur, identification of radionuclides is recommended.

4. Furnish results of the radiological surveys to the appropriate State and Federal agencies for evaluation by fish and wildlife specialists.

During the past year, we reviewed 151 safety analysis reports, amendments, and environmental monitoring reports in evaluating possible radiological effects on fishery resources by various nuclear power plants.

As part of our radiological consulting activities, we participated in the following meetings, hearings, and conferences:

J. P. Baptist, T. R. Rice - Symposium, "Environmental Aspects of Nuclear Power Stations," New York, N.Y., August 10-14, 1970.

J. P. Baptist, T. R. Rice - North Carolina Nuclear Environmental Workshop, Pinehurst, N.C., October 16-17, 1970.

J. P. Baptist - Conference, U.S. Atomic Energy Commission personnel, Washington, D.C., February 2, 1971.

J. P. Baptist - Expert witness, public hearing, Shoreham Nuclear Power Station, Long Island, N.Y., February 8-10, 1971.

J. P. Baptist - North Carolina Nuclear Environmental Workshop, Durham, N.C., April 6-7, 1971.

J. P. Baptist - Conference on proposed nuclear fuel reprocessing plant, Chester, S.C , April 23, 1971.

J. P. Baptist - Conference with representatives of U.S. Atomic Energy Commission and other agencies on environmental monitoring, Las Vegas, Nev., June 9, 1971.

STAFF PUBLICATIONS

1. ADAMS, SIDNEY MARSHALL, AND J. W. ANGELOVIC. 1970. Assimilation of detritus and its associated bacteria by three species of estuarine animals. Chesapeake Science 11(4): 249-254.
2. ANGELOVIC, J. W., and D. W. ENGEL. 1970. Effects of radiation on estuarine organisms. Marine Pollution Bulletin, New Series, 1(1): 103-105.
3. BAPTIST, J.P., AND D. E. HOSS, and C. W. LEWIS. 1970. Retention of ^{51}Cr, ^{59}Fe, ^{60}Co, ^{65}Zn, ^{85}Sr, ^{95}Nb, ^{141m}In, and ^{131}I by the Atlantic croaker (Micropogon undulatus). Health Physics 18: 141-148.
4. CROSS, FORD A., THOMAS W. DUKE, and JAMES N. WILLIS. 1970. Biogeochemistry of trace elements in a coastal plain estuary: Distribution of manganese, iron, and zinc in sediments, water, and polychaetous worms. Chesapeake Science 11(4): 221-234.
5. HETTLER, W. F., JR. 1970. Rearing larvae of yellowfin menhaden, Brevoortia smithi. Copeia 1970(4): 775-776.
6. HETTLER, W. F., JR., and D. E. HOSS. 1971. A comparison of two flowing respirometers for measuring fish oxygen consumption. (Abstract) Association of Southeastern Biologists Bulletin 18(2): 38.
7. HETTLER, WILLIAM F., JR., RICHARD W. LICTHENHELD, and HERBERT R. GORDY. 1971. Open seawater system with controlled temperature and salinity. The Progressive Fish-Culturist 33(1): 3-11.

8. PETERS, DAVID S. 1971. Planktonic copepod (Crustacea: Harpacticoida) distribution and regulating factors in the Pamlico River Estuary. (Abstract) Association of Southeastern Biologists' Bulletin 18(2): 50.

9. PRICE, T. J., G. W. THAYER, and M. W. LACROIX. 1971. The organic content of shells, tissues, and extrapallial fluid in some estuarine pelecypods and its ecological implications. (Abstrct) Association of Southeastern Biologists Bulletin 18(2): 50-51.

10. RICE, T. R. 1969. Progress report of the Bureau of Commerical Fisheries Radiobiological Laboratory, Beaufort, N.C., fiscal year 1968. U.S. Fish and Wildlife Service, Circular 309. 59 p.

11. RICE, T. R., and J. W. ANGELOVIC. 1969. Radioactivity in the sea: Effects on fisheries, p. 574-578. In F. E. Firth [ed.], Encyclopedia of marine resources. Van Nostrand Reinhold Co., New York.

12. RICE, T. R., and J. P. BAPTIST. 1970. Ecological aspects of radioactivity in the marine environment, p. 107-180. In John C. Clopton [ed.], Environmental Radioactivity Symposium. The Johns Hopkins University, Baltimore, Md.

13. RICE, T. R., and T. W. DUKE. 1969. Radioactivity in the sea: General, Classification of radionuclides, p. 566-569. In F. E. Firth [ed.], Encyclopedia of marine resources. Van Nostrand Reinhold Co., New York.

14. RICE, T. R., J. P. BAPTIST, F. A. CROSS, and T. W. DUKE. 1970. Potential hazards from radioactive pollution of the estuary. FAO Technical conference on marine pollution and its effects on living resources and fishing, Rome, Italy, 9-18 December 1970. FIR: MP/70/E-34. 9 p.

15. THAYER, GORDON W. 1970. Comparison of two storage methods for the analysis of nitrogen and phosporus fractions in estuarine water. Chesapeake Science 11(3): 155-158.

16. THAYER, G. W., and M. W. LACROIX. 1971. Standing crop, biomass, and respiration of the epibenthic invertebrate community of an eelgrass bed. (Abstract) Association of Southeastern Biologists Bulletin 18(2): 58.

17. THAYER, GORDON W., and RICHARD B. WILLIAMS. 1970. Identity and regulation of nutrients limiting phytoplankton photosynthesis in an estuarine system. (Abstract) Bulletin of the Ecological Society of America 51(2): 32.

18. WILLIAMS, RICHARD B. 1969. A table of mean effective temperatures for the metabolism of biological systems subjected to sinusoidal cycles in temperature. Journal of Theoretical Biology 24: 240-245.

19. WOLFE, DOUGLAS A. 1969. Ecosystems stressed by additons of man-made radioactivity, p. 1304-1330. <u>In</u> H. T. Odum, B. J. Copeland, and E. A. McMahan (eds.) Coastal ecological systems of the United States, Preliminary report to the Federal Water Pollution Control Administration (Contract RFP 68-128).

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20. WOLFE, DOUGLAS A. 1969. A compact cabinet for the storage and display of shells. Bulletin of the North Carolina Shell Club (1968), No. 5: 32-34.

21. WOLFE, DOUGLAS A. 1970. Levels of stable Zn and ^{65}Zn in *Crassostrea virginica* from North Carolina. Journal of the Fisheries Research Board of Canada 27(1): 47-57.

22. WOLFE, DOUGLAS A. 1970. Zinc enzymes in *Crassostrea virginica*. Journal of the Fisheries of Research Board of Canada 27(1): 59-69.

23. WOLFE, DOUGLAS A., and C. B. COBURN, JR. 1970. Influence of salinity and temperature on the accumulation of cesium 137 by an estuarine clam under laboratory conditions. Health Physics 18: 499-505.

24. WOLFE, DOULGAS, and NANCY WOLFE. 1970. Molluscs of North Carolina, a check-list of marine and brackish species with notes on geographic and ecological distribution. Published jointly with the Regional Marine Science Project, Carteret County Public Schools, Beaufort, N.C. 69 p.

PUBLICATIONS IN PRESS

CROSS, FORD A., AND JERALDINE H. BROOKS.

Concentrations of Mn, Fe, and Zn in estuarine fish. In D. J. Nelson [ed.], Third National Symposium on Radioecology.

CROSS, FORD A., JAMES N. WILLIS, AND JOHN P. BAPTIST.

Distribution of radioactive and stable zinc in an experimental marine ecosystem. Journal of the Fisheries Research Board of Canada.

ENGEL, D. W., J. W. ANGELOVIC, AND J. C. WHITE, JR.

The radiation sensitivities of selected estuarine Crustacea. (Abstract) Radiation Research.

ENGEL, D. W., E. M. DAVIS, J. W. ANGELOVIC, AND D. E. SMITH.

The effect of radiation, salinity, and temperature on the ionic regulation of the blue crab, Callinectes sapidus. In D. J. Nelson [ed.], Third National Symposium on Radioecology.

FORSTER, W. O., D. A. WOLFE, F. G. LOWMAN, AND RAUL McCLIN.

Trace elements interactions between river water and seawater. In D. J. Nelson [ed.], Third National Symposium on Radioecology.

HETTLER, W. F., JR.

A yellowfin menhaden without pelvic fins. Florida Academy of Sciences.

HOSS, D. E.

Metabolism of larval estuarine fish. (Abstract) Proceedings of Estuarine Workshop, Charleston, S.C.

HOSS, D. E., AND J. P. BAPTIST.

Accumulation of soluble and particulate radionuclides by estuarine fish. In D. J. Nelson [ed.], Third National Symposium on Radioecology.

LOWMAN, F. G., T. R. RICE, AND F. A. RICHARDS.

Accumulation and redistribution of radionuclides by marine organisms. In A. H. Seymour [ed.], Radioactivity in the Marine Environment. NAS-NRC.

PORTER, H. J., AND D. W. WOLFE.

Mollusca associated with calico scallop, Argopecten gibbus (Linne). in North Carolina offshore waters. Journal de Conchyliologie.

RICE, T. R., AND J. P. BAPTIST.

Ecologic effects of radioactive emissions from nuclear power plants In Leonard Sagan [ed.], Human and ecologic Effects of Nuclear Power Plants.

SCHELSKE, C. L., D. A. WOLFE, AND D. E. HOSS.

Ecological implications of fallout radioactivity accumulated by estuarine mollusks and fishes. In D. J. Nelson [ed.], Third National Symposium on Radioecology.

THAYER, G. W.

Phytoplankton ecology and the distribution of nutrients in a shallow unstratified estuarine system near Beaufort, N.C. Chesapeake Science.

WILLIAMS, RICHARD B.

Computer simulation of energy flow in Cedar Bog Lake, Minnesota based on the classical studies of Lindeman (1941, 1942), Chapter 9. In B. C. Patten [ed.], Systems Analysis and Simulation in Ecology. Academic Press, New York.

WILLIAMS, RICHARD B.

Steady state equilibriums in simple nonlinear food webs, chapter 13. In B. C. Patten [ed.], Systems Analysis and Simulation in Ecology. Academic Press, New York.

WILLIAMS, R. B., AND M. B. MURDOCH.

The effects of continuous low level gamma radiation on estuarine microcosms. In D. J. Nelson [ed.], Third National Symposium on Radioecology.

WOLFE, D. A.

Estuarine biogeochemistry of cesium: Fallout ^{137}Cs in clams and water from the Neuse River estuary, North Carolina. Limnology and Oceanography.

WOLFE, D. A. AND C. D. JENNINGS.

^{55}Fe and ^{103,106}Ru in the brackish-water clam, Rangia cuneata. In D. J. Nelson [ed.], Third National Symposium on Radioecology.

WOLFE, DOUGLAS A., AND THEODORE R. RICE.

Artifacts of man--radioactivity. In Don Hood [ed.], Impingement of Man upon the Oceans. John Wiley, New York.

RESEARCH BY STUDENTS FROM WEST CARTERET HIGH SCHOOL

MOREHEAD CITY, NORTH CAROLINA

Three staff members of the Center acted as advisors for three students who conducted original research problems.

Student	Advisor
Rice, Scott	G. W. Thayer
Rumfelt, James	R. B. Williams
White, Mabo	D. W. Engel

A summary of their work is presented in the following abstracts.

EFFECTS OF TEMPERATURE CHANGES ON THE RESPIRATION OF ZOOPLANKTON

By

Scott Rice

ABSTRACT

Increasing amounts of heated water being released into the aquatic environment may adversely affect the animals living there, particularly small animals that cannot avoid the heated water. Adverse effects upon small animals, such as zooplankton, also are of interest because larger animals feed upon them. The influence of temperature and rapid increases in temperature upon the respiration of *Artemia salina*, *Tigriopus californicus*, and a mixture of estuarine zooplankton was determined. Respiration rates were measured at 5° C increments between 5° and 30° C after the animals had been acclimated at these temperatures. Respiration rates of those zooplankton acclimated at 5°, 15°, and 25° C, also were measured after the animals had been subjected to a rapid increase in temperature of 5° C.

These data showed that the respiration rates generally increased with increasing temperature of acclimation and that the

respiration of Tigriopus and of estuarine zooplankton was maximum at 25° C. The Q_{10}'s for Artemia, when exposed to rapid temperature increases, were reduced at all temperatures tested. Q_{10}'s for Tigriopus were reduced at low temperatures and increased at high temperatures, and Q_{10}'s for estuarine zooplankton were increased at lower temperatures and reduced at the highest temperature, compared to the Q_{10}'s of acclimated organisms.

The data for estuarine zooplankton indicated that rapidly increasing temperatures during spring and summer may induce physiological impairment, whereas elevated temperatures during fall and winter may result in an increase in the amount of assimilated energy used for respiration. This would leave less energy for reproduction and growth, and increase the food consumed by the zooplankton.

THE EFFECT OF TEMPERATURE AND NUTRIENT FEEDING ON THE DECOMPOSITION RATE OF SPARTINA ALTERNIFLORA

By

James Rumfelt

ABSTRACT

The effect of nutrient concentration and temperature on the rate of decomposition of Spartina alterniflora was studied in laboratory experiments to evaluate the probable importance of these factors in the decay of Spartina in nature. The ratio of carbon to nitrogen to phosphorus (125:2:0.3) in the Spartina is different from that required by decomposers for the most efficient breakdown of organic matter (125:5:1). Inorganic nitrogen and/or phosphorus was added to dead Spartina to bring the concentration of these elements nearer the optimal level.

Finely ground Spartina in suspension (2 grams dry weight per 2 liters of seawater) was placed into each of 32 flasks. Eight flasks were placed in each of four constant temperature control rooms at 4°, 12°, 15°, and 28° C. Into six of the flasks at each temperature were added the following concentrations or combinations of nutrients. Low concentrations were N - 0.058 g/2 liters, P - 0.007 g/2 liters, and

N + P (0.058 + 0.007 g/2 liters). These concentrations were one-half the amounts needed to establish the proper ratio. High concentrations were N - 0.21 g/2 liters, P - 0.170 g/2 liters, and N + P (0.21 + 0.170 g/2 liters). These amounts were twice that required to establish the proper ratio. Of the remaining two flasks at each temperature, one contained pure seawater and the other seawater and nutrient-rich silt in solution (0.272 g dry weight of silt/2 liters of seawater). The flasks were aerated to provide sufficient oxygen for decomposer metabolism, and were shielded from light to prevent algal growth. At irregular intervals 50 ml subsamples of agitated Spartina in suspension were drawn off from each flask, filtered through Millipore filters, dried at 50° C for 48 hours, and weighed to determine dry weight.

Results from the 4° C experiments are being calculated at present. Results from other temperatures reveal that the fastest rate of decomposition was accomplished at the higher temperature. With the addition of nitrogen and phosphorus in both low and high concentrations there was a noticeable increase in the rate of decomposition of Spartina as compared to samples where no nutrients were added. However, the results showed little difference in the rate of decomposition in samples in low concentrations and in high concentrations of added nutrients.

THE RELATIONSHIP BETWEEN SALINITY AND THE UPTAKE OF ALANINE BY EXCISED GILL TISSUE OF THE BLUE CRAB, CALLINECTES SAPIDUS

By

Mabo White

ABSTRACT

Salinity was found to exert an effect upon the uptake of ^{3}H-alanine (tritium labelled alanine) by the excised gill tissue from adult female blue crabs. The crabs were acclimated for two weeks at a constant temperature of 22° C in 100 percent (35 p.p.t.) seawater. The gills, removed from the sacrificed blue crabs, were diced into beakers containing 25, 50, and 100 percent seawater. The excised gills then were tagged with tritium (^{3}H-alanine), and after 15, 30, and 60 minutes were removed from the beakers, blotted and dried at 90° C for 24 hours. After determining dry weights, the gills were burned in a Packard Sample Oxidizer, and placed in a Liquid Scintillation Counter to determine tritium content of the tissue.

It is a well-known fact that alanine functions in the osmoregulatory processes of euryhaline crustaceans. In our experiments, there was a correlation between uptake of alanine and the salinity of the water. While the differences in magnitude of uptake were not directly related to salinity, the differences in levels achieved in

25 and 100 percent seawater probably are real. The uptake of alanine also may be connected with (1) the adsorption of alanine to the chitin of the gills (2) the use of alanine in protein synthesis, and (3) as a source of energy for breakdown of protein.

DISTRIBUTION AND CYCLING

OF ELEMENTS

DISTRIBUTION AND CYCLING OF ELEMENTS

The continued multiplicity of man's demands upon estuarine environments (as producers of food, avenues of transportation, receptacles for wastes, and a source of recreation or esthetic pleasure) makes it imperative that we understand the intricate interrelationships operating within the ecosystem. Radionuclides and trace metals are two types of pollutants which enter estuaries as a result of our generally expanding industrialization and the necessary location of nuclear power reactors along rivers and in coastal zones. Estuaries are very complex chemical environments, where the materials dissolved or suspended in fresh water become mixed with sea water, so that elemental concentrations may vary widely within an estuarine zone. Superimposed upon these concentration gradients are the physico-chemical processes of ion-exchange, precipitation, and adsorption, as well as the biological processes of accumulation, secretion, and excretion. In order to assess the potential effects of pollution by trace metals and radionuclides, we must know which estuarine components represent major reservoirs for individual trace elements, and what processes are most significant determinants for that distribution. The Elemental Cycling Program is gathering data on the distribution of trace elements in estuarine organisms, sediments and water, and on the transfer of these elements between the various biotic and abiotic components of the estuary.

The overall objective of the research program is to describe in detail the chemical budgets of important radionuclides and trace metals in our extensive salt-marsh estuaries in the southeastern United States so that we can predict levels of radionuclides and trace metals that will occur in important organisms, in water, and in sediments at various times after introduction of pollutants into estuaries. This increased emphasis on defining overall chemical budgets for certain radionuclides and trace metals in estuarine systems will ultimately require the use of systems analysis and modeling.

During this fiscal year, we continued both field and laboratory research on the distribution and cycling of trace elements in the estuarine environment. Most of the research reported in this section represents the completion of work from either this fiscal year or from the previous fiscal year. In addition, several of the projects mentioned below are nearing completion and will be reported in next year's annual report.

Our field research was a continuation of our work on the distribution of manganese, iron, copper, and zinc in sediments, water, and biota of the Newport River estuary. Our research this year dealt with the distribution of these elements in marsh plants, juvenile fish, and invertebrates collected from the estuary.

In the laboratory, projects are underway to determine (1) the turnover of ^{65}Zn in estuarine fish grown in a tank containing a constant specific activity of ^{65}Zn, (2) the uptake and accumulation of ^{3}H by estuarine organisms, and (3) the use of ^{203}Hg to determine the accuracy of the Hatch and Ott procedure for stable mercury analysis as well as the use of biologically incorporated ^{203}Hg to determine if losses of stable mercury occur during dissolution and oxidation of biological samples prior to stable mercury analysis. In addition, we participated in intercalibration studies with Woods Hole Oceanographic Institution and the Monaco Oceanographic Laboratory to determine concentrations of trace elements and radionuclides in sea water.

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CONCENTRATIONS OF Mn, Fe, AND Zn IN ESTUARINE FISH

Ford A. Cross, Jeraldine H. Brooks,
Larry H. Hardy and Jo-Ann M. Lewis

In recent years, research at our laboratory has been directed toward understanding the flow of materials and energy in shallow estuaries and embayments in the vicinity of Beaufort, N.C. These estuaries are highly productive systems that yield substantial quantities of oysters, shrimp, crabs, and fish and also serve as nursery grounds for a variety of marine fish and invertebrates that spawn in coastal waters. Field studies have been carried out in these estuaries to describe the distribution of fallout radioactivity in bivalve mollusks and fish (Schelske, Wolfe, and Hoss, In Press; Wolfe, 1967; Wolfe and Schelske, 1969; Wolfe, 1970; Wolfe, In press; and Wolfe and Jennings, In Press, as well as to describe the distribution of Mn, Fe, and Zn in estuarine sediments, water, and biota (Cross, Duke, and Willis, 1970; Duke, Willis and Price, 1966; Duke, 1967; and Williams and Murdoch, 1969).

The purpose of this research was to describe the concentrations of Mn, Fe, and Zn in the more abundant species of juvenile fish inhabiting estuaries in the vicinity of Beaufort, N.C. Knowledge of cycling of these elements is necessary to determine if these elements follow the same pathways in the marine environment as their radioisotopes; a critical assumption of the specific activity concept

(National Academy of Sciences--National Research Council, 1962). Wolfe and Jennings (In Press) suggest that ^{55}Fe from nuclear fallout may not follow the same pathway as stable Fe in the estuarine environment.

The species of fish examined were the Atlantic croaker (Micropogon undulatus), spot (Leiostomus xanthurus), pinfish (Lagodon rhomboides), bay anchovy (Anchoa mitchilli), and Atlantic menhaden (Brevoortia tyrannus). These five species constitute over 90 percent of the total number of juvenile fishes in the Newport River estuary (Turner, 1971).

These species represent a variety of feeding types ranging from filter feeders to carnivores. Croaker and spot are benthic feeders that feed predominantly on polychaetes, crustaceans, and mollusks (Hildebrand, 1930). Pinfish are omnivorous and consume both benthic and pelagic forms of polychaetes, crustaceans, and mollusks, as well as larval fish and plant material (Caldwell, 1957). Representing the lowest trophic level are menhaden which are efficient filter feeders that indiscriminantly strain both phytoplankton and zooplankton from the water. Anchovy are also plankton feeders that rely mainly on zooplankton, especially copepods, and detritus for nutrition (Darnell, 1958).

Materials and Methods

Field procedures

A general survey of the distribution of fish in the Newport

River estuary was conducted from November, 1967 to December, 1969. Samples of fish were collected monthly during this period with a bottom trawl from five locations in the estuary (Fig. 1) of which the general features have been described previously (Cross, Duke, and Willis, 1970; Williams and Murdoch, 1966). From these collections of fish we obtained data on biomass, length-weight relationships, and feeding habits (D. E. Hoss, unpublished data), as well as on concentrations of trace metals. Our initial goal was to make measurements of trace metals on 10 individual fish collected from each station on each sampling date. We were not able to do this for each collection, however, due to either a scarcity of fish or because the fish were not large enough to provide an adequate sample size. When fish less than 1 g. (dry weight) were collected they were pooled for a single analysis.

Analytical procedures

Samples of fish were measured for length, weighed, and dried at 90° C to a constant weight. The samples were then ashed at 500° C, weighed, the ash dissolved at 70° C in concentrated HNO_3 and then evaporated to dryness. The residue was redissolved in 0.25 N HCl and filtered through a Whatman #42 filter[1] paper. The filtrate was analyzed for concentrations of Mn, Fe, and Zn by atomic absorption spectrophotometry.

[1] The mention of trade names in this publication does not imply endorsement by the National Marine Fisheries Service

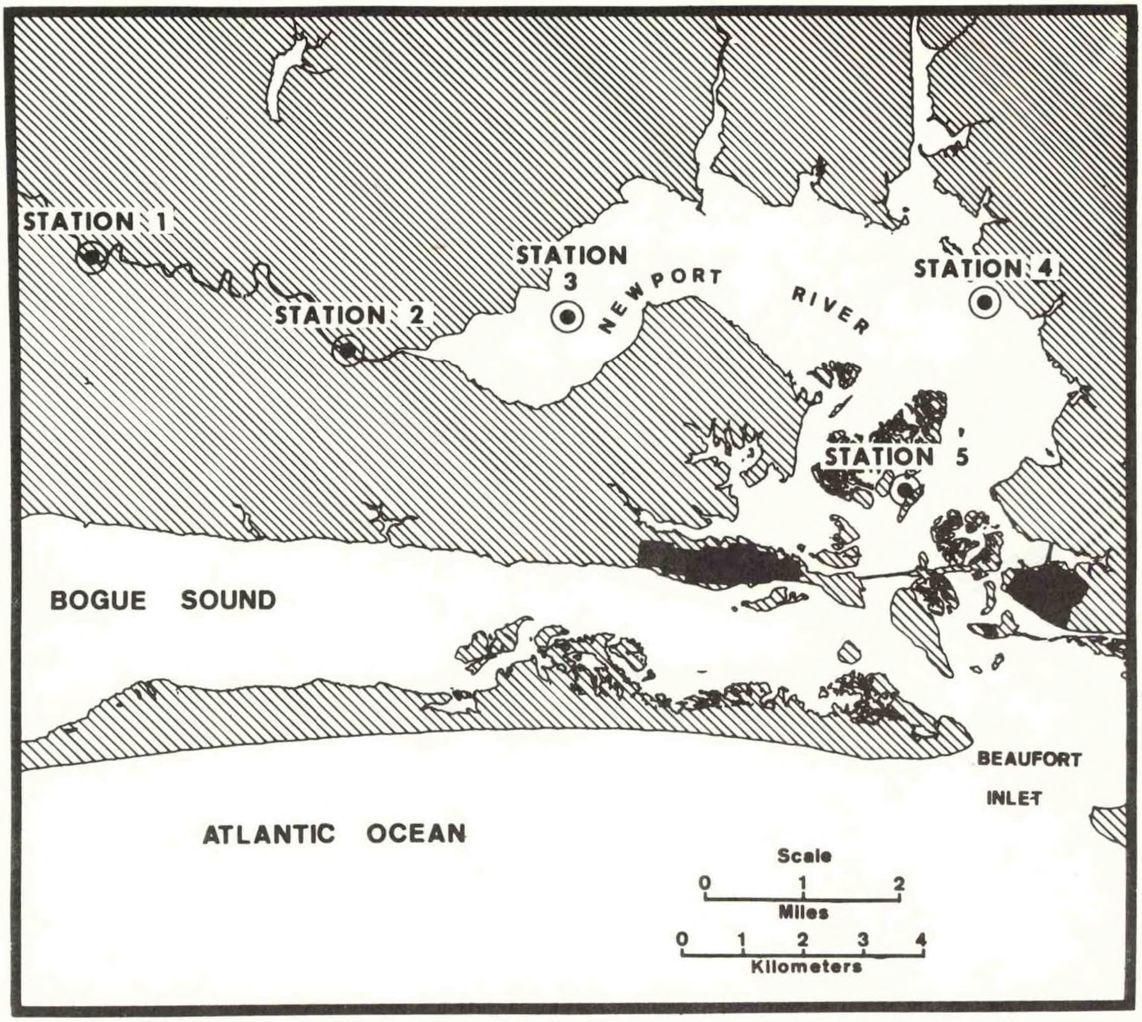

Figure 1.--Location of trawling stations in the Newport River estuary.

Results and Discussion

Effect of weight

To determine if weight had a significant effect on concentrations of Zn, Fe, and Mn in young estuarine fish during their period of most rapid growth, we collected and analyzed samples of anchovy, menhaden, and croaker over a wide range in weights. Dry weights of individual specimens varied by a factor of 11 in anchovy, 184 in menhaden, and 83 in croaker. With the exception of Mn in anchovy, concentrations of the above elements varied significantly with weight (Figs. 2, 3, and 4) and, except for Mn in menhaden, decreased as weight increased.

The relationship between concentrations of trace metals and weight varied for one element among different species and among different elements for the same species. The rate of decrease in concentrations of Zn with body weight, however, was the same for all three species (Fig. 2). The regression analysis for each species was highly significant ($P < 0.005$), although the three slopes were not significantly different ($P > 0.05$). Differences in intercepts among these species, however, were highly significant ($P < 0.005$). Thus concentrations of Zn decreased at the same rate as all three species increased in weight, although the absolute concentrations of Zn present in each species were different. The slopes of the regression line for these fish are substantially less than the slope of -0.5 given for the relationship between Zn and body weight for oysters collected from the Blackwater estuary in England (Preston, 1966).

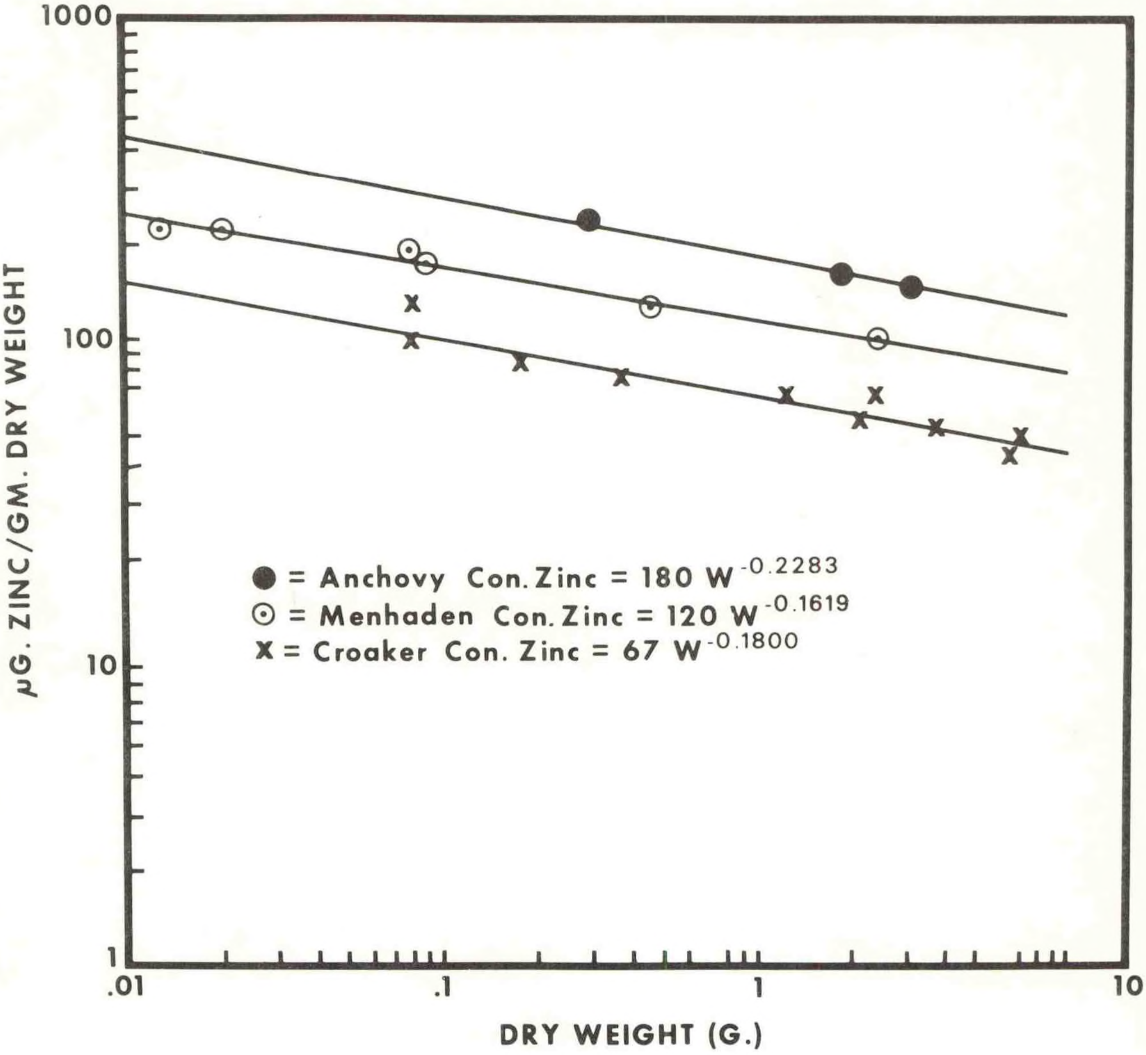

Figure 2.--Effect of weight on concentrations of Zn in anchovy, menhaden, and croaker. Each point represents the mean of at least five fish and the term "W" in the equations represents the dry weight (g) per fish.

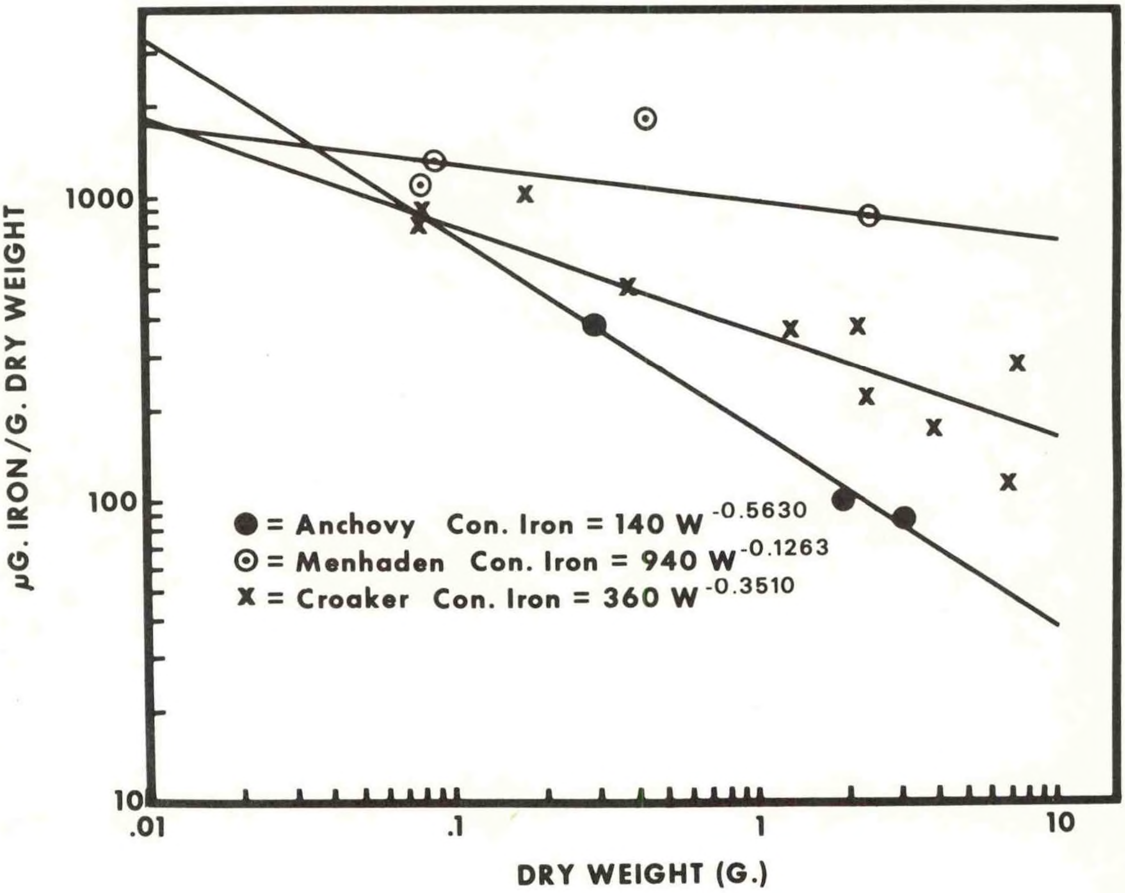

Figure 3.--Effect of weight on concentrations of Fe in anchovy, menhaden, and croaker. Each point represents the mean of at least five fish and the term "W" in the equations represents the dry weight (g) per fish.

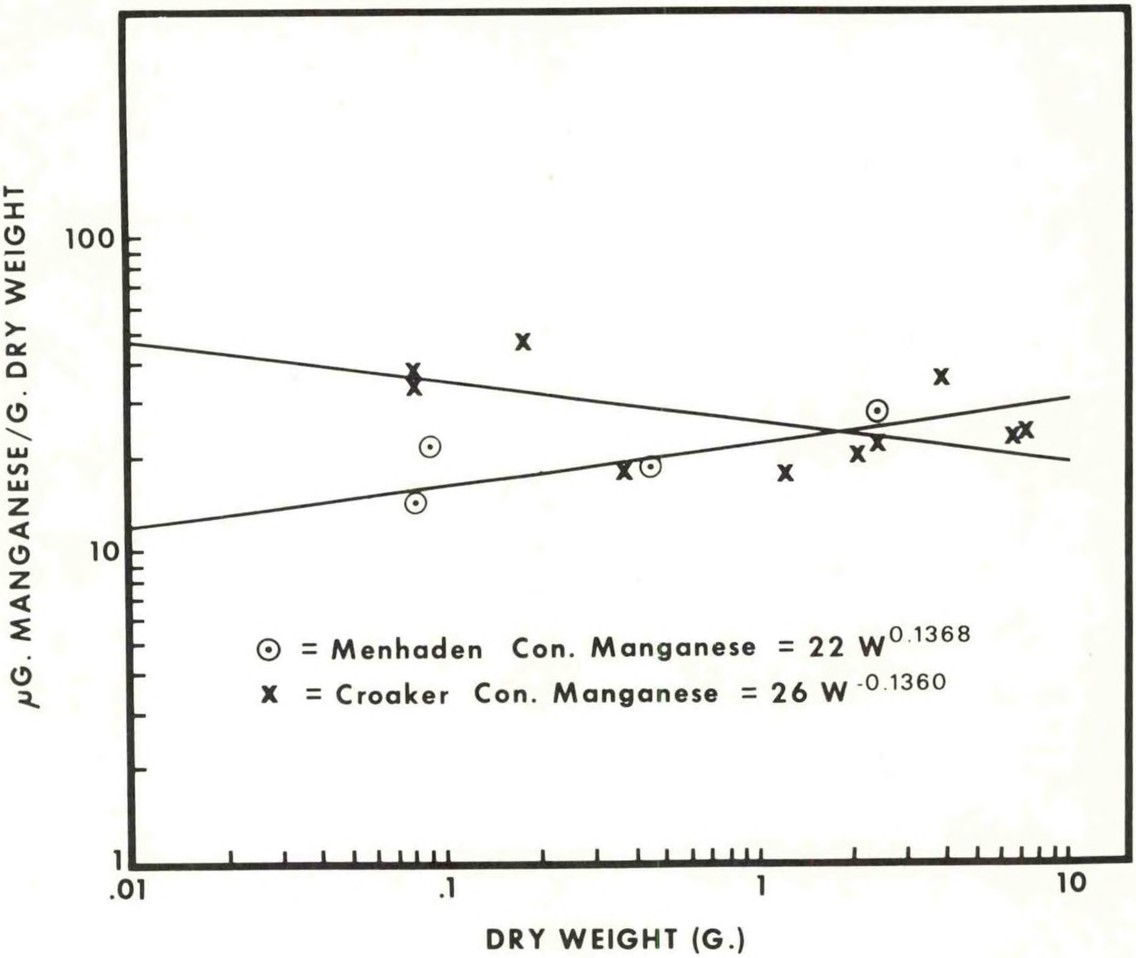

Figure 4.--Effect of weight on concentrations of Mn in menhaden and croaker. Each point represents the mean of at least five fish and the term "W" in the equations represents the dry weight (g) per fish.

estuarine fish. As these fish grow, the proportion of tissues which might accumulate highest concentrations of these metals, such as the G. I. tract, decreases as compared with muscle and bone; two tissues that contain relatively low concentrations of trace metals (Hoss and Baptist, In press). Baptist and Price (1962) also reported a reduced rate of accumulation of ^{137}Cs per unit weight in postlarval flounder during periods of rapid weight increase. Availability of the element for accumulation may also change during growth. All three species listed here are spawned in offshore waters and their larvae enter the estuary in early spring; many of which live in brackish water near the head of the estuary. As these fish increase in size, they move into the lower portion of the estuary and finally in the fall, migrate into the ocean. Earlier work in the Newport River estuary (Cross, Duke, and Willis, 1970) has shown that concentrations of Zn, Fe, and Mn in 0.1 N HCl extracts of sediment samples and concentrations of Fe and Mn in estuarine water decrease in a seaward direction. Therefore, as the fish move down the estuary, the environmental concentrations of Zn, Fe, and Mn are decreasing, which may be reflected in lower concentrations of these metals in the larger fish. For example, the smaller croaker (< 0.59 g dry weight) were collected at either station 1 or 2 and the larger fish were taken from station 3 and 4 (Fig. 1). The sample of smallest anchovy was taken at station 3 and the two samples of larger fish were taken at station 4. Menhaden also increased in weight as they were taken at progressively more seaward stations in the White Oak estuary.

The largest menhaden shown in figure 2 (2.4 g dry weight) were collected in the Newport River estuary as were all samples of anchovy and croaker. The other five menhaden samples, however, were collected from the White Oak River estuary which is located about 20 miles to the west of the Newport River estuary. It is interesting to note that the relationship between concentrations of Zn and weight in menhaden collected from two estuaries were described by the same equation.

The relationship between Fe and weight in anchovy and croaker was different from the relationship between Zn and weight in these two species. The slope of the regression line for Fe in anchovy was -0.5630 (Fig. 3) as compared with a slope of -0.2283 for Zn. The slope for Fe in croaker (-0.3510) was also higher than for Zn (-0.1800). Both of the slopes for Fe in each species were significantly different from their respective slopes for Zn ($P < 0.05$). The slopes for Zn and Fe in menhaden, however, were not different at the 5 percent level of significance.

The relationship between concentrations of Mn and body weight also varied among the three species (Fig. 3). Menhaden had a positive slope (0.1368); croaker had a negative slope (-0.1363) and the slope for Mn in anchovy was not significant and is not shown in figure 4. In addition, the slopes for Zn and Mn in croaker were not significantly different ($P > 0.05$).

The data represented by figures 2, 3, and 4 indicate the complex manner by which Zn, Fe, and Mn is accumulated by young

An interesting point concerning the relationship between trace metals and weight in menhaden is that these fish undergo a change in feeding type at a dry weight of about 0.02 g during their transformation from post-larvae to juveniles (Lewis, Wilkens, and Gordy, unpublished manuscript). They change from a selective particulate-feeding carnivore in their larval stages to a non-selective, filter-feeding omnivore (Reintjes and Pacheco, 1966). This change in feeding type, however, did not affect the relation between concentrations of Zn and body weight as no change in slope occurred (Fig. 2).

Differences among species

Because weight affected concentrations of Zn, Fe, and Mn in fish, comparisons of differences in concentrations of these metals among species were made only for fish that had dry weights of 1-10 g. In addition to anchovy, menhaden, and croaker, we also collected samples of spot and pinfish that had dry weights in this range. The wet/dry and ash/dry weight ratios for these five species are listed in Table 1. Because concentrations of trace metals may not be distributed normally in marine organisms (Ting and de Vega, 1969; Wolfe, 1970), the arithmetic mean of individual measurements of concentrations of Zn, Fe, and Mn in five species of fish were compared with the median and concentration at the mean log value for each element in each species (Table 2). All medians were within two standard errors

Table 1.--Mean wet/dry and ash/dry weight ratios for five species of estuarine fish that had dry weights from 1-10 g

Species	N[1]	Wet/Dry	Ash/Dry
Spot	89	4.0	0.22
Croaker	31	4.1	0.20
Pinfish	52	3.7	0.23
Anchovy	19	4.0	0.16
Menhaden	10	4.2	0.22

[1] Number of individuals

Table 2.--Concentrations of Zn, Fe, and Mn in five species of fish. These values are expressed as the mean ± two standard errors, the median, and the concentration at the mean log value

Expression of concentration[1]	Spot (89)[2]			Croaker (31)[2]			Pinfish (52)[2]			Anchovy (19)[2]			Menhaden (10)[2]		
	Zn	Fe	Mn	Zn	Fe	Mn	Zn	Fe	Mn	Zn	Fe	Mn	Zn	Fe	Mn
Mean conc. ± 2 S.E.	68±2	670±112	35±4.8	49±2.6	180±36	28±6.6	74±4.0	420±48	32±3.6	150±10.6	90±8.6	19±1.6	100±13.2	850±220	27±6.6
Median Value	67	510[3]	28[3]	49	180	23	75	410	31	150	86	19	100	780	24
Conc. at mean log value	67	500	28	48	160	24	72	380	31	150	88	20	100	670	25

[1] μg/g dry wt.

[2] Number of individuals analyzed.

[3] More than two standard errors from the mean.

of the arithmetic mean with the exception of concentrations of Fe and Mn in spot. Concentrations of both of these elements were positively skewed as the arithmetic mean was greater than the median. Their concentrations at the mean log value, however, were equal to the median. In addition, the median values for all other concentrations of Zn, Fe, and Mn listed in Table 2 were within two standard errors of the mean log value. We, therefore, used the log-transformed values to compare differences among species.

Concentrations of Zn and Fe varied significantly among samples of spot, croaker, pinfish, anchovy, and menhaden although concentrations of Mn did not (Figs. 5, 6, and 7). Concentrations of Zn were highest in the two plankton feeders (anchovy and menhaden) and lowest in croaker. Spot and pinfish, however, had similar concentrations of Zn. Highest concentrations of Fe were found in menhaden and spot. Lowest concentrations of Fe were found in anchovy even though this species had the highest concentrations of Zn. The differences in the mean Fe values between menhaden and anchovy is striking inasmuch as both of these species feed on plankton. Another interesting comparison can be made between spot and croaker. These two species are closely related phylogenetically, are both primarily bottom feeders, live in the same habitat, and yet have significantly different concentrations of both Zn and Fe. Therefore, subtle differences in feeding habits may occur between

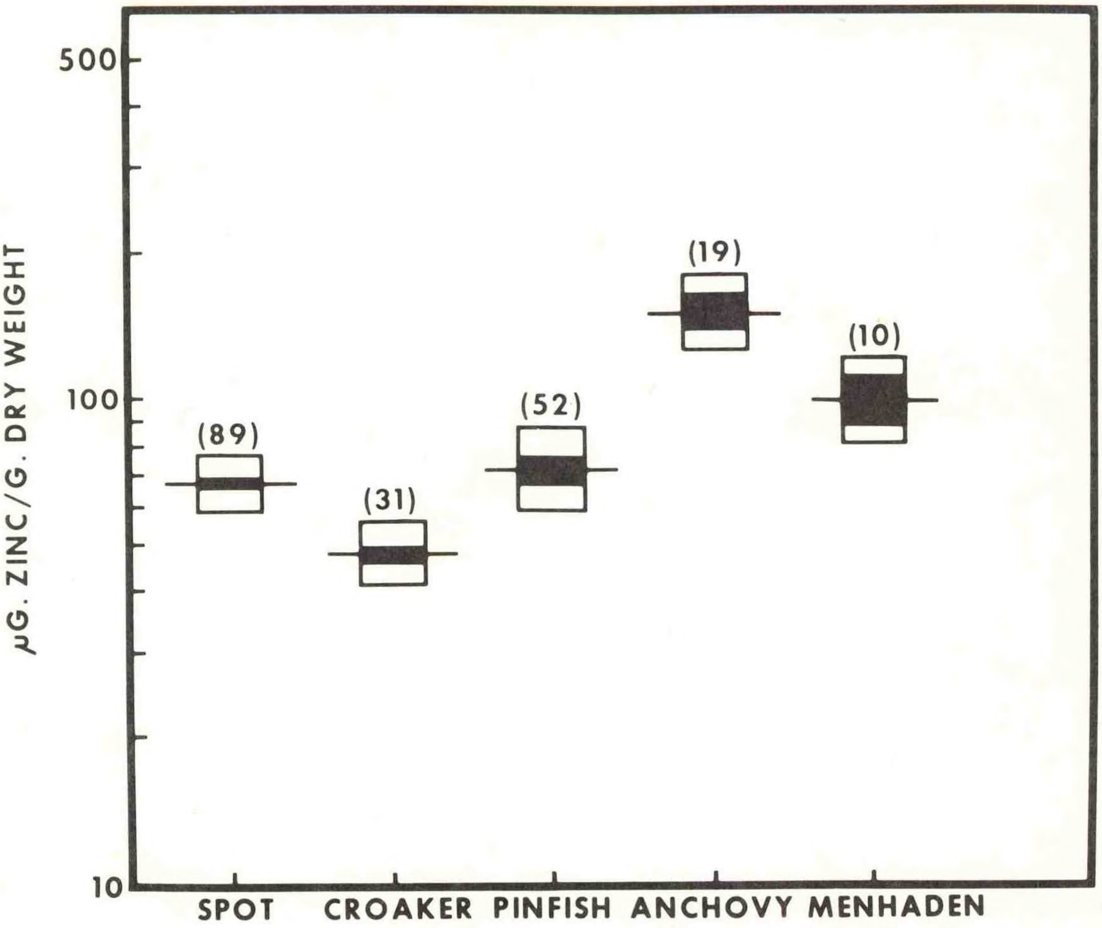

Figure 5.--Distribution of Zn among five species of estuarine fish which had dry weights from 1-10 grams. The mean, ± one standard deviation and ± two standard errors of the mean were computed on log-transformed values and the antilogs are shown on the graph. The number in parentheses above each set of values represents the number of individuals analyzed in each species.

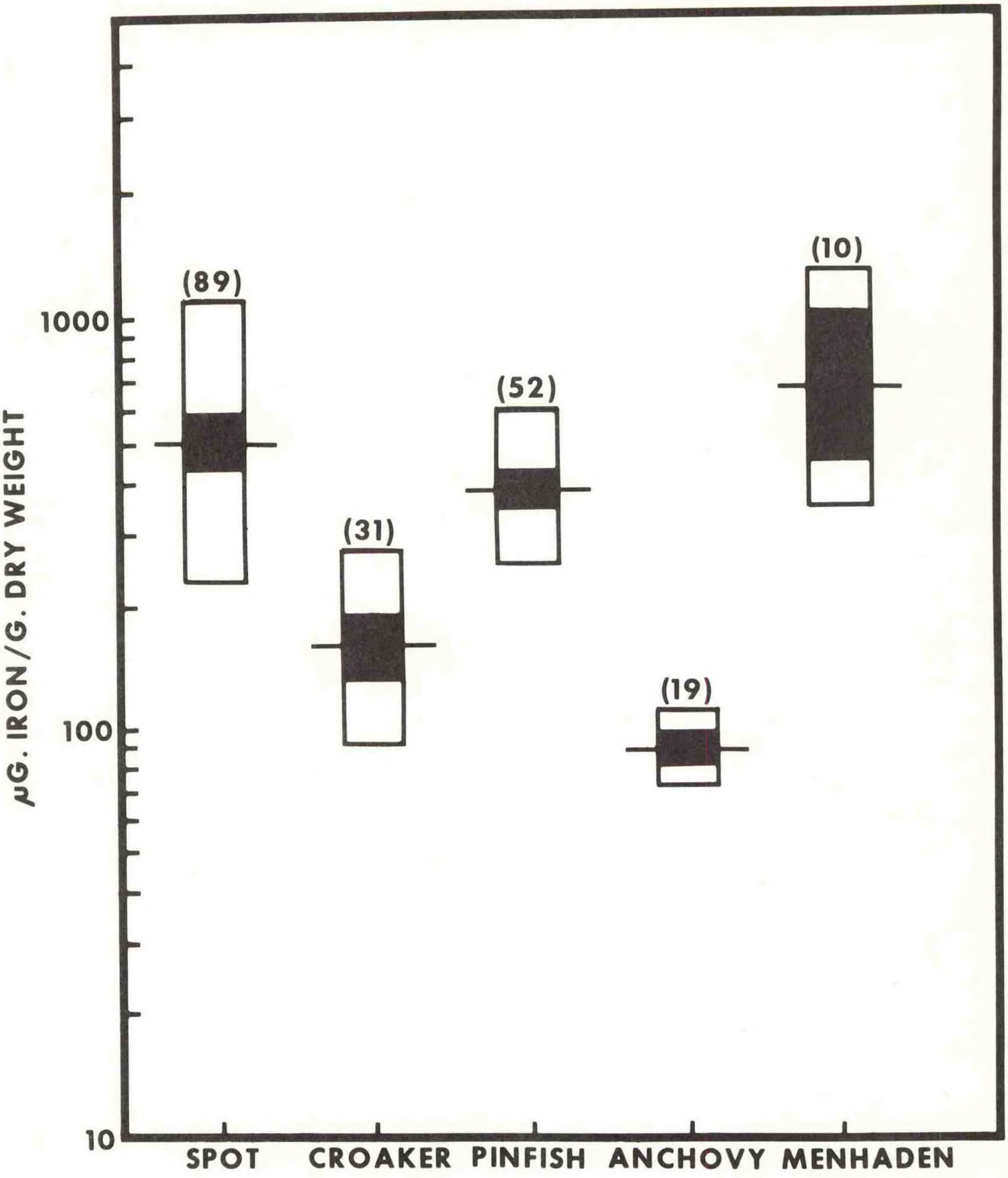

Figure 6.--Distribution of Fe among five species of estuarine fish which had dry weights from 1-10 grams. The mean, ± one standard deviation and ± two standard errors of the mean were computed on log-transformed values and the antilogs are shown on the graph. The number in parentheses above each set of values represents the number of individuals analyzed in each species.

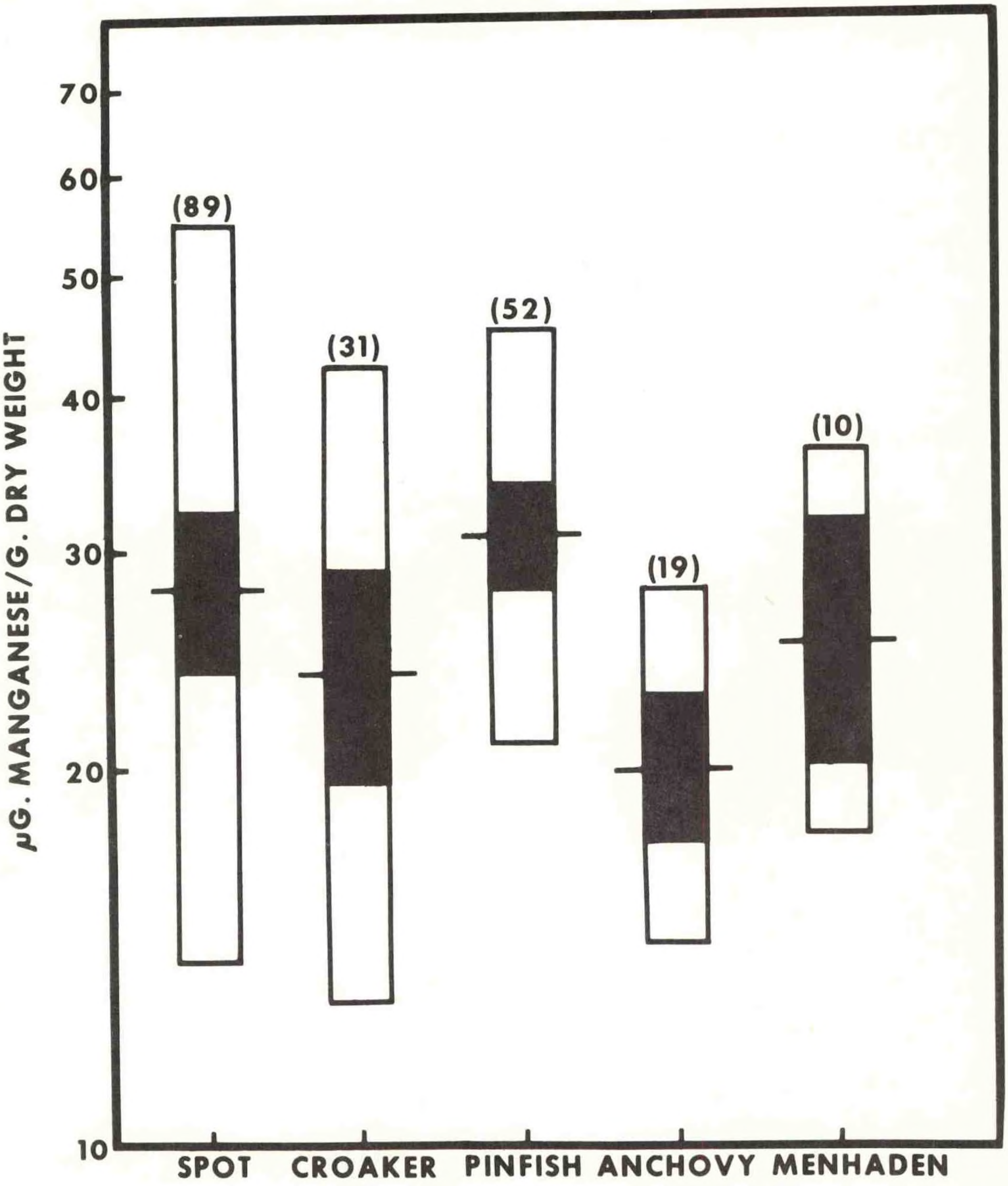

Figure 7.--Distribution of Mn among five species of estuarine fish which had dry weights from 1-10 grams. The mean, ± one standard deviation and ± two standard errors of the mean were computed on log-transformed values and the antilogs are shown on the graph. The number in parentheses above each set of values represents the number of individuals analyzed in each species.

anchovy and menhaden and between spot and croaker that influences the concentrations of Zn and Fe in these species. Manganese, was the least abundant of the three elements measured in these species, and was also more evenly distributed among species than either Zn or Fe (Fig. 7).

References

Baptist, J. P., and T. J. Price. 1962. Accumulation and retention of cesium ^{137} by marine fishes. U.S. Fish Wildl. Serv., Fish. Bull. 62: 177-187.

Caldwell, D. K. 1957. The biology and systematics of the pinfish *Lagodon rhomboides* (Linnaeus). Bull. Florida State Museum 2: 75-173.

Cross, F. A., T. W. Duke, and J. N. Willis. 1970. Biogeochemistry of trace elements in a coastal plain estuary: Distribution of manganese, iron, and zinc in sediments, water, and polychaetous worms. Chesapeake Sci. 11: 221-234.

Darnell, R. M. 1958. Food habits of fishes and larger invertebrates of Lake Pontchartrain, Louisiana, an estuarine community. Inst. Mar. Sci., Univ. Texas 5: 353-416.

Duke, T. W., J. N. Willis, and T. J. Price. 1966. Cycling of trace elements in the estuarine environment. I. Movement and distribution of zinc-65 and stable zinc in experimental ponds. Chesapeake Sci. 7: 1-10.

Duke, T. W. 1967. Possible routes of zinc-65 from an experimental estuarine environment to man. J. Water Pollut. Contr. Fed. 39: 536-542.

Hoss, D. E., and J. P. Baptist. In press. Accumulation of soluble and particulate radionuclides by estuarine fish. 3rd Nat. Symposium on Radioecology, May 10-12, 1971. Oak Ridge, Tenn.

Hildebrand, S. F., and L. E. Cable. 1930. Development and life history of fourteen teleostean fishes at Beaufort, N.C. Bull. U.S. Bureau Fish. 46: 383-488.

Lewis, R. M., E. P. J. Wilkens, and H. R. Gordy. In preparation. Description of young Atlantic menhaden, *Brevoortia tyrannus*, in the White Oak River estuary, North Carolina.

National Academy of Sciences--National Research Council. 1962. Disposal of low-level radioactive waste into Pacific coastal waters. NAS--NRC Publ. 985, Washington, D.C. 87 p.

Preston, A. 1966. The concentration of zinc-65 in the flesh of oysters related to the discharge of cooling pond effluent from the C.E.G.B. nuclear power station at Bradwell-on-Sea, Essex, p. 995-1004. *In* B. Åberg and F. P. Hungate (eds.), Radioecological concentration process. Pergamon, New York.

Reintjes, J. W., and A. L. Pacheco. 1966. The relation of menhaden to estuaries. Amer. Fish. Soc., Special Publ. 3: 50-58.

Schleske, C. L., D. A. Wolfe, and D. E. Hoss. In press. Ecological implications of fallout radioactivity accumulated by estuarine mollusks and fishes. 3rd Nat. Symposium on Radioecology, May 10-12, 1971. Oak Ridge, Tenn.

Ting, R. Y., and V. Roman de Vega. 1969. The nature of the distribution of trace elements in longnose anchovy (*Anchoa lamprotaenia* Hildebrand), Atlantic thread herring (*Opisthonema oglinum* LaSueur) and alga (*Udotea flabellum* Lamouroux), p. 527-534. *In* D. J. Nelson and F. C. Evans (eds.), Symposium on radioecology. USAEC CONF-670503. Oak Ridge, Tenn.

Turner, W. R. 1971. Distribution and relative abundance of fishes in the Newport River, North Carolina. This report.

Williams, R. B., and M. B. Murdoch. 1966. Phytoplankton production and chlorophyll concentration in the Beaufort Channel, North Carolina Limnol. Oceanogr. 11: 73-82.

Williams, R. B., and M. B. Murdoch. 1969. The potential importance of *Spartina alterniflora* in conveying zinc, manganese, and iron into estuarine food chains, p. 431-439. *In* D. J. Nelson and F. C. Evans (eds.), Symposium on radioecology. USAEC CONF-670503. Oak Ridge, Tenn.

Wolfe, D. A. 1967. Seasonal variation of caesium 137 from fallout in a clam, *Rangia cuneata* Gray. Nature 215: 1270-1271.

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

Wolfe, D. A. In press. Fallout ^{137}Cs in clams (*Rangia cuneata*) from the Neuse River estuary, North Carolina. Limnol. Oceanogr.

Wolfe, D. A., and C. D. Jennings. In press. Iron-55 and $^{103-106}$Ru in the brackish-water clam *Rangia cuneata*. 3rd Nat. Symposium on Radioecology, May 10-12, 1971. Oak Ridge, Tenn.

Wolfe, D. A., and C. L. Schelske. 1969. Accumulation of fallout radioisotopes by bivalve molluscs from the lower Trent and Neuse Rivers, p. 493-504. *In* D. J. Nelson and F. C. Evans (eds.), Symposium on radioecology. USAEC CONF-670503. Oak Ridge, Tenn.

^{55}Fe and ^{103} ^{106}Ru IN THE BRACKISH-WATER CLAM RANGIA CUNEATA

Douglas A. Wolfe, C. David Jennings, J. Lewis

and J. H. Brooks

A wide array of γ-emitting radionuclides from nuclear fallout has been detected in the estuarine clam *Rangia cuneata* (Wolfe and Schelske 1969). Because it occurs over a very wide range of salinities (<1 to ~20 o/oo), this species has proved useful in describing the distribution and variation of ^{137}Cs in the Trent-Neuse Estuary of the North Carolina coastal plain (Wolfe 1967, In Press). It was noted earlier that ^{103} & ^{106}Ru were less concentrated in *Rangia* from relatively fresh upstream stations than in those from the higher salinities downstream (Wolfe and Schelske 1969). At that time we speculated: "If ^{106}Ru exhibits a high solubility and mobility in fresh water (Auerbach and Olson 1963), it was probably less available for uptake by *Rangia* at the upstream stations. In the more brackish waters downstream, ^{106}Ru may be adsorbed onto precipitating ferric hydroxide particles (Jones 1960) which could be directly filtered by *Rangia*." In this paper, we explore this observation further, reporting additional data on ^{103} & ^{106}Ru in *Rangia*, along with analyses of the highly significant fallout isotope ^{55}Fe and of the stable elements Fe, Mn, Zn, and Cu.

Methods

The general characteristics of the Trent-Neuse Estuary, the sampling stations for Rangia, and the preparation of samples for gamma spectrometry have been described previously (Wolfe and Schelske 1969).

After spectral stripping of ^{40}K, ^{65}Zn, ^{54}Mn, ^{95}Zr-^{95}Nb, and ^{137}Cs, ruthenium-106 and ruthenium-103 were estimated from their gamma-energy photopeaks at 0.513 and 0.498 MeV, respectively. These energies were not resolved by our 4 X 4 inch NaI(Tl) scintillation crystal coupled to a Nuclear Data 512-channel analyzer (Computer Series 130) (Schelske 1966), and samples were recounted at least once in order to establish the presence or absence of ^{103}Ru and to determine the relative amounts of the two ruthenium isotopes. When ^{103}Ru was present in the samples, ^{106}Ru was estimated from a recount made at least 53 days (average: 165 days) after the first analysis and ^{103}Ru was calculated to account for the difference in the 0.5 MeV radioactivity between the first and last analyses of the sample. Immediately after the Chinese nuclear tests of May 9 and December 28, 1966, ^{140}Ba-^{140}La accompanied ^{103}Ru in Rangia. Interference from the 0.487 MeV photopeak of ^{140}Ba-^{140}La was corrected by a proportionate amount of its 1.60 MeV photopeak in the first count. Ruthenium-106 was not analyzed until after ^{140}Ba-^{140}La had decayed below detectable limits in the samples. Half-life studies on the radioactivity of the 0.5 MeV photopeak substantiated the presence of ^{103}Ru and ^{106}Ru (Fig. 8), and showed that the interferences from ^{140}Ba-^{140}La and other nuclides were satisfactorily corrected.

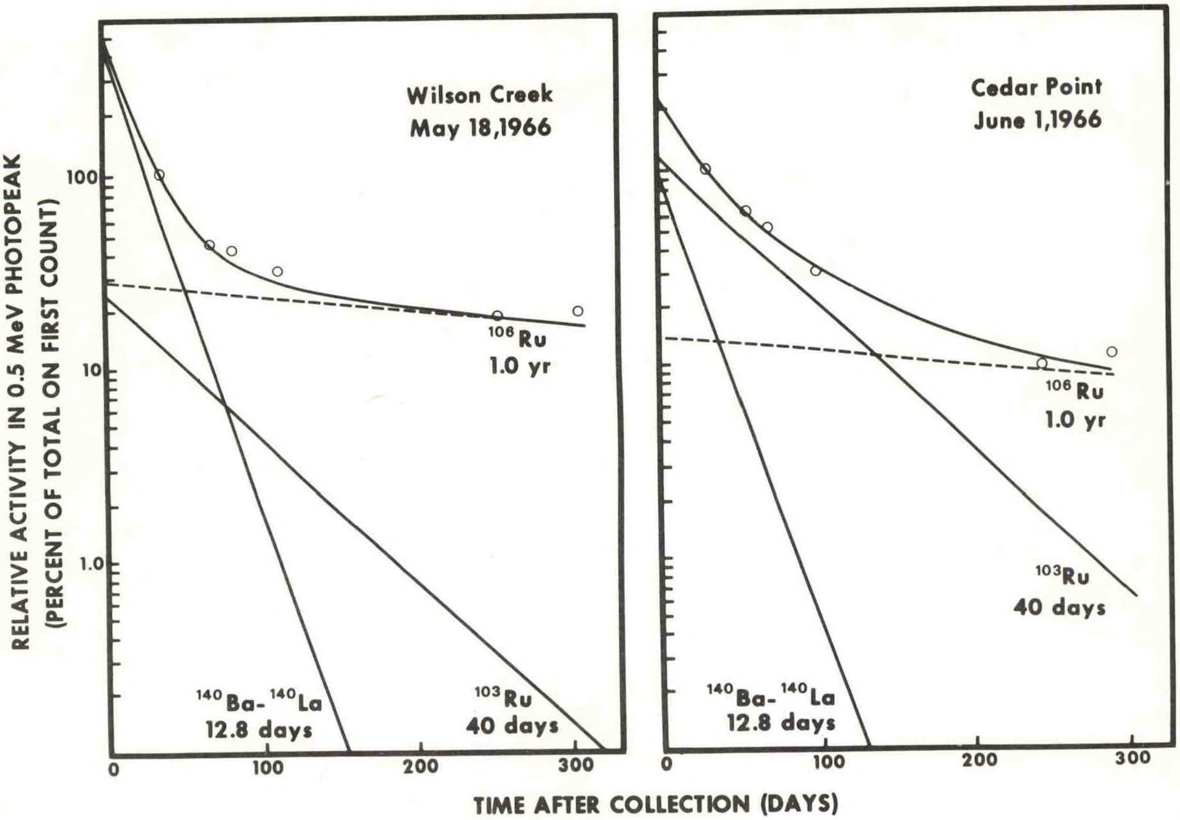

Figure 8.--Resolution of 0.5 MeV photopeak radioactivity into three components: ^{106}Ru, ^{103}Ru, and ^{140}Ba-^{140}La. Open circles represent the photopeak radioactivity as percent of total on the first analysis, after correction for contributions for the Compton radioactivity of ^{40}K, ^{65}Zn, ^{54}Mn, ^{95}Zr-^{95}Nb, and ^{137}Cs. Straight lines represent the reported analyses of ^{106}Ru (dotted) and ^{103}Ru and ^{140}Ba-^{140}La (solid), and the curved solid lines are the sum of the three separate components.

For the determination of ^{55}Fe, ash samples were dissolved in 6 M HCl; and iron was separated by complexing with 10 percent alamine-336 (General Mills Chemical Division, Kankakee, Illinois) in xylene, then back-extracted into 1 M perchloric acid and precipitated as $Fe(OH)_3$ by the addition of NH_4OH. The precipitates were then dissolved in 16 ml of 0.5 N HCl and carried through the procedure of Cosolito et al (1968), in which ^{55}Fe is ultimately determined by liquid scintillation counting of the 5.9 keV X-ray of the manganese-55 daughter product. Results for ^{55}Fe and radioruthenium were decay-corrected to the date of sample collection.

Iron, manganese, zinc and copper were analyzed by atomic absorption spectrophotometry (Perkin-Elmer Model 303), following treatment of the ash with concentrated HNO_3, evaporation to dryness, and dissolution of the residue in 0.25 N HCl (1 g ash/50 ml).

Ruthenium-106 in *Rangia*

Rangia cuneata from our two downstream stations contained about 60 percent more ^{106}Ru than did *Rangia* from the four upstream stations (Table 3). Most of these analyses have been reported previously (Wolfe and Schelske 1969), but are supplemented here by additional samples from Wilson Creek, Union Point and Pinecliff during summer and fall of 1967. In addition, the correction for ^{103}Ru has been further refined, so that the mean values in

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Table 3.--Ruthenium-106 in *Rangia cuneata* from the Trent-Neuse estuary, 1965-1967, expressed as mean pCi/100 grams wet weight ± S.E. for each station

Station	Number of samples	^{106}Ru
Wilson Creek	15	4.18 ± 0.37
Brice Creek	13	4.91 ± 0.42
Lewis Ferry	12	3.97 ± 0.51
Union Point	16	3.43 ± 0.36
Pinecliff	16	6.38 ± 0.57
Cedar Point	9	7.58 ± 0.59
4 upstream stations	56	4.11 ± 0.22
2 downstream stations	25	6.72 ± 0.43

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table 3 are 6 to 7 percent lower than previous estimates. By the Student t-test, there were no significant differences at the 99 percent confidence level between the mean ^{106}Ru-contents of clams from any of the four upstream stations nor between clams from the two downstream stations. With one exception (Brice Creek-Pinecliff), however, each of the upstream station means was significantly (at the 99 percent level) lower than either mean from the downstream stations, and the difference between means of all upstream samples and all downstream samples is significant at the 99.9 percent level.

The difference between upstream and downstream stations is evident also when the values are graphed as monthly averages against sampling time (Fig. 9). The seasonal cycle (with a winter minimum and a midsummer maximum) which was so pronounced for ^{137}Cs in these clams (Wolfe 1967) is not readily apparent for ^{106}Ru. Such a cyclic pattern would correspond to that reported for seasonal variation of deposition of atmospheric fallout (Parker and Crookall 1961). Identifying any possible cyclic nature of ^{106}Ru in Rangia is made very difficult, however, by the variability among individual stations and samples (Fig. 9), which is complicated further by the introduction of fresh ^{106}Ru immediately after the third and fifth Chinese nuclear tests of May 9 and December 28, 1966. This effect of the Chinese tests is especially apparent at the downstream stations (Fig. 9). The initial decreasing trend (September 1965-April 1966) may have been produced by the second Chinese test

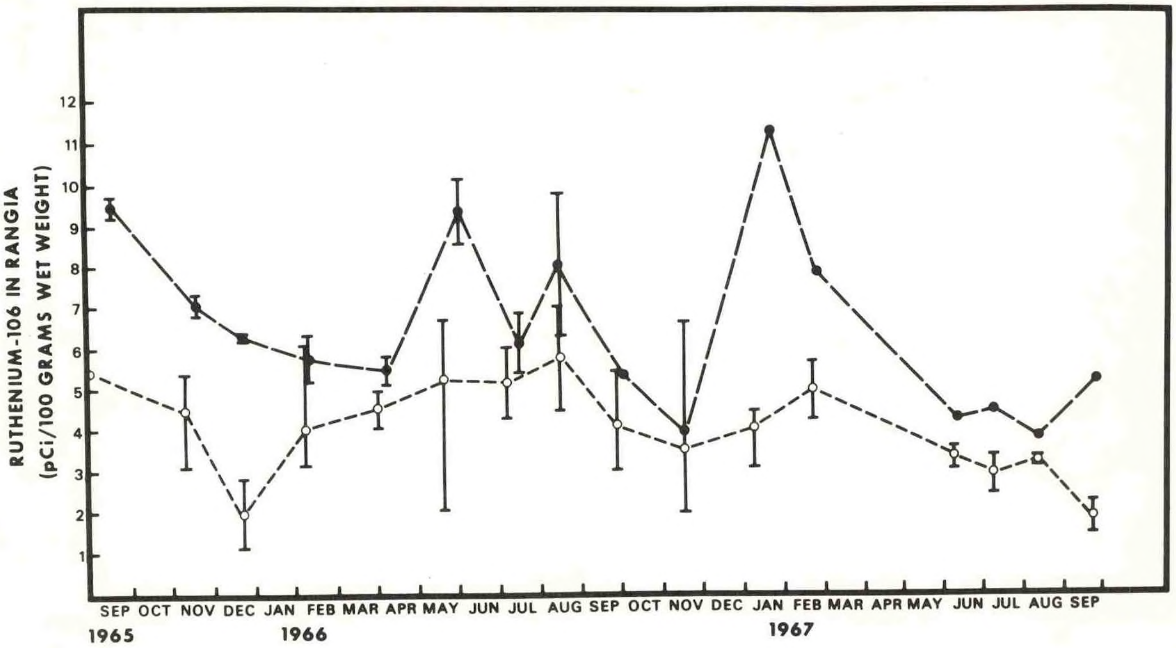

Figure 9.--Ruthenium 106 in <u>Rangia</u> <u>cuneata</u> from the Trent-Neuse estuary, 1965-1967. Values are shown as monthly averages and ranges for four upstream stations (open circles) and two downstream stations (solid circles). After August 1966, only one downstream station (Pinecliff) was sampled because <u>Rangia</u> were very scarce at the other station. After February 1967, only two upstream stations (Wilson Creek and Union Point) were sampled.

conducted on May 14, 1965. The third and fifth Chinese tests produced sudden increases in ^{106}Ru in *Rangia*, also followed by periods of generally decreasing trends. It appears that the sudden influxes of ^{106}Ru from the early Chinese fission tests "equilibrated" at about 5 to 6 pCi/100 g in *Rangia* within about 6 months after the tests were conducted.

Apart from the fluctuations caused by Chinese testing or seasonality of fallout deposition, the concentration of ^{106}Ru in *Rangia* appears generally to be decreasing very slowly during 1965-1967. This long-range trend cannot be quantified from the data, but the concentration appears to be decaying with a half-life of more than 1 year, which is the physical half-life of the isotope. This situation was observed also for ^{65}Zn in oysters during 1964-1966 (Wolfe 1970), and indicates the continued introduction of ^{106}Ru into *Rangia's* environment during the sampling period, probably accompanied by slow turnover of the isotope by *Rangia*.

Ruthenium-103 from Chinese Nuclear Tests

Samples of *Rangia* collected between May 1966 and February 1967 usually contained ^{103}Ru in addition to ^{106}Ru (Fig. 10). The ^{103}Ru activity at 0.50 MeV was distinguished from the 0.51 MeV γ-activity of ^{106}Ru by successive recounts on the basis of half-life (40 days for ^{103}Ru; 1.0 yr for ^{106}Ru). Samples collected during May and June, 1966, and January-February, 1967 also contained ^{140}Ba-^{140}La, whose 0.487 MeV photopeak interfered with the $^{103-106}$Ru analysis and required correction (Fig. 8).

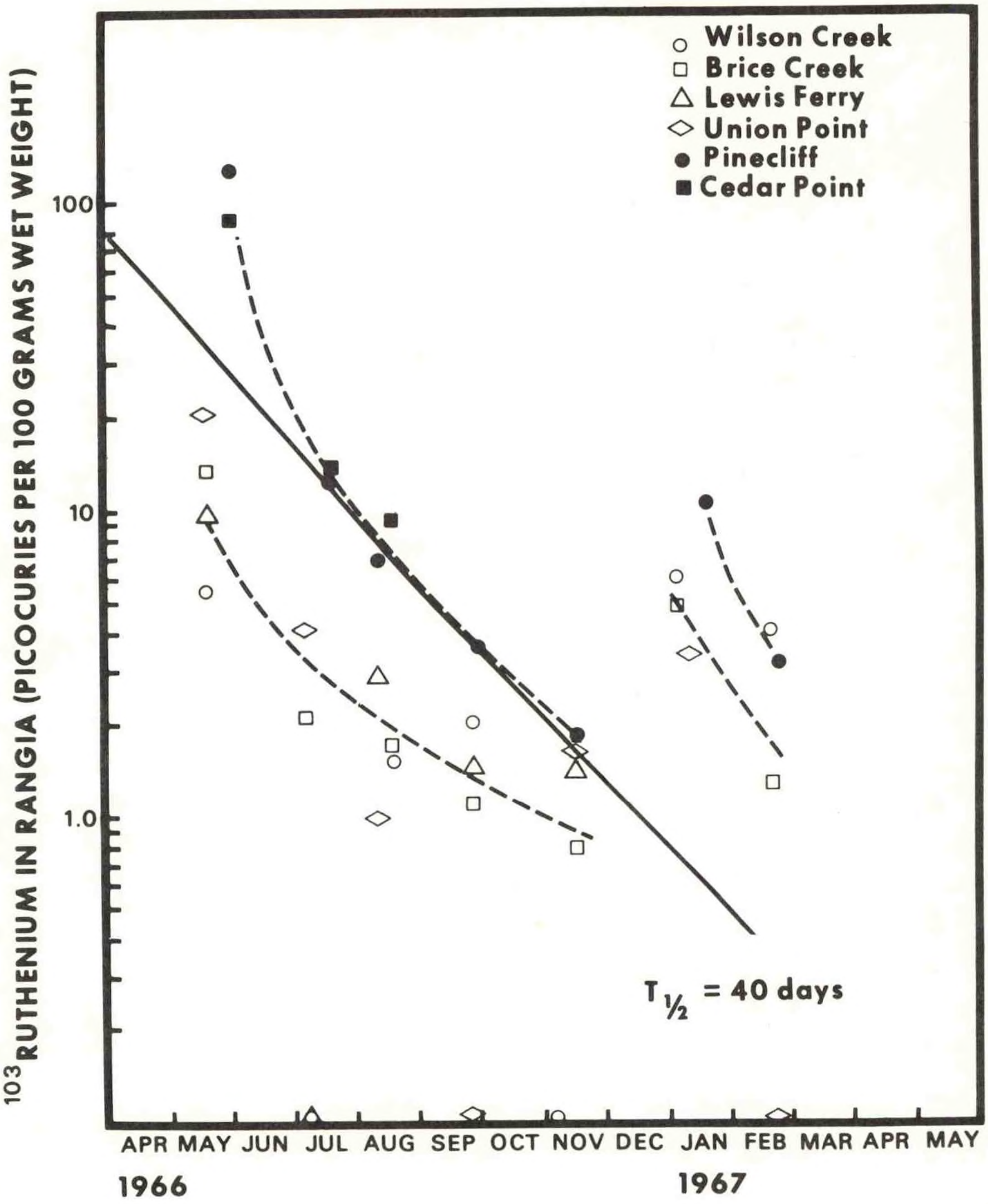

Figure 10.--Ruthenium 103 in Rangia cuneata after the 3rd and 5th Chinese nuclear tests May 9 and December 28, 1966. The dotted lines are fitted by inspection to the data from upstream stations (open symbols) and downstream stations (solid symbols). The physical half-life of ^{103}Ru (40 days) is shown as the solid line, which is coincident with the loss of ^{103}Ru from Rangia downstream. In five upstream samples collected during this period, ^{103}Ru was below the limit of detectability (points appear on the abscissa, above).

Samples collected before May 1966 and after May 1967 contained no significant activity at 0.5 MeV except ^{106}Ru. Any ^{103}Ru from the second Chinese test (May 14, 1965) was below detectable limits when our September, 1965 samples were analyzed.

Several significant points of interest are raised by the data in figure 10. First--^{103}Ru was present in Rangia on May 18, 1966, less than 10 days after the third Chinese test; and the concentration was again elevated on January 4, 1967, less than 8 days after their fifth test. Fallout from the Chinese nuclear tests conducted in 1964 and 1965 initially reached surface air at New York City 8 to 10 days after the tests, and reached peak concentrations only after 12 to 13 days (Krey and Rosa 1965). One can surmise, therefore that fallout ruthenium nuclides rapidly become available to Rangia, and that the concentrations of ^{103}Ru measured in Rangia collected on May 18, 1966 and January 4, 1967 were probably not yet at their respective maximum after the two tests.

Secondly, even under those conditions of "instantaneous" introduction of ^{103}Ru, the isotope was concentrated to much higher levels by Rangia at the downstream stations (Fig. 10), suggesting as with ^{106}Ru a greater availability of the isotope to the clams at the higher salinities.

Third--the data on ^{103}Ru in Rangia simulate a biological radioisotope-retention experiment, from which the biological half-life ($Tb_{1/2}$) of ^{103}Ru in Rangia can be estimated. For this exercise, two assumptions are required: that the initial levels of ^{103}Ru represent a maximum level; and that no additional ^{103}Ru is available to the clams during the loss period. Probably neither of these assumptions is met, and the loss rate or turnover will therefore be underestimated and $Tb_{\frac{1}{2}}$ will be overestimated. Proceeding on the assumptions, however, it appears (Fig. 10) that retention of ^{103}Ru by Rangia consists of more than one rate function and that the slow component has an effective half-life of about 40 days. (To exceed 40 days negates the second assumption above.) Using the procedures followed by Baptist et al. (1970), we resolved the curve drawn in figure 10 for the downstream stations, June-December 1966, into 2 components: a slow component with an infinite biological half-life (an obvious over-estimate), and a fast component with a maximum effective half-life of 7 days and a corresponding maximum $Tb_{\frac{1}{2}}$ of 8.5 days. The long biological half-life estimated here for the slow component of ^{103}Ru retention is consistent also with the effective retention of ^{106}Ru by Rangia (Fig. 9).

Iron-55 and Total Iron in Rangia

Iron-55 was analyzed in seven samples from an upstream station (Union Point) and in eight samples from downstream at Pinecliff (Table 4), while total iron and other elements were analyzed in several samples from each of our six stations (Table 5). Iron-55 was more concentrated in clams at the down-stream station than in those from upstream, whether expressed as concentration on a wet weight basis or as specific activity.

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Table 4.--Iron-55 in *Rangia*

Date	^{55}Fe pCi/100 g wet wt (± counting error)	Specific activity pCi ^{55}Fe/g Fe	^{106}Ru/^{55}Fe pCi/pCi
	Union Point Station		
5/18/66	0.40 ± 0.10	85	5.1
7/5/66	0.72 ± 0.10	88	6.1
8/10/66	0.79 ± 0.11	76	7.1
9/26/66	0.32 ± 0.07	52	17
11/15/66	0.50 ± 0.08	82	3.9
1/11/67	0.77 ± 0.13	67*	5.7
2/23/67	0.44 ± 0.08	61*	13
	Pinecliff Station		
4/5/66	1.54 ± 0.20	340	3.3
6/1/66	1.52 ± 0.20	260	4.7
7/14/66	1.07 ± 0.11	260	5.0
8/10/66	0.88 ± 0.10	160	7.2
9/29/66	0.51 ± 0.07	160	10
11/16/66	2.03 ± 0.23	280	2.0
1/18/67	1.46 ± 0.20	220*	7.7
2/23/67	1.27 ± 0.17	170*	6.2

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Table 4.--Continued

Station	Number of samples	^{55}Fe pCi/100 g wet wt (±S.E.)	Specific activity pCi ^{55}Fe/g Fe (±S.E)	^{106}Ru/^{55}Fe pCi/pCi (±S.E.)
Union Point Upstream	7	0.56 ± 0.07	73 ± 5	8.3 ± 1.8
Pinecliff Downstream	8	1.29 ± 0.16	230 ± 23	6.1 ± 0.9
Probability level (Upstream vs Downstream)		$P<.002$	$P<.0001$	$P>.20$
All samples	15	0.95 ± 0.13	157 ± 24	7.1 ± 1.0

*Fe was estimated by atomic absorption immediatelyafter dissolution of $Fe(OH)_3$ in 0.5 N HCl, during preparation of samples for ^{55}Fe analysis.

Table 5.—Mean concentrations of Fe, Mn, Zn, and Cu (± S.E.) in *Rangia cuneata* from the Trent-Neuse estuary. Samples were analyzed by atomic absorption spectrophotometry.

Station	Number of samples	Fe	Mn	Zn	Cu
		Ppm, wet weight basis			
Wilson Creek	9	58.9 ± 7.4	3.19 ± 0.52	9.35 ± 0.74*	0.70 ± 0.09††
Brice Creek	7	49.2 ± 3.9†	2.52 ± 0.54	7.99 ± 0.65	1.28 ± 0.13
Lewis Ferry	10	63.6 ± 6.2	3.60 ± 0.69	11.9 ± 0.80††	1.32 ± 0.12
Union Point	11	69.4 ± 6.9†	2.51 ± 0.64	13.3 ± 0.58††	1.13 ± 0.08
Pinecliff	8	55.8 ± 5.3	2.52 ± 0.78	7.42 ± 0.47	1.43 ± 0.13
Cedar Point	8	49.3 ± 7.0	4.86 ± 1.44	6.24 ± 0.63	1.24 ± 0.09
Overall Mean:	49	56.9 ± 2.7	3.24 ± 0.34	9.64 ± 0.45	1.17 ± 0.05

*For Zn, Wilson Creek was significantly different (.95) from all stations except Brice Creek.

†Different significantly at .95 level

††Different significantly at .95 level from all means in column not marked similarly

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The upstream-downstream distribution of ^{55}Fe was very similar to that of ^{106}Ru, as evidenced by the non-significant difference between activity ratios for the two nuclides upstream and downstream (Table 4).

In order to estimate the loss rate of ^{55}Fe from _Rangia_ during the sampling period, each value for specific activity was decay-corrected to April 5, 1966, and was expressed as a percent of the mean value for the station where the sample was collected. The mean specific activities (pCi ^{55}Fe/g Fe) corrected to April 5, 1966 were 83±4.7 (S.E., 7 samples) for Union Point and 260±22 (S.E., 8 samples) for Pinecliff. Least squares regression of log (percent remaining) versus time for all 15 values produced at best a poor fit to the data, such that the effective half-life was estimated at 1.6±0.7 years. This estimate corresponds to the "ecological half-life" of Renfro and Osterberg (1969), and suggests that _Rangia_ and its associated ecosystem retain ^{55}Fe (like ^{103} & ^{106}Ru) very effectively with a "biological half-life analog" of about 4 years.

Analyses for total Fe, as well as Mn, Zn, and Cu, in Rangia were quite variable, and showed no consistent distributional patterns either between individual stations or between upstream-downstream combinations of stations (Table (5). In the case of Fe, only two stations (Brice Creek and Union Point) differed significantly at the 95 percent confidence level, and the mean concentration in p.p.m., for all upstream values, 61.5 ± 3.2 (S.E., 37 samples), did not differ significantly from the mean for all downstream samples, 52.6 ± 4.1 (S.E., 16 samples). No significant differences were evident in the distribution of Mn; Rangia from the Wilson Creek station contained significantly less Cu than did those from other stations; and Zn-values showed a two-fold range of variation with significant differences between means for several stations (Table 5).

Discussion

In the Trent-Neuse estuary, the distribution and biological availability of ^{55}Fe from fallout appears to be more comparable to $^{103 \,\&\, 106}$Ru than to stable Fe. This suggests that similar biogeochemical processes may control the introduction and cycling of these fallout radionuclides in the environment, and that these processes differ from those which control the distribution of any of these stable elements in Table 5. Specific activity obviously has limited predictive value for ^{55}Fe in Rangia, and further studies are required to determine its applicability for ^{55}Fe in other estuarine organisms.

Iron-55 is an activation product of (n,γ) and (n,2n) reactions with ^{54}Fe and ^{56}Fe in structural materials, such as weapons casings, whereas the Ru isotopes are fission products which might occur also in effluents from nuclear fuel-reprocessing plants. Ruthenium isotopes are mainly particulate, whether in sea water or fresh water (Greendale and Ballou 1954); but Ru can exist in a large number of valence states, as oxides, halides, and nitrosyl complexes, and the chemical forms of $^{103 \,\&\, 106}$Ru from fallout have not been identified in the environment. Electrochromatography of seawater and distilled water containing recently distilled RuO_4 (one probable form of $^{103 \,\&\, 106}$Ru in fallout) showed the formation of particulate oxides, whereas stable ruthenium chloro complexes and nitrosyl-nitrato complexes were formed when the RuO_4 was absorbed in HCl or HNO_3 (Marazović and Pučar 1967). Furthermore, the separated cationic, neutral, and anionic forms of ^{106}Ru nitrosyl-nitrato and chloro complexes were accumulated by mussels at different rates and to different levels, and the loss rate varied for different forms, indicating that different binding mechanisms are operative simultaneously (Keckeś et al 1966, 1967). Jones (1960) showed that Fe complexes nitrosyl ruthenium-106 and that adsorption of ^{106}Ru on sand or silt is enhanced by a surface layer of ferric hydroxide. Particulate Fe is readily ingested by oysters, and is absorbed also by leucoytes on oyster gill surfaces (Galtsoff 1964). Ingestion of particulate matter directly into cells by pynocytosis may be a general characteristic of the mantle epithelium of pelecypod molluscs (Nakahara and Bevelander 1967). Thus, iron and ruthenium might precipitate together in the upper estuarine zone of the Trent-Neuse system and be more available to clams at our downstream sampling stations.

Another distinction between our upstream and downstream stations should be noted also. The Trent and Neuse Rivers drain extensive areas of coastal plain cypress-pine forest and the water at all four upstream stations is characteristically stained a dark brown color. At the downstream stations where oceanic tidal influence is greater, the color is generally absent. Humic and fulvic acids form very stable complexes with certain metal ions, including Fe, Co, and Ag (Malcolms 1969). In experimental aquaria, chelation by HEDTA diminished the adsorption of ^{59}Fe from sea water onto the fiberglass tank walls and onto montmorillonite clay, and decreased the accumulation of ^{59}Fe by clams, oysters, and crabs (Rice 1965). The formation of organic complexes with ^{55}Fe and $^{103\ \&\ 106}$Ru in the upstream reaches of the Trent and Neuse rivers could decrease the availability to <u>Rangia</u> of these fallout nuclides in the upper limits of the estuary. Even if stable Fe from runoff were similarly complexed in the estuary, the relative availability of Fe to <u>Rangia</u> might be unaffected over the sampling area because of the very low content of Fe in the oceanic water supplied to the downstream stations.

Our data suggest that the upstream-downstream distinction in ^{55}Fe-^{106}Ru distribution occurs at a mean salinity of 2-3 o/oo (Fig. 1), or, if distances are plotted instead, at 28 miles upstream from Cedar Point, which corresponds to the vicinity of New Bern or our Union Point Station. Both ^{55}Fe and $^{103\ \&\ 106}$Ru seem dramatically more available to <u>Rangia</u> at salinities greater than 2-3 o/oo. This salinity corresponds to the critical range for the precipitation of (certain elements) in experimental mixtures of river water and sea water (Forster et al. In press).

The specific activity of ^{55}Fe in <u>Rangia</u> during 1966-1967 was very much lower than in most marine organisms analyzed. Jennings (1968) and Jennings and Osterberg (In press) suggested that ^{55}Fe was deposited in narrow belts at about 52° N and 75° N latitude mainly as troposheric

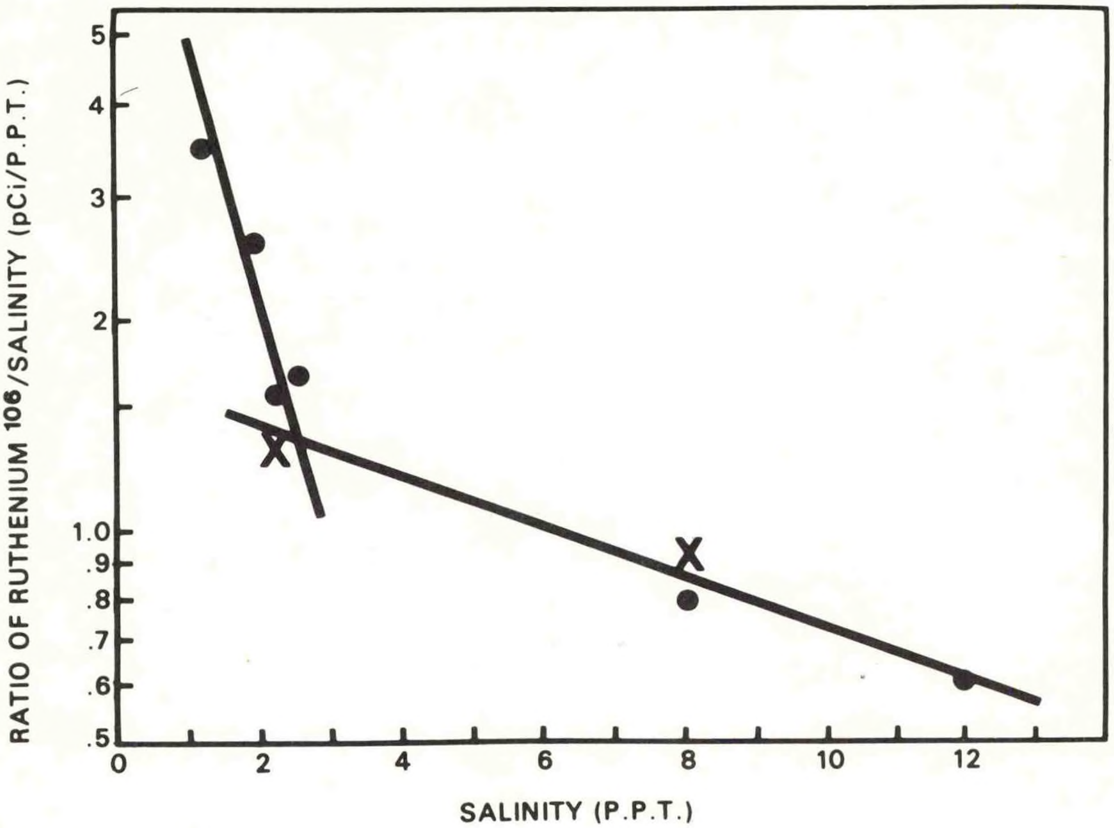

Figure 11.--Distribution of ^{106}Ru (●) and ^{55}Fe (X) in Rangia as a function of the mean salinity measurements made at each of the six sampling stations in the Trent-Neuse estuary during 1965-1967. Mean values for ^{106}Ru are from Table 1, and our two mean values for ^{55}Fe were converted to "^{106}Ru-Equivalents" via the mean ^{106}Ru/^{55}Fe ratio of 7.1 (Table 2). Two straight lines were fitted by inspection: one for upstream and one for downstream stations.

fallout from the Soviet test series of 1962. Preston (1970) showed that latitude had a very significant effect on the specific activity of ^{55}Fe in blood of cod from the North Atlantic in 1968, with peak values of about 100 pCi ^{55}Fe/mg Fe at 65° N dropping to 20 at 52° N and 9 at 45° N latitude. Since Fe is much more abundant in coastal zones than in mid-ocean, our values for <u>Rangia</u> cannot be compared directly to these analyses of fish, but at 35° N <u>Rangia</u> had only .073-.23 pCi ^{55}Fe/mg Fe (Table 4). Perhaps the most appropriate values for comparison are the analyses of Pacific clams and oysters by Palmer and Beasley (1965), who found in 1964 specific activities of 2.5 and 0.51 pCi ^{55}Fe/mg Fe, respectively, in these molluscs, and 0.58 pCi ^{55}Fe/mg Fe in Atlantic oysters. The samples that originated in the Pacific Ocean, however, probably received much higher quantities of tropospheric fallout ^{55}Fe than those from the Atlantic, and latitude was not specified for the origin of these molluscan samples.

References

Auerbach, S. I., and J. S. Olson. 1963. Biological and environmental behavior of ruthenium and rhodium, p. 509-519. In V. Schultz and A. W. Klement, Jr. (eds.), Radioecology. Reinhold, New York.

Baptist, J. P., D. E. Hoss, and C. W. Lewis. 1970. Retention of ^{51}Cr, ^{59}Fe, ^{60}Co, ^{65}Zn, ^{85}Sr, ^{95}Nb, ^{141m}In and ^{131}I by the Atlantic croaker (*Micropogon undulatus*). Health Phys. 18: 141-148.

Cosolito, F. J., N. Cohen, and H. G. Petrow. 1968. Simultaneous determination of iron-55 and stable iron by liquid scintillation counting. Anal. Chem. 40: 213-215.

Forster, W. O., D. A. Wolfe, F. G. Lowman, and Paul McClin. In Press. Trace element interactions between river water and seawater. 3rd Nat. Symposium on Radioecology, May 10-12, 1971, Oak Ridge, Tenn.

Galtsoff, P. S. 1964. The American oyster *Crassostrea virginica* Gmelin, p. 388 U.S. Fish Wildl. Serv. Fish. Bull. 64: 1-480.

Greendale, A. E., and N. E. Ballou. 1954. Physical state of fission product elements following their vaporization in distilled water and sea water. USNRDL-436. (U.S. Naval Radiological Defense Laboratory, San Francisco). 24 p.

Jennings, C. D. 1968. Iron-55 in Pacific Ocean organisms. Ph. D. Thesis, Oregon State University, 81 p.

Jennings, C. D., and C. L. Osterberg. In Press. Specific activity of iron-55 in Pacific salmon. 3rd Nat. Symposium on Radioecology, May 10-12, 1971. Oak Ridge, Tenn.

Jones, R. F. 1960. The accumulation of nitrosyl ruthenium by fine particles and marine organisms. Limnol. Oceanogr. 5: 312-325.

Kećkeś, S., Z. Pućar, and Lj. Marazović. 1966. The influence of the physico-chemical form of ^{106}Ru on its uptake by mussels from sea water, p. 993-994. *In* B. Åberg and F. P. Hungate (eds.), Radioecological concentration processes. Pergamon, New York.

Kećkeś, S., Z. Pućar, and Lj Marazović. 1967. Accumulation of electrodialytically separated physico-chemical forms of ^{106}Ru by mussels. Int. J. Oceanol. Limnol. 1: 246-253.

Krey, B. W., and W. C. Rosa, Jr. 1965. Fallout from the second Chinese nuclear test and comparison with the first, p. 288-297. USAEC Health and Safety Laboratory, Fallout Program, Quarterly Summary Report, HASL-161.

Malcolm, R. L. 1969. Ionic-scavenging ability of organic matter, p. 47-48. (Abstract) Program, 18th Annual Meeting, Southeastern Section, Geological Society of America.

Marazović, Lj., and Z. Pućar. 1967. Two-dimensional electrochromatography of ^{106}ruthenium and some other radiomicroconstituents in sea water. J. Chromatogr. 27: 450-454.

Nakahara, H., and G. Bevelander. 1967. Ingestion of particulate matter by the outer surface cells of the mollusc mantle. J. Morphol. 122: 139-146.

Palmer, H. E., and T. M. Beasley. 1965. Iron-55 in humans and their foods. Science 149: 431-432.

Parker, R. P., and J. O. Crookall. 1961. Seasonal variation and age of radioactive fallout. Nature 190: 574-576.

Preston, A. 1970. Concentrations of iron-55 in commercial fish species from the North Atlantic. Mar. Biol. 6: 345-349.

Renfro, W. C., and C. Osterberg. 1969. Radiozinc decline in starry flounders after temporary shutdown of Hanford reactors, p. 372-379. In D. J. Nelson and F. C. Evans (eds.), Symposium on radioecology. USAEC CONF-670503. Oak Ridge, Tenn.

Rice, T. R. 1965. Annual Report of the Bureau of Commercial Fisheries Radiobiological Laboratory, for the fiscal year ending June 30, 1963. U.S. Fish Wildl. Serv., Circ. 204. 44 p.

Schelske, C. L. 1966. The fate of fallout radioactivity in an estuary. Amer. Biol. Teacher 28: 373-380.

Wolfe, D. A. 1967. Seasonal variation of caesium-137 from fallout in a clam, Rangia cuneata Gray. Nature 215: 1270-1271.

Wolfe, D. A. In Press. Fallout ^{137}Cs in clams (Rangia cuneata) from the Neuse River estuary, North Carolina. Limnol. Oceanogr.

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

Wolfe, D. A., and C. L. Schelske. 1969. Accumulation of fallout radioisotopes by bivalve molluscs from the lower Trent and Neuse Rivers, p. 493-504. In D. J. Nelson and F. C. Evans (eds.), Symposium on radioecology. USAEC CONF-670503. Oak Ridge, Tenn.

THE UPTAKE OF TRITIUM FROM TRITIATED WATER BY DRY BRINE SHRIMP CYSTS

David W. Engel

Tritated water and its uptake and the incorporation of tritium into biological material has become an area of concern to the general public and the scientific community. The cause for the concern revolves around the proliferation nuclear power generating facilities and the attendent release of tritiated water. At the present time there is very little data available on the movement and metabolism of tritiated water and on the effects of incorporated tritium on aquatic organisms. The incorporation of tritium is generally accomplished by simple exchange of tritium atoms for hydrogen on molecules. Such exchanges are random and only influenced by exchange sites and the availability of tritium atoms. The second mode of incorporation is in biochemical synthetic or degradative processes in cellular metabolism.

To determine the amount of tritium incorporated into a dry biological system, dry brine shrimp cysts were soaked in tritated sea water and then the amount of tritium incorporated was measured.

Methods

The material used in these experiments was dry dormant cysts of the brine shrimp, Artemia salina. The cysts were weighed out in 100 mg lots and placed in 20 mm X 5 mm plastic petri-dishes. To each dish 2 ml of sea water, 35 p.p.t., was added which contained 0.4 μCi of tritium. Measurements of total tritium in dry and wet cysts were made after 4, 24, and 48 hours of incubation at room temperature.

The cysts were filtered and washed with three washes of non-active water on Whatman #42 filter paper. Duplicate samples were taken and one was combusted wet and the other was dried at 90° C for 24 hours and then combusted.

All combustions were performed with a Packard Tri-Carb Tritium Oxidizer. The tritiated water produced in combustion was collected in a toluene-dioxane-methanol cocktail and counted in a liquid scintillation counter. All results were reported as counts per minute per milligram dry weight of cysts. This was necessary because the free water in the wet cysts evaporated significantly during the weighing procedure.

Discussion of Result

The uptake of tritium by the cysts over the 48 hour period followed a linear relationship (Fig. 12). The uptake of tritium doubled

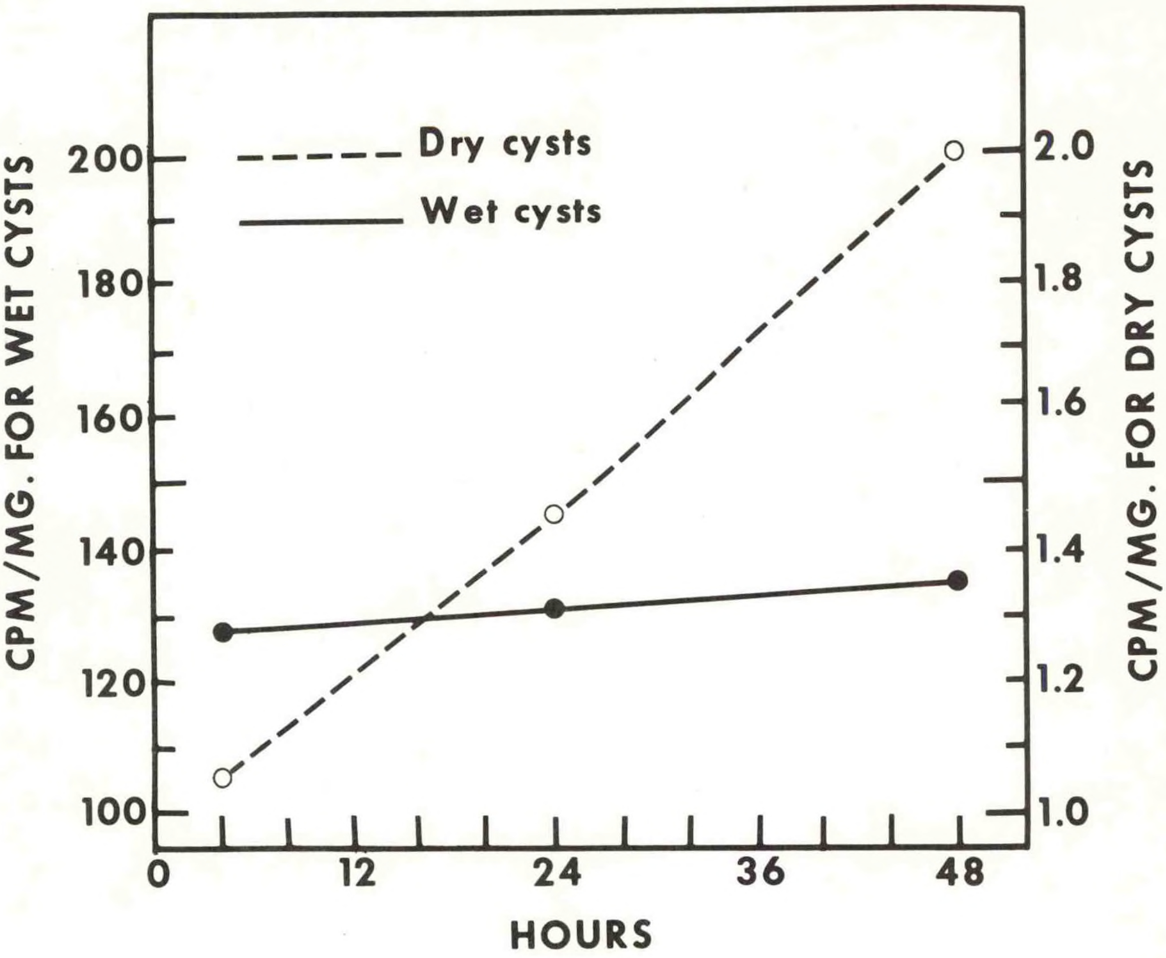

Figure 12.--The incorporation of ^3H into the developing brine shrimp embryo. The weight of cysts in milligrams at the beginning of the experiment, prior to hydration, was used to calculate cpm/mg.

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between 4 and 48 hours for the dry cysts, while there was only a slight increase with the wet cysts. Even though the uptake for the dried cysts was greater on a percentage basis, more activity was found in the wet cysts.

During the 48 hours of hydration the brine shrimp embryos developed practically to hatching. So the incorporated tritium may have been bound to biochemically and biological active molecules or simply to the chitinous shell of the cyst. The data derived from these experiments do not answer these questions, but future investigations will involve biochemical fractionation of both embryos and nauplii esposed to tritiated water.

BEHAVIOR OF SELECTED RADIONUCLIDES IN EXPERIMENTAL MIXTURES OF SEAWATER AND AÑASCO RIVER WATER[1]

D. A. Wolfe, W. O. Forster, F. G. Lowman,
and Raul McClin

In order to study the processes controlling the distribution of elements in estuaries, we have studied the distribution of several radioisotopes added to experimental mixtures of sea water and fresh water over the salinity range 0 to 34 o/oo. Preliminary results from these studies were presented at the 3rd National Symposium on Radioecology (Forster et al., In Press).

Methods

In the process of improving our experimental design, we conducted several experiments. In all of these, we added radioisotopes (^{155}Eu, ^{125}Sb, ^{110m}Ag, ^{54}Mn, ^{65}Zn, ^{60}Co, and occasionally ^{113}Sn, and ^{59}Fe) to a large volume of fresh water from the Añasco River (unfiltered or HA .45 μ-filtered). Unfiltered river water was used directly with its load of suspended sediment included. After thorough mixing of the tracer radioactivity with the river water, the experimental mixtures with sea water were prepared.

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[1] Work was performed during D. A. Wolfe's 1-year training assignment at the Puerto Rico Nuclear Center, Mayaguez.

Seawater was filtered (HA .45μ) before use and then mixed in varying proportions with the labeled river water in 10-liter polyethylene containers. For example, duplicate 10-liter mixtures containing 5, 15, 25, 50, 75, 90, and 100 percent river water were prepared for our ultimate experimental design. After preparation of these 14 experimental containers, a mixture of penicillin and streptomycin was mixed with the remaining half of the labeled river water, and a second series of 14 mixtures was prepared.

After mixing of the water, the containers were allowed to stand 5-10 days with frequent agitation. Radioactivity was then fractionated into six samples from each experimental container by the following procedure: The water was pumped off the settled sediment through a .45 μ filter (Fraction #1) and into a second clean 10-liter polyethylene container. The sediment (Fraction #2) was collected from the container, and the walls of the container were washed three times with 4<u>N</u> HNO_3 and three times with distilled water to remove adsorbed activity (Fraction #3). Soluble radionuclides were coprecipitated in the second container by the addition of $FeCl_3$ and NH_4OH. The precipitate of $Fe(OH)_3$ was filtered off (Fraction #4), and 1 liter of the water was then evaporated to dryness (Fraction #5) to determine the radioisotopes not coprecipitated with Fe. The walls of the second container were then washed in the same way as the first (Fraction #6).

Particulate radioactivity is thus represented by fractions 1 and 2, and soluble activity is represented by fractions 4, 5, and 6. Fraction 3 represents activity adsorbed onto the walls of the container directly or onto particulate matter adhering to the container, whereas Fraction 6 contains activity adsorbed directly from solution onto the polyethylene. The content of radioisotopes in each fraction was determined with a Ge(Li) detector and a 1024-channel gamma spectrometer.

Results

The distribution of radioisotopes among the soluble (Fractions 4+5+6), particulate (Fractions 1+2), and container sides (Fraction 3) is shown in table 6 for one experiment conducted during May 1970. In this experiment, only three different proportions of sea water-river water were prepared (in duplicate) and antibiotics were not used.

The distributions of ^{155}Eu, ^{125}Sb, and ^{65}Zn were not significantly affected by salinity. Europium associated strongly with the sides of the containers, whereas ^{125}Sb and ^{65}Zn remained largely soluble at all three salinities. Cobalt-60 was much more soluble at lower salinities than at 34 o/oo, and ^{110m}Ag showed a similar pattern to a lesser degree. Manganese-54, on the other hand, showed lower solubility in the fresh water mixture than at higher

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Table 6.--Distribution of radioisotopes (mean of 2 values, in percent) in soluble and particulate phases and on the sides of the containers in three different experimental mixtures of full-strength sea water and Añasco River water

Radio-nuclide	5% river water (34 o/oo)			60% river water (14.5 o/oo)			100% river water (<1 o/oo)		
	Soluble	Particulate	Sides	Soluble	Particulate	Sides	Soluble	Particulate	Sides
^{155}Eu	41.01	4.23	54.76	50.85	7.67	41.48	38.58	10.29	51.13
^{125}Sb	98.76	.007	1.23	99.78	0.00	0.23	99.61	0.00	0.40
^{110m}Ag	78.25	18.38	3.37	93.50	6.13	0.38	94.54	4.67	0.80
^{54}Mn	85.03	3.16	11.81	90.03	7.95	2.02	37.87	28.37	33.77
^{65}Zn	88.62	0.76	10.63	93.06	0.81	6.13	86.99	1.39	11.63
^{60}Co	47.75	2.87	47.59	91.98	4.02	4.00	91.50	3.83	4.68

salinities. If the activities on the sides of the container are ignored, then ^{125}Sb, ^{65}Zn, ^{60}Co, and ^{155}Eu (in order of decreasing solubility) all partition between the soluble and particulate phases more or less constantly, independent of the salinity of the mixture. Silver-110m still is less soluble, and ^{54}Mn is more soluble at higher salinities than in the fresh water mixture.

Detailed interpretation of these results is made quite complicated because the amount of suspended river sediment added to the experimental containers was related directly with the amount of river water. Because the antagonistic processes of desorption-ion exchange and coprecipitation probably occur simultaneously and vary from element to element, however, it is not possible simply to weight the values for sediment radioactivity on the basis of the sediment added initially to the containers. These data, along with those from our other experiments, are undergoing intensive examination to determine their relevance to the natural processes occurring in estuaries.

ENERGY RELATIONS IN ESTUARINE ECOSYSTEMS

ENERGY RELATIONS IN ESTUARINE ECOSYSTEMS

The estuaries of the United States presently represent a resource of great value to the nation. The future value of this resource could be markedly decreased through poor management or markedly increased through wise management. The selection of wise management practices requires a great deal of detailed information beyond that already at hand on the normal operation of the estuarine ecosystem and on the immediate and long-term effects of the many human activities which impinge upon the estuarine ecosystem. For the past several years, we have been actively engaged in gathering information on the general ecology of estuaries in the vicinity of Beaufort, N.C., in order eventually to construct mathematical models simulating the operation of this ecosystem and suitable for predicting its responses to environmental stresses. Immediate realization of this ultimate goal of systems analysis, however, still is precluded by the general lack of the necessary data. Systems analysis does, however, have immediate application in ecology as a tool for drawing together isolated fragments of information on an ecosystem into a unified description of that system suitable for determining what information is needed to complete construction of a model and for detecting any mutually contradictory pieces of information. On the basis of preliminary models synthesized from data on the estuarine ecosystem at Beaufort, we have been able to identify numerous previously unnoticed gaps and inconsistencies in knowledge of the ecosystem and thus plan the way for more meaningful research in the future.

Predictive and even descriptive mathematical models of ecosystems require large amounts of detailed quantitative data. Data suitable for incorporation in a general model of the estuarine ecosystem are being gathered on several animal groups: zooplankton, infauna, and epifauna of eel-grass beds, the benthic macrofauna and the more common fishes. All of these groups are important in the overall flow of energy and materials in the ecosystem and contain or provide food for species of importance to commercial fisheries. Our progress on these research endeavors during fiscal year 1971 is indicated by the results presented in the following papers.

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STANDING CROP, BIOMASS AND ENERGETICS OF THE ZOOPLANKTON POPULATION OF THE NEWPORT RIVER ESTUARY

Gordon W. Thayer and Michael W. LaCroix

Zooplankton are a primary link in the transfer of energy from producers to carnivores in aquatic systems, but the importance of zooplankton in this transfer in shallow systems has been questioned. Numerical abundance and biomass estimates suggest that zooplankton generally decrease in importance as primary links in the transfer of energy with decreasing depth below 100 m and that benthic invertebrates are more important phytoplankton consumers at these shallower depths. Even though the estuaries near Beaufort are shallow--having a mean depth at low tide of 1.2 m--and benthos are probably more important than zooplankton, the knowledge of precise importance and role of zooplankton in the transfer of energy and radionuclides is necessary for the development of a model of this system because zooplankton are still of considerable importance in total energy flow, contain the larvae of many benthos and support the larvae of many important fishes.

In December 1968 we began collecting plankton samples in the lower part of the Newport River estuary for caloric content. These analyses revealed a pronounced increase in the energy content of the total planktonic material which coincided with the migration of larval and post-larval fishes into the Newport River. In November 1969 we began sampling the zooplankton population for a study of the dynamics of these invertebrates and reported the preliminary results for the period of November 1969 to April 1970 in the Center for Estuarine and Menhaden Research Annual Report to the AEC, July 1, 1970. The present report summarizes results for the period January 1970 - January 1971, and thus contains data for the first complete year of the 2-year project which will be terminated in November 1971. Results of this project will be used in modeling the dynamics of the Newport River ecosystem under normal conditions and under conditions of elevated temperature.

Construction of this model requires knowledge of the biomass of zooplankton and their caloric content, standing crop and its species composition, metabolism, and production. Thus far the dynamics of the entire population have been estimated utilizing species dynamic relations developed for _Acartia tonsa_. In addition, the weights of all organisms collected have been estimated from a length-weight relationship developed for _Acartia tonsa_. Our assumption that all of the zooplankton have this length-weight relationship undoubtedly has biased somewhat our energetics values. Upon termination of field work in November 1971, length-weight relationships will be determined for the major species collected during the past 2 years. Our energetics data then will be reevaluated on the basis of these new relationships.

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Area and Methods

Zooplankton were collected at approximately 2 week intervals with a net made of nylon bolting cloth with 160μ openings. Water volume filtered was estimated with a calibrated current meter at the mouth of the net. Three 5 minute midwater tows were taken over each of three measured courses in the lower Newport River estuary (Fig. 13) 2 hours after the start of ebb tide. At the laboratory the samples were combined and the total volume measured. Part of this sample was preserved with buffered formalin for later analysis of zooplankton standing crop and of species composition. Approximately one-third of the sample was filtered through a 44μ filter for total net planktonic material biomass and the remainder was placed in a white pan which was partially covered to exclude light. Zooplankton were largely separated from extraneous material by siphoning off animals attracted by light to the surface of the uncovered portion of the container, and filtering out animals on a 44μ filter. The zooplankton and the net planktonic samples were weighed wet, freeze-dried, and reweighed.

Respiration rates of the mixed zooplankton population were measured within 1 hour of collection at environmental temperatures and at environmental temperatures plus 5° C. Growth or production was calculated from field data using formula described in the Center for Estuarine and Menhaden Research Annual Report to the AEC, July 1, 1970.

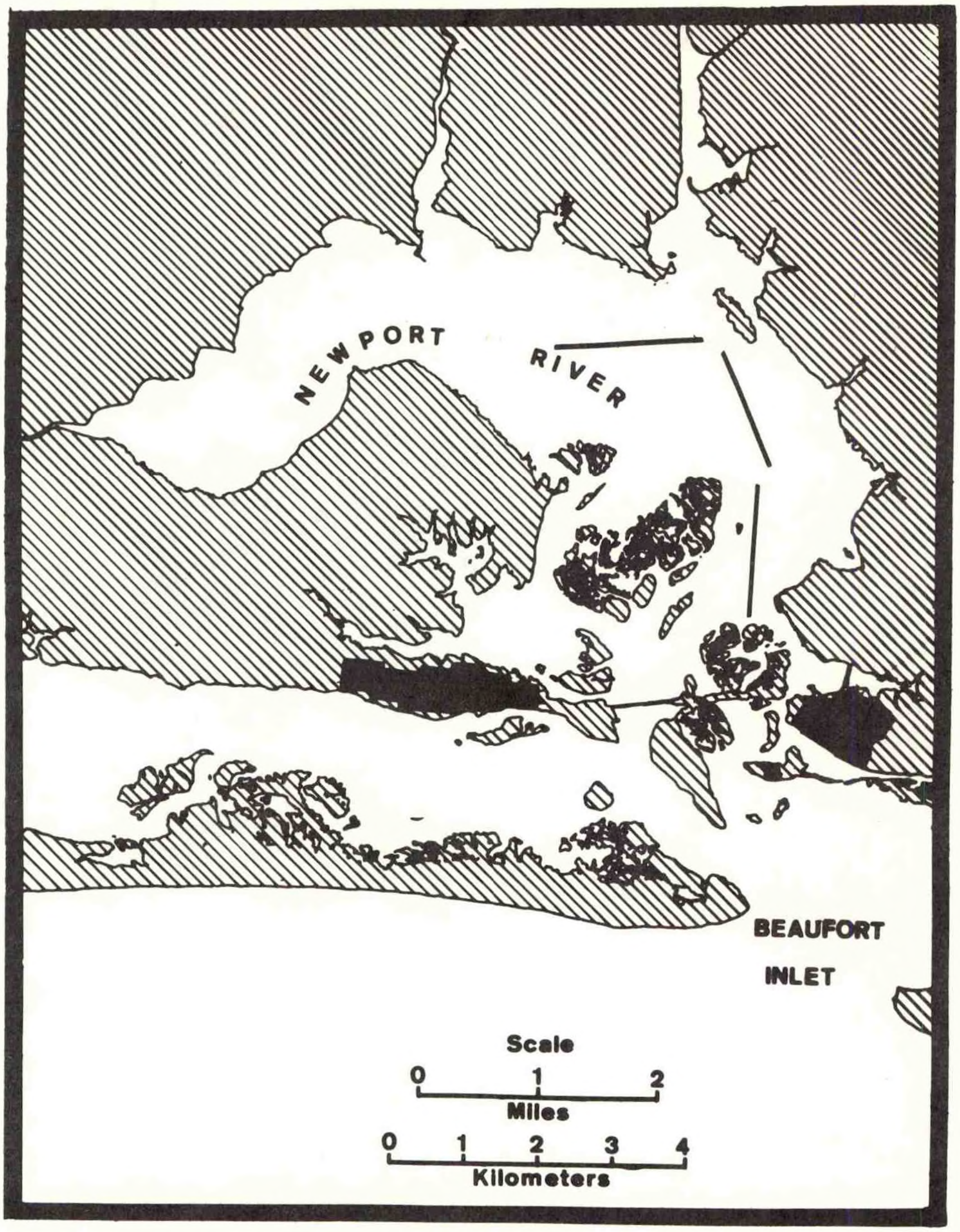

Figure 13.--Map of the Newport River estuary showing location of stations where plankton tows were made.

Production and respiration were summed according to the Gibb's free energy relation to estimate assimilation or energy flow:

Energy assimilation = growth + respiration

We estimated energy consumed by the zooplankton by assuming an assimilation efficiency of 33.3 percent, which is typical of herbivores.

Biomass, Energy Content and Standing Crop

The zooplankton population of the lower Newport River estuary was dominated by copepods. The seasonal distribution of standing crop and of biomass was roughly inverse to that of water temperature. The numerical abundance of zooplankton averaged 4,000/m^3 and ranged from a maximum of 9,500/m^3 during October to a minimum of 1,000/m^3 during July. The dry weight biomass averaged 14 mg/m^3 during the year and ranged from 22.5-27.0 mg/m^3 during March, October and January (1971) to a minimum of 3.5 mg/m^3 during July.

The distribution of both standing crop and of biomass was inversely correlated to phytoplankton production and directly correlated to the migration of larval and postlarval fish into the Newport River estuary. Data in Fig. 14 present a classical picture of the inverse relationship between zooplankton abundance and phytoplankton production. From March to May the zooplankton population decreased in abundance while

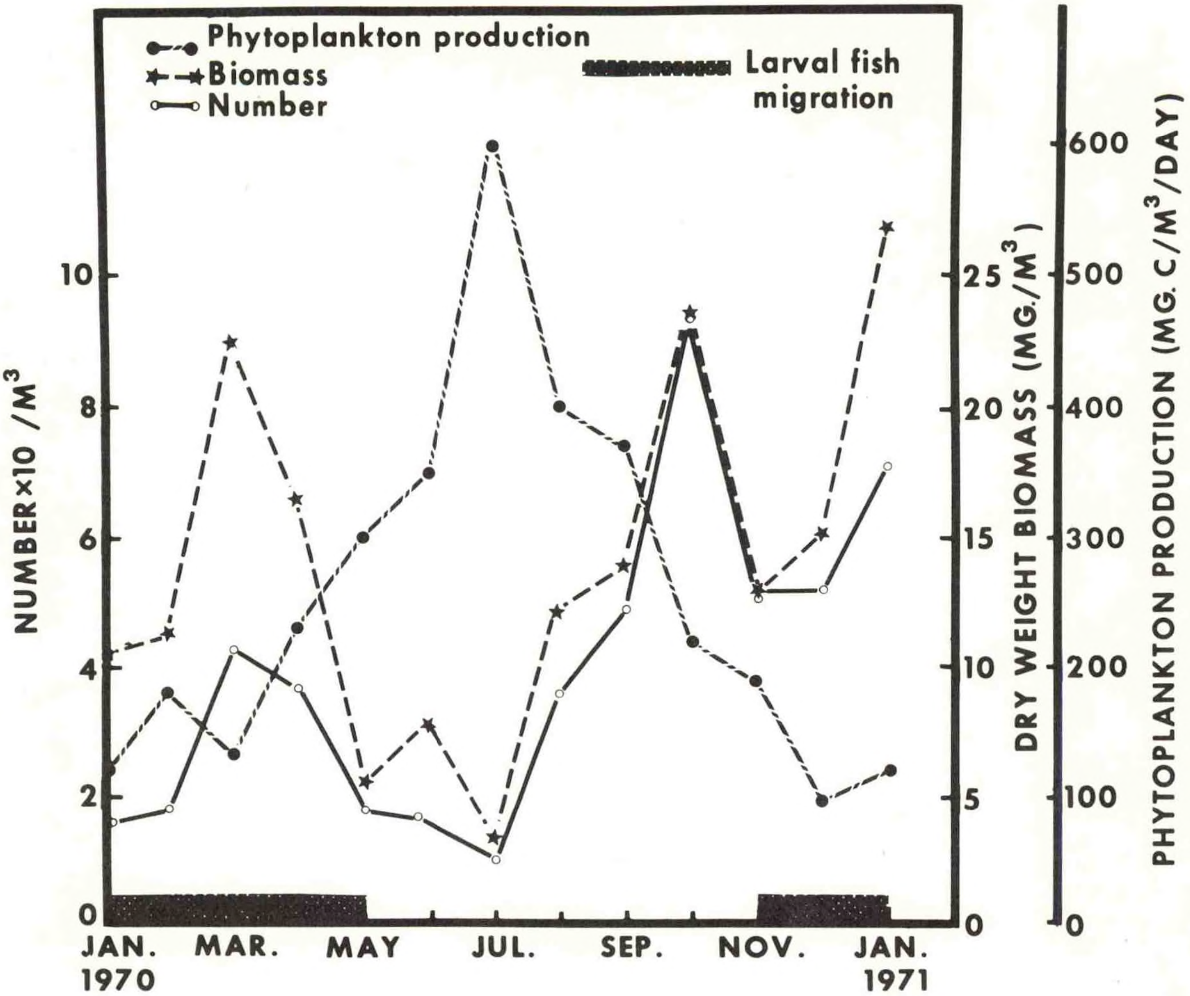

Figure 14.--Distribution of zooplankton abundance and biomass, and the distribution of phytoplankton production in the Newport River estuary. Stippled bars at the base of the graph indicate the period of larval and postlarval fish migration into the estuary.

phytoplankton production increased. From July to October the zooplankton increased in number and phytoplankton production decreased. There was, however, no important causal relationship between the abundance of phytoplankton and zooplankton because the zooplankton population in this shallow system was not abundant enough to appreciably graze down the phytoplankton.

There may be, however, a cause and effect relationship between the zooplankton distribution and the migration of larval and postlarval fishes into the estuary. Spot, pinfish, croaker and menhaden larvae began to enter the Newport estuary during November when the zooplankton population began its fall increase. Maximum migration occurred during February and March during a period of high zooplankton biomass and abundance (Fig. 14). Since these fishes utilize zooplankton as a major food source, the decrease in zooplankton abundance after March may have been the result of increased utilization by fish following peak migration. This fish migration also coincided with the periods of maximum caloric content/mg dry weight, and since the zooplankton biomass was high at this time the migration also coincided with maximum standing crop energy content (Fig. 15). Thus, at the time of estuarine larval fish migration the major food source--zooplankton—was not only abundant but also energetically richer than later in the year.

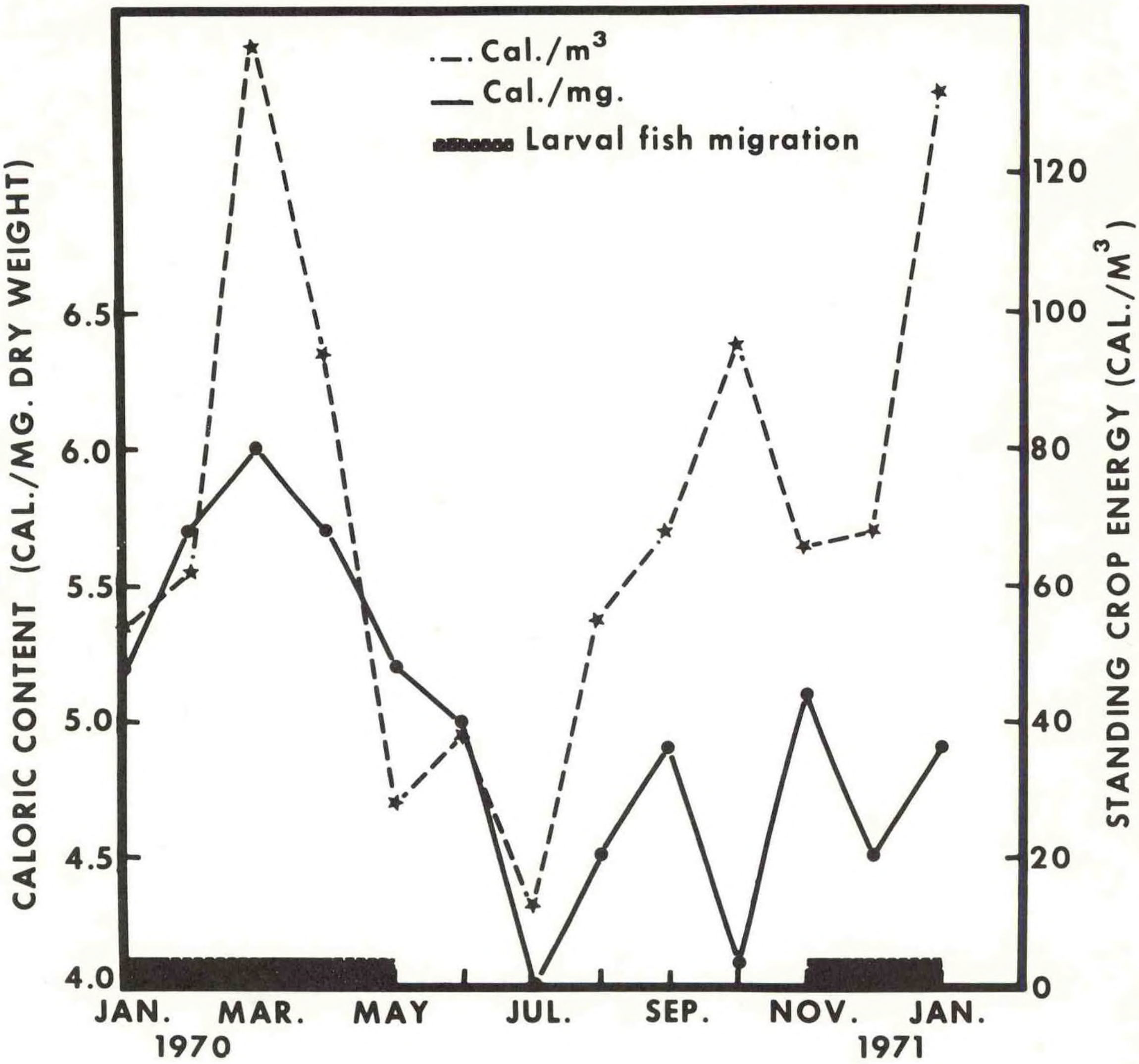

Figure 15.--Distribution of zooplankton energy per unit dry weight and zooplankton standing crop energy. Stippled bars at the base of the graph indicate the period of larval and postlarval fish migration into the estuary.

During the study there was a shift in zooplankton species dominance correlated with water temperature. Only 15 of the 25 species identified were numerically important and of these *Acartia tonsa*, *Centropages* spp., *Oithona similis*, *O. brevicornus*, *Corycaeus americanus* (?), and *Euterpina acutifrons*, a benthic herpacticoid, dominated the population. *Acartia tonsa* and *Centropages*, both relatively large species (adults 0.7 - 1.5 mm in cephalothorax length) were dominant during the fall and winter, whereas *Oithona* and *Corycaeus*, both small species, were dominant during spring and summer (Fig. 16). *Euterpina acutifrons*, a benthic herpacticoid, was present throughout the year but was most common during fall and spring when they were suspended in the water column by wind turbulance. Barnacle larvae and copepod nauplii both were present in substantial numbers throughout the year but were most common between 18°-26° C (Fig. 16). This naupliar distribution suggested that, although copepod production was spread over the year, production was greatest during fall and late spring.

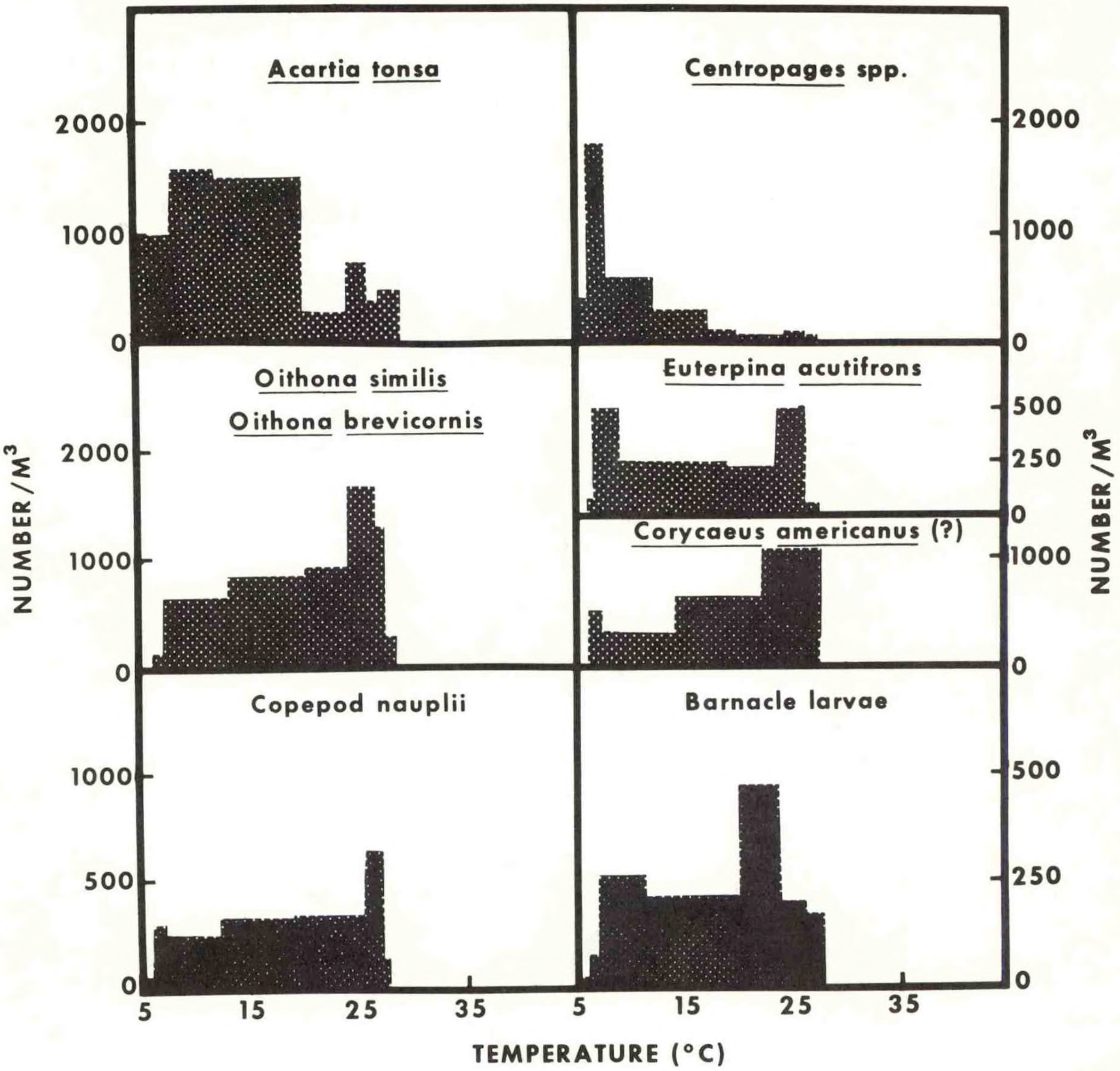

Figure 16.--Relationship between temperature and the numerical abundance of the major zooplankton species.

Energetics

The energetics of the zooplankton population in the Newport River estuary were estimated from respiration and growth rates of the entire population. The respiration rate per unit dry weight (Fig. 17 and per organism were positively correlated with temperature between 2° C and about 27° C but temperatures above 27° C apparently surpressed respiration. A similar relationship with temperature was found for winter zooplankton acclimated to temperatures between 5° and 30° C. Rapid increases in temperature from 25° to 30° C produced a decreased rate of respiration of zooplankton acclimated to 25° C, suggesting possible thermal stress beginning between 25° C and 30° C. Although the rate of individual respiration decreased at these higher temperatures the respiration of total population in the estuary increased (Fig. 18) as a result of increased standing crop and biomass (Fig. 14).

Growth or production, the other component of assimilation in the Gibb's free energy relation, as indicated by the distribution of nauplii (Fig. 16), was spread over the year, but on an individual basis production was maximum at temperatures between 5°-13° C and between 24°-30° C (Fig. 17). Our values during the year for production/individual (cal/individual/day) indicated that zooplankton in the Newport River estuary could be divided into two distinct populations based on time of reproduction (Fig. 17). The

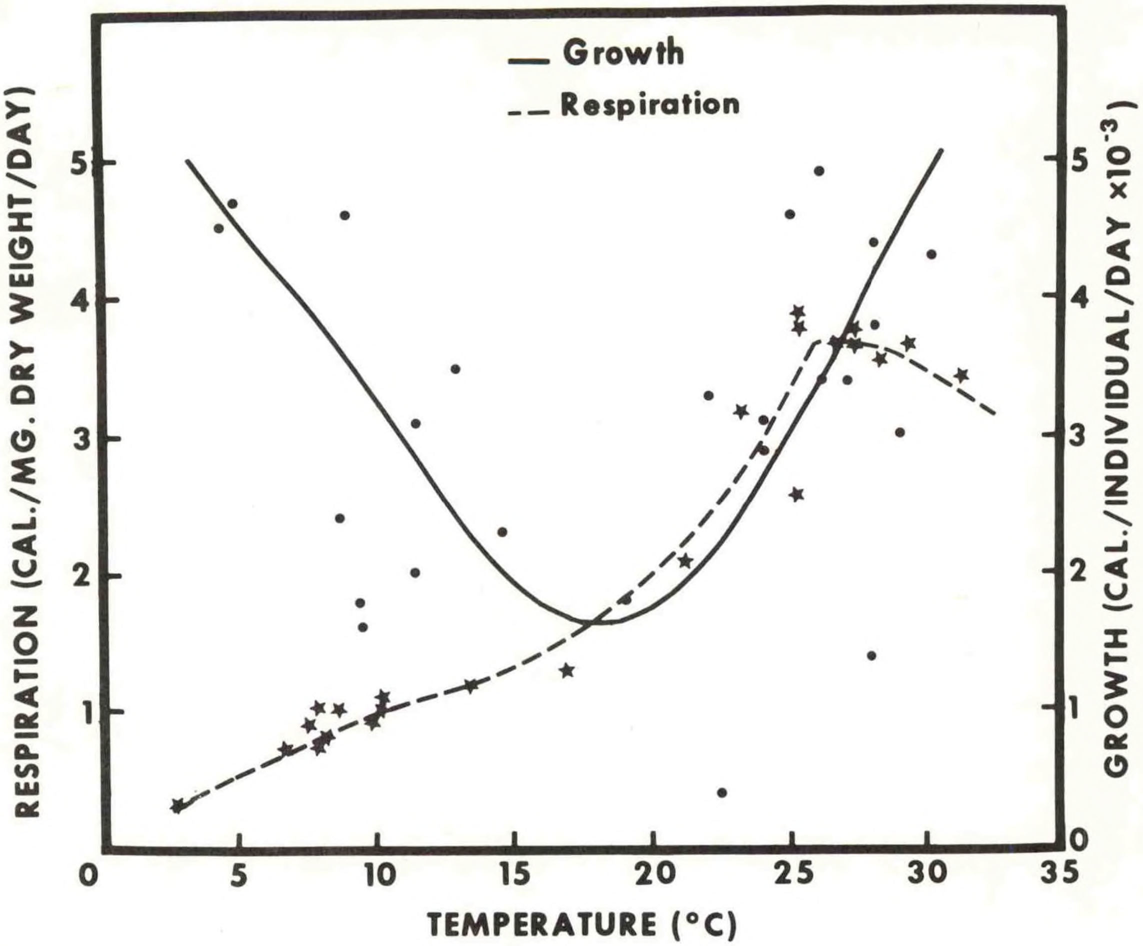

Figure 17.--Relationship between temperature and daily zooplankton respiration and growth rate.

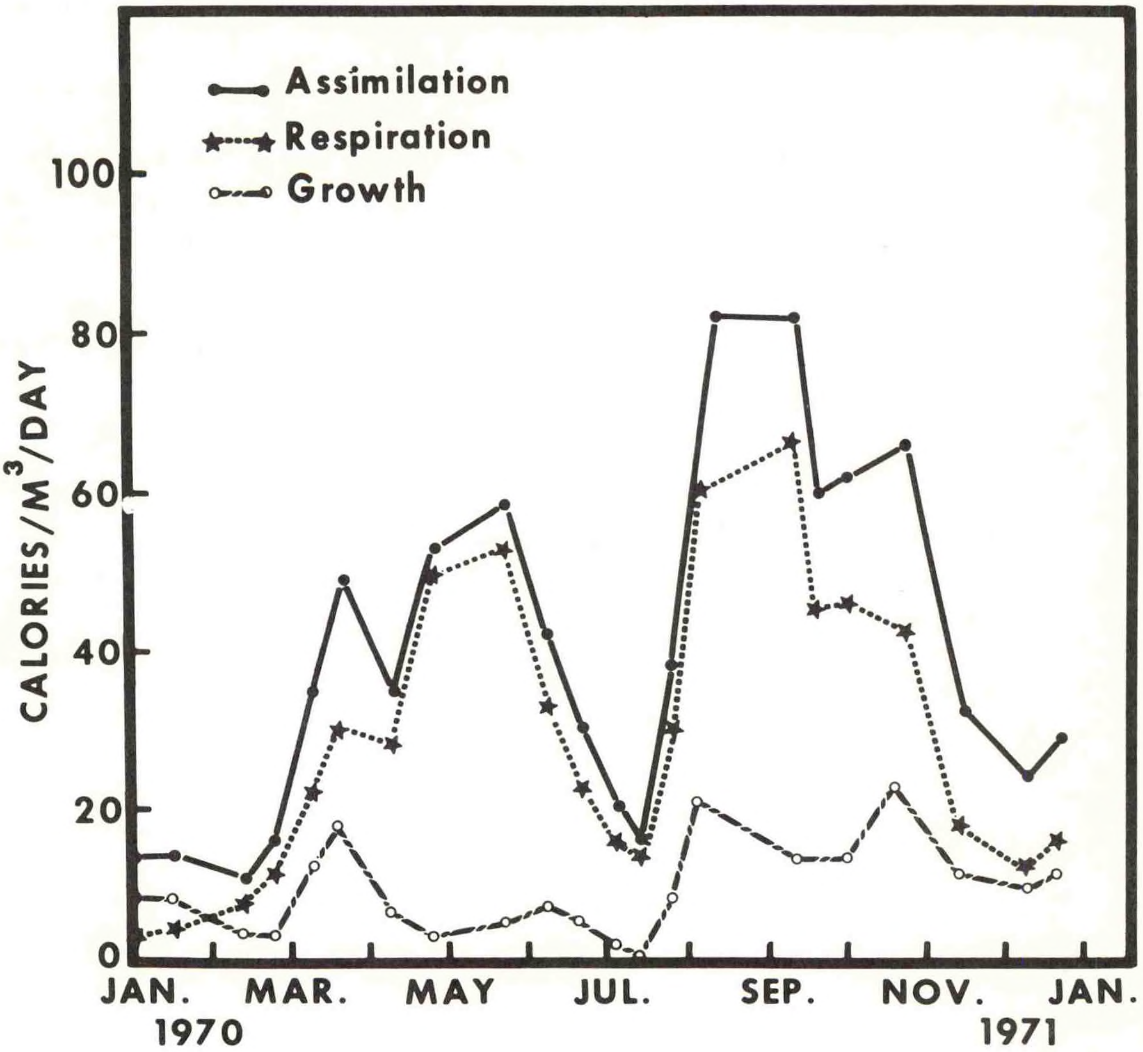

Figure 18.--Distribution of growth, respiration, and assimilation for the zooplankton population in the Newport River estuary.

distribution of species (Fig. 16) suggested that among the warm temperature adapted zooplankton which reproduced during spring and summer were Oithona and Corycaeus, whereas representatives of cool temperature adapted species reproducing during fall and late winter were Acartia and Centropages. Euterpina reproduced during both periods since microscopic examination of samples revealed that this herpacticoid copepod carried eggs throughout the year. Reproduction and standing crop were positively correlated and hence, the growth rate of the population was maximum during spring and fall (Fig. 18).

Zooplanktonic organisms are a primary link in the transfer of energy and radionuclides from phytoplankton to the carnivores, and like other herbivores are considered to utilize 75 percent of the energy they assimilate for maintenance and 25 percent for tissue growth. The zooplankton population in the Newport River utilized an average 75.6 percent of the energy assimilated during the year for respiration and the remainder for tissue growth (Table 7). These percentages, however, were not uniform throughout the year but ranged from 6-68 percent for the growth/assimilation efficiency (G/A) (Fig. 19). The percentage of the assimilated energy utilized for growth was minimum from May-August and high, but not maximum, during the periods of maximum population growth (Fig. 19). The occurrence of minimum G/A efficiency and

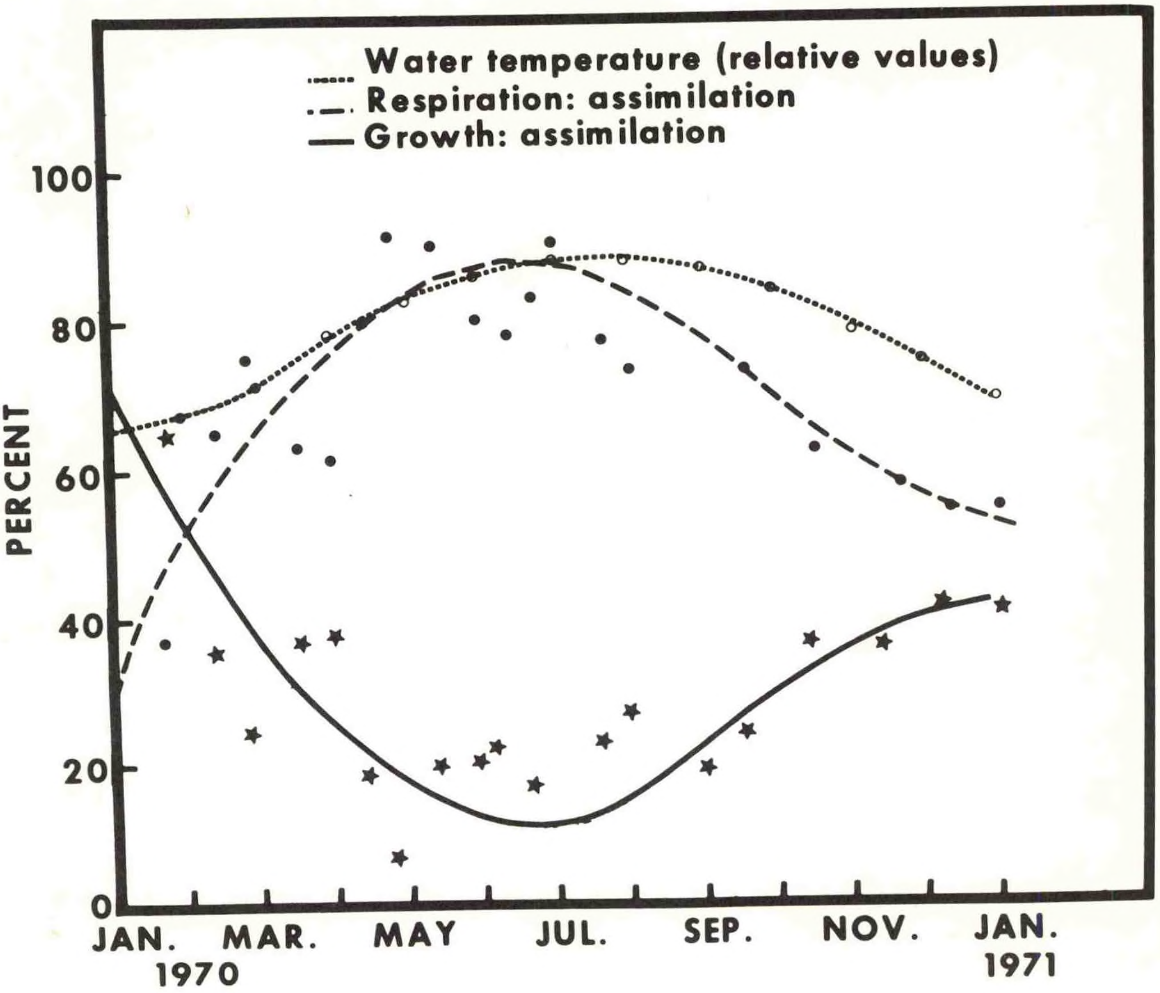

Figure 19.--Distribution of relative temperature (arbitrary values) and the distribution of population growth and respiration as a percent of assimilation.

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Table 7.—Mean daily values during the 4 yearly quarters for growth, respiration, assimilation and consumption (cal/m^3/day) and for the growth/assimilation (G/A) and respiration/assimilation (R/A) ratios for the zooplankton population in the lower Newport River for January 1970-January 1971. Mean temperature values are in parentheses

Quarter	Temperature	Growth	Respiration	Assimilation	Consumption	G/A	R/A
	°C	cal/m^3/day				Percent	
Jan. (1970) - Mar.	4.9-13.3 (9.1)	8.8	20.9	29.7	89.2	29.6	70.4
Apr. - Jun.	13.3-27.2 (22.3)	7.5	41.1	48.6	145.9	15.4	84.6
Jul. - Sept.	24.1-28.6 (27.1)	11.5	51.3	62.8	188.6	18.3	81.7
Oct. - Jan. (1971)	8.4-24.1 (15.6)	14.2	27.2	41.4	124.3	34.3	65.7
Mean	18.4	10.5	35.1	45.6	137.0	24.4	75.6
Sum for the year		3,832.5	12,811.5	16,644.0	50,005.0		

maximum R/A during May-August was not unexpected since sustained high temperatures during this period resulted in the highest rates of respiration (Fig. 17).

We estimated the importance of zooplankton in the flow of energy in the Newport River estuary by computing assimilation from the sum of growth plus respiration. The population produced an average 10.5 cal/m^3/day, respired 35.1 cal/m^3/day and assimilated 45.6 cal/m^3/day (Table 7). During the year the growth rate ranged from 3.7-24.3 cal/m^3/day and respiration from 4.3-66.1 cal/m^3/day (Fig. 18). Assimilation and respiration were maximum from March-June and from August-November, whereas growth was maximum in mid March and from August to November (Fig. 18, Table 7). Calculated zooplankton consumption ranged from 37.9 to 246.3 cal/m^3/day (average 137.0 cal/m^3/day) (Table 7).

We determined the flow of energy from the phytoplankton to the carnivores feeding on zooplankton by integrating estimates of assimilation and consumption with data on phytoplankton production. Previous Annual Reports to the AEC have shown that in the estuarine system near Beaufort, N.C., the mean daily net phytoplankton production approximates 137 mg C/m^3/day. Assuming that 1 mg C is equivalent to 10 calories, net phytoplankton production averaged

1,370 cal/m^3/day. Therefore the zooplankton population, in consuming and assimilating an average 137.0 and 45.6 cal/m^3/day, respectively, consumed energy equivalent to 10.0 percent of the net phytoplankton production and assimilated energy equivalent to 3.3 percent.

Our results indicate that the zooplankton population of Newport River estuary contributes little to the overall flow of energy and radionuclides in this system. Estimates of the energetics of the epifauna of an eelgrass bed in the Newport River (reported elsewhere in this Annual Report) indicated that these invertebrates assimilated 4.0 times more energy than the zooplankton population. This calculation was made by dividing the total yearly benthic epifaunal community assimilation by the total assimilation by zooplankton on an area basis. This suggests that benthic herbivores contribute most of the energy transferring from the primary producers to carnivores in this shallow system. The importance of zooplankton in this system cannot truly be estimated from a single year of data unless the population remains similar in biomass and standing crop from year to year. Analysis of data collected since January 1971 indicates that the standing crop and biomass are about twice that collected during the same time the previous year. If this is the case, the abundance of zooplankton in this shallow system may be cyclical and zooplankton may be much more important some years than others in the transfer of energy and radionuclides to successive trophic levels.

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SPECIES COMPOSITION, BIOMASS, AND ENERGETICS OF THE EPIBENTHIC INVERTEBRATE COMMUNITY OF A NEWPORT RIVER EELGRASS BED

Gordon W. Thayer and Michael W. LaCroix

Eelgrass, Zostera marina, forms one of the most important temperate seagrass systems, and as such serves as an important nursery ground for many fish and shellfish of commercial importance. These seagrass beds are probably the most productive areas in estuaries and the abundance of many estuarine organisms is related to the abundance of eelgrass. Few organisms, however, utilize the living plant as a food source (Day, 1967); rather the organic detritus derived from the decay of eelgrass is the basic source of nutrition of the benthic invertebrates of these beds. The epibenthic and benthic invertebrates also utilize phytoplankton and epiphytes on the blades of eelgrass, and in turn support numerous fish species.

Species composition and biomass of epibenthic invertebrates of seagrass beds have been examined numerous times (Dexter, 1947; Day, 1967; O'Gower and Wacasey, 1967; Moore et al., 1968; Nagle, 1968) and the energetics of some of the species common to these beds has been determined (Saunders, 1956; Richards and Riley, 1967; Pamatmat, 1968). The energetics of the invertebrate community of eelgrass beds, however, has not been considered as a whole. A few studies have been carried out on the benthic invertebrate fauna in the Beaufort area (Brett, 1963; Williams and Thomas, 1967) but these studies were limited to either species composition or standing crop and have not specifically examined the seagrass beds. In addition, none of these studies analyzed the energetics of the invertebrate populations.

This report is part of a comprehensive study of the plant and animal communities of a particular eelgrass bed in Newport River. In the previous Center for Estuarine and Menhaden Research Annual Report to the AEC, July 1, 1970, we reported estimates of the energetics of the epibenthos of this eelgrass bed based on 9 months of study. The present report summarizes the data from 14 months of study on the energetics of the community and of its major invertebrate taxa. Samples collected during this study are still being analyzed for chemical composition including fat, carbon, nitrogen, and hydrogen, and for trace metal content. Current and future studies on this bed pertain to deposition and entrainment of detrital material, to ecological aspects of the benthic infauna and sediments, to the ecology of fish populations utilizing the bed, and to total benthic metabolism and the contribution of the meio- and microbenthos to the total benthic community respiration. The aim of these investigations is to obtain sufficient information on the abundance, ecology, and physiology of the plant and animal community inhabiting eelgrass beds in the Newport River estuary to construct mathematical models simulating the energetics and operation of this system suitable for predicting its responses to environmental stresses with particular reference to thermal pollution and dredging operations.

Area and methods

Invertebrates, eelgrass, and benthic algae were collected from an eelgrass bed in a semiprotected embayment on Phillips Island (Fig. 20) from August 1969 through September 1970, to determine the species composition, biomass, and respiration of the organisms present. Methods used for collection and analysis and the area studied are described in detail in the Center for Estuarine and Menhaden Research Annual Report to the AEC, July 1, 1970. Dry weights reported here are tissue dry weights and include the protein matrices of molluscan shells. These were obtained by decalcification with 20 percent HCl.

Species Composition, Biomass, and Respiration

During the study we collected 45 species of invertebrates. The majority of the species were distributed on or among the blades of eelgrass and benthic algae (Table 8). *Bittium varium*, *Mitrella lunata*, *Carinogammarus mucronatus*, *Caprella geometrica*, *Paleomonetes pugio*, *Hippolyte pleurocantha*, and *Macoma tenta* were the most common species of

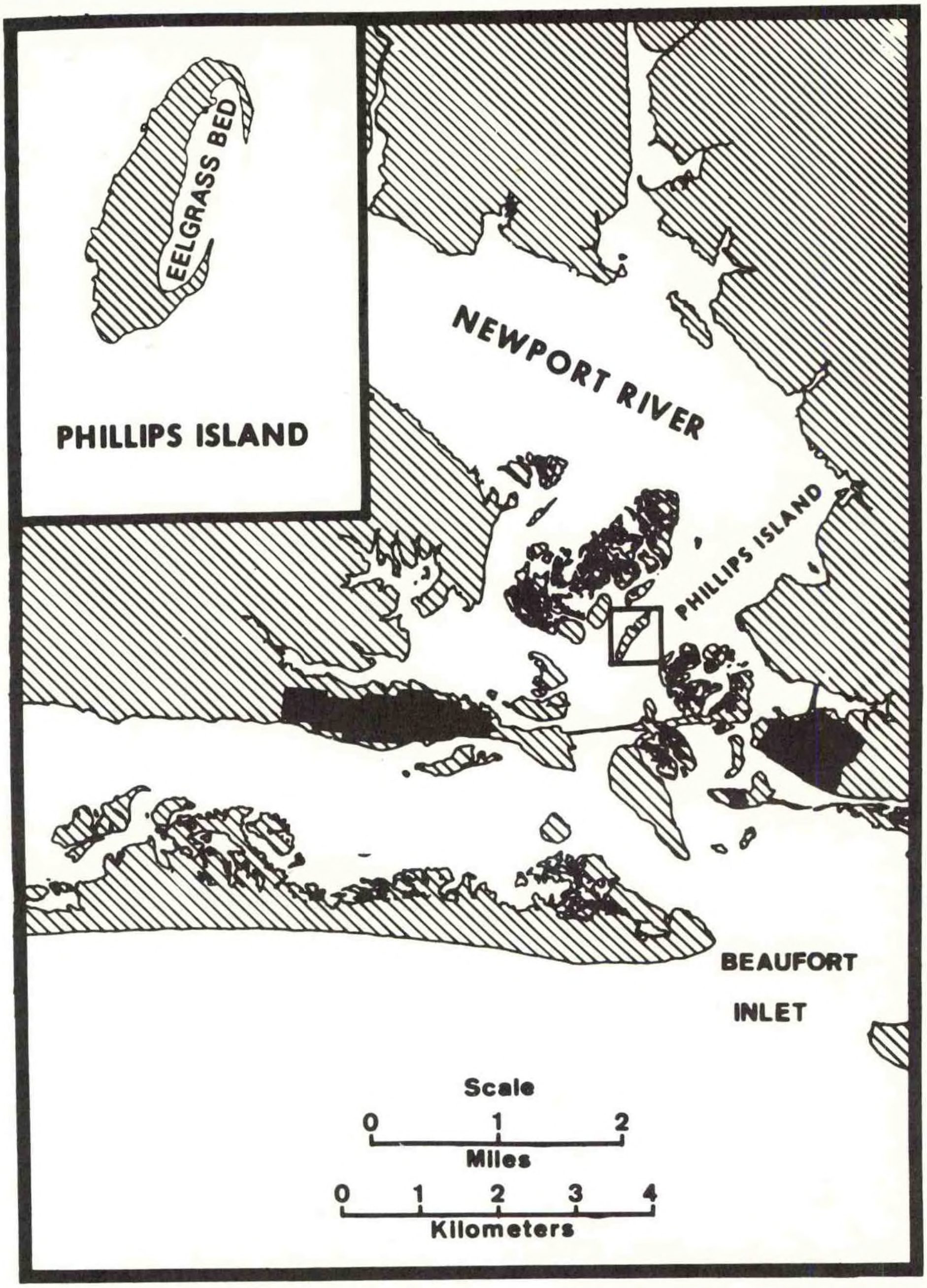

Figure 20.--Map of the Newport River estuary showing the location of Phillips Island. Inset of Phillips Island shows the location of the eelgrass bed.

Table 8.--Major taxonomic groups and dominant organisms collected from an eelgrass bed in the Newport River estuary, and their distribution and feeding type. (C = Carnivore, D = Detrital feeder, H = Herbivore, S = Scavenger)

	Distribution	Feeding type
Amphipoda		
Amphithoe longimana	Among eelgrass and algae	H-D
Caprella geometrica	Among eelgrass and algae	H-D
Carinogammarus mucronatus	Among eelgrass and algae	H-D-C
Decapoda		
Hippolyte pleuracantha	Among eelgrass and algae	D-H-C
Paleomonetes pugio	Among eelgrass and algae	D-H-C
Panopeus occidentalis herbstii	Substrate surface	D-C
Gastropoda		
Anachis avara	On eelgrass, algae, and substrate	H-D
Bittium varium	On eelgrass, algae, and substrate	H-D
Mitrella lunata	On eelgrass and substrate	H-D
Nassarius vibex	On eelgrass and substrate	S-D
Pelecypoda		
Argopecten irradians	On eelgrass	H-D
Anadana transversa	On eelgrass and substrate	H-D
Macoma tenta	Top 2 cm of substrate	D-H
Tellina versicolor	Top 2 cm of substrate	D-H

this group. The majority of the species collected were detrital, phytoplanktonic or epiphytic feeders and by weight these feeding types comprized about 93 percent of the population.

Gastropods were the dominant invertebrate taxon present in this eelgrass bed and ranged from 54 to 97 percent of the standing crop in terms of numbers (averaging 71 percent) (Tables 9 and 10). Bittium varium, the most dominant organism, alone constituted 48 percent of the average standing crop. Amphipods, pelecypods, and decapods each represented less than 10 percent of the standing crop (Tables 9 and 10). The Thoracica (barnacles) and Ophiuroidea (brittle stars) occasionally were collected and together only represented 0.6 percent of the community. Polychaetes, which were considered in the computation of the epibenthic community energetics even though they were collected from the upper 2 cm of substrate, represented 5.2 percent of the mean standing crop. The mean percent of the standing crop, biomass, and energy content of this biomass for all groups is summarized in table 9, and the data for the community and for the four major taxa are summarized in table 10.

The total dry weight biomass of the epibenthic community ranged from a mean of 206 mg/m^2 during September and October to 2520 mg/m^2 during June (averaging 933 mg/m^2) (table 10). The dry weight biomass of pelecypods and gastropods represented 53 percent of the community biomass. The biomass of this community was low in comparison with those reported in other benthic studies because all the organisms we collected

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Table 9.--Mean percent of the standing crop, dry weight, biomass, and energy content of the standing crop of major invertebrate taxa collected from a Newport River eelgrass bed

Classification	Standing crop	Biomass	Energy
	Percent		
Gastropoda	71.4	40.5	39.4
Amphipoda	9.3	5.2	5.0
Pelecypoda	7.3	12.4	12.2
Decapoda	6.2	28.4	23.3
Polychaeta	5.2	5.2	10.5
Thoracica	0.4	2.2	5.6
Ophiuroidea	0.2	6.1	4.0

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Table 10.--Mean and range (in parentheses) of monthly measurements for the epibenthic invertebrate community and for the major invertebrate taxa collected

	Community[1]	Amphipoda	Decapoda	Gastropoda	Pelecypoda
Number/m^2	595(99-1698)	56(2-294)	37(3-195)	428(72-1238)	44(1-112)
Biomass (mg/m^2)	933(206-2520)	49(1-120)	265(24-1424)	378(41-903)	116(7-394)
Biomass Energy content (cal/m^2)	4186(715-10672)	208(2-727)	975(89-5268)	1651(166-4800)	513(17-1567)
Respiration ($cal/m^2/day$)	135.6(9.1-508.0)	9.2(0.2-40.3)	44.9(2.6-293.5)	41.8(1.3-76.6)	15.9(0.9-64.7)

[1] Includes *Balarus balanoides*, *Ophioderma brevispina*, and *Nereis pelagica* which occasionally were collected.

were small or immature. The average dry weight per individual was 0.88 mg for the amphipods and gastropods, 2.64 mg for the pelecypods, and 7.16 mg for the decapods. As seen from these mean individual dry weight values, most of the organisms collected from this eelgrass bed were small enough to serve as food sources for carnivorous or omniverous fishes utilizing the bed. During our study we collected several species of fish with guts full of small gastropods and pelecypods. If the organic content of these molluscan shells is similar to that of some larger pelecypods (see paper by Price et al., in this Annual Report) and if fishes can crush or decalcify these small molluscan shells, it is likely that significant amounts of energy would be derived not only from the tissues but also from the protein matrix of the shell.

The energy available for carnivores utilizing this bed increased from 715 cal/m^2 during the fall to a maximum of 10,672 cal/m^2 during mid spring and averaged 4,186 cal/m^2 throughout the study period (table 10). The average energy content of an individual ranged from 3.5 to 4.9 cal/mg. The increase in caloric content of the individuals, which occurred during spring, was associated with an increase in sexual maturity and increased lipid content of the organisms prior to reproduction. Because of their high biomass the gastropods contributed 39.4 percent of the communities energy content. The four major taxa together contributed about 80 percent of the average energy content of the standing crop.

The loss of energy to respiration represented 3.3 percent per year of the energy of the community biomass and was correlated with water temperature and biomass changes. The community respired an average 28 ml $0_2/m^2$/day or 136 cal/m^2/day over the year (table 11). Minimum temperatures and minimum individual respiration rates occurred in December and maximum values during June and July. Although the decapods comprized only 6 percent of the mean standing crop and 23 percent of the community biomass, the respiration rate of this group was very rapid and was responsible for 33 percent of the mean daily community respiration. The gastropods, which represented 71.4 percent of the standing crop and 40.5 percent of the average community biomass, however, contributed only 31 percent of the total respiration.

Plant Biomass and Production in the Eelgrass Bed

The plant community was dominated by Zostera marina, and several benthic algae, Gracilaria, Bryopsis, Ectocarpus, Enteromorpha, and Ulva. The dry weight biomass of total benthic plants averaged 8.4 g/m^2 and ranged from 0.0 to 44.2 g/m^2 (table 12). Eelgrass represented 5.7 g/m^2 of the mean biomass. Plant biomass was large from April to July and very small during the remainder of the year; the numerical abundance and biomass of invertebrates were significantly correlated with plant biomass.

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Table 11.--Mean values for daily respiration, production, and assimilation based on a respiration/assimilation ratio of 0.75, and for consumption based on an assimilation/consumption ratio of 0.30. Values in parentheses indicate the percentage of the daily net plant production assimilated or consumed by each group. Values are in calories/m^2/day

	Respiration	Production	Assimilation	Consumption
Community[1]	135.6	45.2	180.8(10.1%)	547.9(30.4%)
Amphipoda	9.2	3.1	12.3(0.7%)	37.3(2.1%)
Decapoda	44.9	15.0	59.9(3.3%)	181.5(10.1%)
Gastropoda	41.8	13.9	55.7(3.1%)	168.8(9.4%)
Pelecypoda	15.9	5.3	21.2(1.2%)	64.2(3.6%)
Ophiuroidea Thoracica Polychaeta	23.8	7.9	31.7(1.8%)	96.1(5.2%)

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Table 12.--Algae and eelgrass cover and average daily net production of benthic algae, phytoplankton, and eelgrass.

Plant cover (grams dw/m^2)	Daily net plant production (cal/m^2/day)	
8.4(0.0-44.2)	Benthic algae	172.5
	Eelgrass	338.5
	Phytoplankton	1288.0
	Total	1799

Plant production, which was substantial from May to September and low during the remainder of the year, averaged 179.9 mg C/m^2/day or 1799 cal/m^2/day (table 12). Phytoplankton production in this bed, estimated from previous studies at the Center, averaged 1288 cal/m^2/day or 71.6 percent of the estimated average net plant production. The eelgrass and associated epiphytes contributed 338 cal/m^2/day and the benthic algae 172 cal/m^2/day. Mean daily production available to the herbivorous invertebrates was considered equal to our value for average net plant production, 1799 cal/m^2/day. Detritus deposited at the base of the eelgrass plants or on the sediment surface was collected during sampling and the average standing crop of this detritus was 19 kcal/m^2. Suspended detritus (seston), which also is available to invertebrates, was estimated to average 18 kcal/m^2.

Energetics of the Invertebrate Community and of the Major Taxanomic Groups of Invertebrates

The majority of species collected from this eelgrass bed utilize plant materials, detritus, phytoplankton, epiphytic algae, and filamentous algae, as food sources (table 8), and as herbivores should utilize approximately 75 percent of the energy assimilated to maintain physiological functions and about 25 percent for growth; these herbivores comprized approximately 93 percent of the dry weight of the community and were therefore the dominant forms. The assimilation of energy by the community and by the four major taxanomic groups was computed assuming a respiration/assimilation ratio of 0.75, and production or growth was computed as the difference between assimilation and respiration from the Gibb's free energy relation:

Assimilation (energy flow) = growth + respiration

Daily energy consumption by the community and by each of the major taxonomic groups needed to satisfy assimilation was estimated by assuming that herbivores and detrital feeders assimilate one-third of their consumed food energy. Consumption, therefore, was computed by dividing assimilation values by 0.33.

Our calculations indicated that the epibenthic community assimilated an amount of energy equivalent to 10.1 percent of the daily net plant production and consumed an amount equivalent to 30.4 percent (table 11). The decapods, although they comprized only 6.2 percent of the standing crop compared to 71.4 percent for the gastropods (table 9), assimilated the same amount of energy as the more abundant gastropods. The three minor taxonomic groups represented in the community, the polychaetes, barnacles, and brittle stars, together only assimilated an average 31.7 $cal/m^2/day$ or energy equivalent to 1.8 percent of the daily net plant production. This is a maximum estimate since brittle stars and to some extent polychaetes are carnivorous. The entire community consumed an average 547.9 $cal/m^2/day$ or an amount of energy equivalant to 30.4 percent of the daily net plant production.

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We constructed a diagram of the trophic relationships and of the flow of energy for the epibenthic plant and animal community of this eelgrass bed utilizing the estimates for daily production, respiration, and assimilation (table 11), and knowledge of the generalized trophic relations for the taxonomic groups collected. The rate of individual energy flows from the producer compartments to the various invertebrate compartments are not known but the combined flows to each invertebrate group have been computed.

Dead eelgrass formed the bulk of the detritus in this eelgrass bed. Eelgrass primarily was utilized as detritus by the invertebrates. As indicated in figure 21, all of the invertebrate compartments were dependent to some extent on the detrital component of this system, either as deposited and entrained detritus or as suspended sestonic detritus. The amphipods, most pelecypods, and barnacles utilize sestonic detritus, whereas the gastropods, decapods, polychaetes, and a few pelecypods utilize deposited detritus. The significance of detritus illustrated by this diagram was reported previously in the Radiobiological Laboratory Annual Report to the AEC, August 1, 1969. This report contained evidence that several of the species inhabiting eelgrass beds derived most of their energy from detritus.

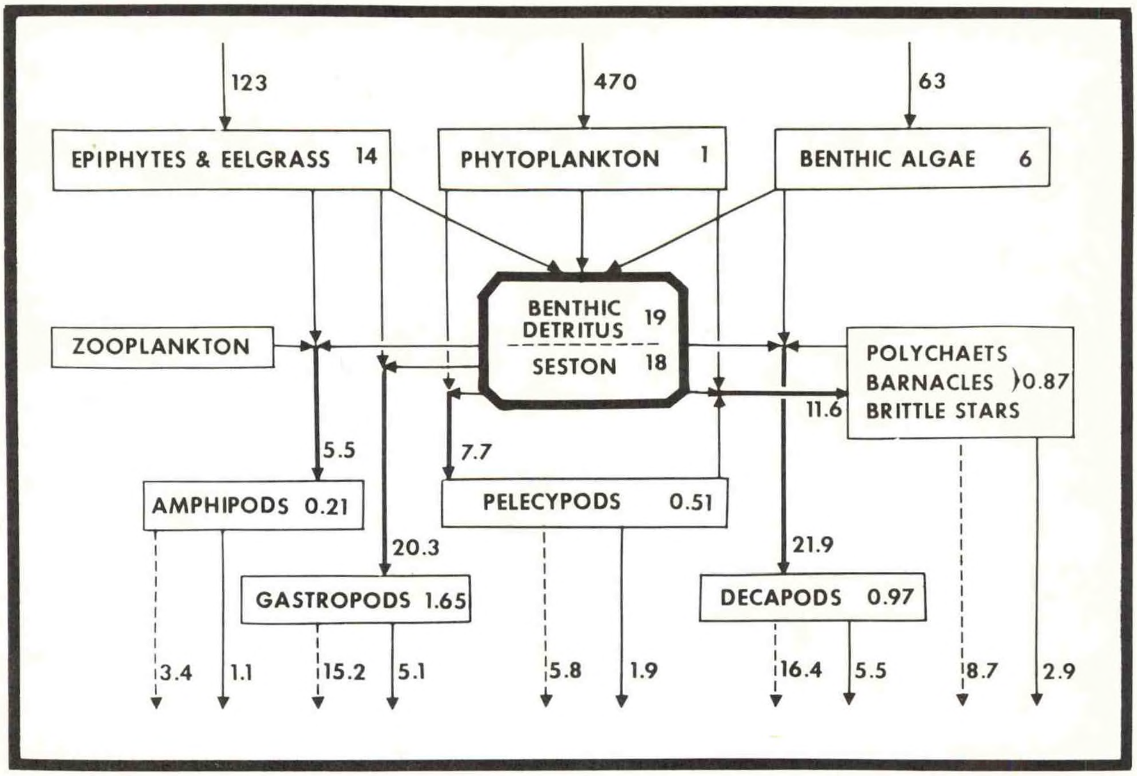

Figure 21.--A diagram of the trophic relationships and of energy flow in an eelgrass bed system in the Newport River estuary. Flows (indicated by arrows) are in kcal/m^2/yr and average standing crops (values in compartments) are in kcal/m^2. Inputs into the three plant compartments are net production and outflows to the detrital compartment represent death of plant material. The flow into each invertebrate compartment is assimilation and is formed of flows from the major food sources for the compartment. Solid line outflows from the invertebrate compartments are production and dotted line outflows are losses due to respiration.

The trophic relationships and flow of energy within the epifauna of this bed seem logical and the production of plant materials is sufficient to satisfy the assimilation and consumption requirements of the various taxa (fig. 21). The caloric content of detritus and of living plants consumed by the invertebrate community was computed as 30.4 percent of the estimated net plant production. Our calculations were based on the assumption that the growth/assimilation and the respiration/assimilation ratios were 0.25 and 0.75, respectively. The respiration was measured and growth estimated from respiration.

To check the reasonableness of our computed production values we have calculated the turnover or the ratio of the total yearly production to the mean standing crop for each invertebrate compartment. The turnover values were similar to those reported in the literature for corresponding invertebrate taxa (table 13), suggesting that our production estimates were reasonable. The turnover ratios further indicated that our amphipods and decapods generally produced two generations per year and represented short-lived species. The gastropods and pelecypods, on the other hand, tended, as groups, to be longer lived and average slightly more than one generation per year. Our turnover values for the amphipods, decapods, and gastropods were slightly higher than published values. This difference may reflect that all our species were small and were collected from a habitat with a high mean annual water temperature; the turnover values from the literature in table 13 are for more northerly species.

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Table 13.--Turnover rates for various invertebrate taxa. All values are relative.

	Amphipods	Decapods	Gastropods	Pelecypods	Echinoderms - Polychaetes - Barnacles
Values reported in the literature	3.7-5.0	1.1-3.8	2.0-2.4	3.9	1.9-8.6
Values calculated from eelgrass bed data	5.2	5.7	3.1	3.7	3.4

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The Energetics of Bittium varium

Bittium varium, a prosobranch gastropod, dominated the invertebrate community in terms of standing crop and was the dominant gastropod in terms of standing crop, biomass, and respiration (table 14). This gastropod, ranging in size from 3 to 10 mm in length and 0.17-0.75 mg in individual tissue dry weight, was present throughout the year and was commonly collected on the blades of eelgrass (table 8). Bittium feeds on deposited detritus and on epiphytes on the eelgrass blades, and derives more energy from the detritus proper than from its associated bacteria (Radiobiological Laboratory Annual Report to the AEC, August 1, 1969).

The respiration rates of these gastropods were measured monthly, and growth, assimilation, and food consumption were computed from the Gibb's free energy relation and the assumption described above. The population of Bittium respired an average 14.6 cal/m^2/day and 5.3 kcal/m^2/yr (table 15). In order to satisfy the estimated assimilation requirements the Bittium population would have had to consume energy equivalent to 3.3 percent of the net plant production or 21.8 kcal/m^2/yr. These estimates indicated that the Bittium population in this bed were not only the dominant invertebrate in terms of standing crop but also required 35 percent of the energy flowing through the gastropod compartment and 11 percent of the energy flow of the entire epibenthic invertebrate community.

Table 14.--Proportion of the community and of the gastropod data contributed by *Bittium varium*

	Total community	Gastropods
	- - - - - - - - - Percent	- - - - - -
Number/m^2	48.4	67.3
Biomass (mg/m^2)	10.5	25.8
Biomass energy (cal/m^2)	8.7	22.1
Respiration (cal/m^2/day)	10.8	34.9

Table 15.--Values for mean daily and yearly energetics of *Bittium varium* values are in cal/m^2/day or kcal/m^2/yr. Values in parenthesis are percent of daily net plant production used

	Respiration	Production	Assimilation	Consumption
Per day	14.6	4.9	19.5 (1.1%)	59.1 (3.3%)
Per year	5.3	1.9	7.2 (1.1%)	21.8 (3.3%)

As we indicated previously, this energy flow scheme is partially dependent upon the assumption that the growth efficiency of herbivores is 25 percent. Yearly turnover for this population of Bittium was 5.2 times the standing crop. This rate of turnover required that the population reproduce at least twice a year and that the individuals be short-lived. Data for dry weight of individuals indicated that this gastropod reproduced twice during the year, fall and late spring, because small snails—offspring from these periods of reproduction—were collected during winter and early spring and again during late summer.

References

Brett, C. E. 1963. Relationships between marine invertebrate infauna distribution and sediment type distribution in Bogue Sound, North Carolina. Ph. D. thesis. Univ. North Carolina. 202 p.

Day, J. H. 1967. The biology of Knysna Estuary, South Africa, p. 397-407. In G. H. Lauff (ed.), Estuaries. American Association for the Advancement of Science. Publ. No. 83.

Dexter, R. W. 1947. The marine communities of a tidal inlet at Cape Ann, Massachusetts: A study of bio-ecology. Ecol. Monogr. 17: 263-294.

Moore, H. B., L. T. Davis, T. H. Fraser, R. H. Gore, and N. R. Lopez. 1968. Some biomass figures from a tidal flat in Biscayne Bay, Florida. Bull. Mar. Sci. 18: 261-279.

Nagle, J. S. 1968. Distribution of the epibiota of macroepibenthic plants. Cont. Mar. Sci. 13: 105-144.

O'Gower, A. K., and J. W. Wacasey. 1967. Animal communities associated with Thalassia, Diplanthera, and sand beds in Biscayne Bay. I. Analysis of communities in relation to water movements. Bull. Mar. Sci. 17: 175-201.

Pamatmat, M. M. 1968. Ecology and metabolism of a benthic community on an intertidal sandflat. Int. Revue ges. Hydrobiol. 53: 211-298.

Richards, S. W., and G. A. Riley. 1967. The benthic epifauna of Long Island Sound. Bull. Bingham. Oceanogr. Coll. 19: 89-135.

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Saunders, H. L. 1956. Oceanography of Long Island Sound, 1952-1954. X. The biology of marine bottom communities. Bull. Bingham. Oceanogr. Coll. 15: 345-414.

Williams, R. B., and L. K. Thomas. 1967. The standing crop of benthic animals in a North Carolina estuarine area. J. Elisha Mitchell Sci. Soc. 83: 135-139.

10/1

THE ORGANIC CONTENT AND PARTICLE SIZE DISTRIBUTION OF THE SEDIMENTS OF A NEWPORT RIVER EELGRASS BED

G. W. Thayer, M. W. LaCroix, and J. N. Walker

The abundance of benthic invertebrates and the distribution and abundance of invertebrate feeding types are partially controlled by the physical and chemical nature of the substrate. The characterization of benthic sediments yields information not only relevant to the biological systems that predominate but also on the source of the sediments, the water currents in the area, and possible effects the sediment may have on the overlying water. Water currents influence the distribution of sediments and of organic matter deposited on the substrate. This in turn directly influences the distribution of invertebrate feeding types. Numerous studies have shown that deposit feeders predominate on muddy substrates, where water currents are slow, and that as current speed increases the sediments become coarser and filter feeders and carnivores replace deposit feeders as the predominant organisms. This distribution is partially the result of higher organic contents of the finer sediments in regions of slow water movement.

The purposes of the continuing research reported here were to initiate (1) a study on relationships between particle size distribution of the sediments of an eelgrass bed and the benthic infauna present in the bed, (2) to determine the amounts of organic material present in the substrate as an index of availability of energy to benthic invertebrates, and (3) to determine the relative quantity of living and detrital organic material in the sediment in relation to the quantity of macroscopic invertebrates present (greater than 1 mm). This project will be continued and expanded to encompass the deposition and entrainment of inorganic and organic material and the contribution of micro- and meio-fauna to the total metabolism of the benthos of this eelgrass bed.

Methods and Area

Triplicate sediment cores are collected quarterly at each of 6 quadrats for 11 stations in an eelgrass bed in the Newport River estuary (fig. 22). The stations and quadrats are shown in Figure 23. The stations are located 40 meters apart and quadrats A and B are between two successive stations and are 15 m apart. Quadrat C is located 15 meters to the southeast of the center of two successive stations and quadrat D is located 15 meters further southeast. Quadrats E and F are located in the same manner to the northwest. Sampling sites were located in this manner to cover as completely as possible the different

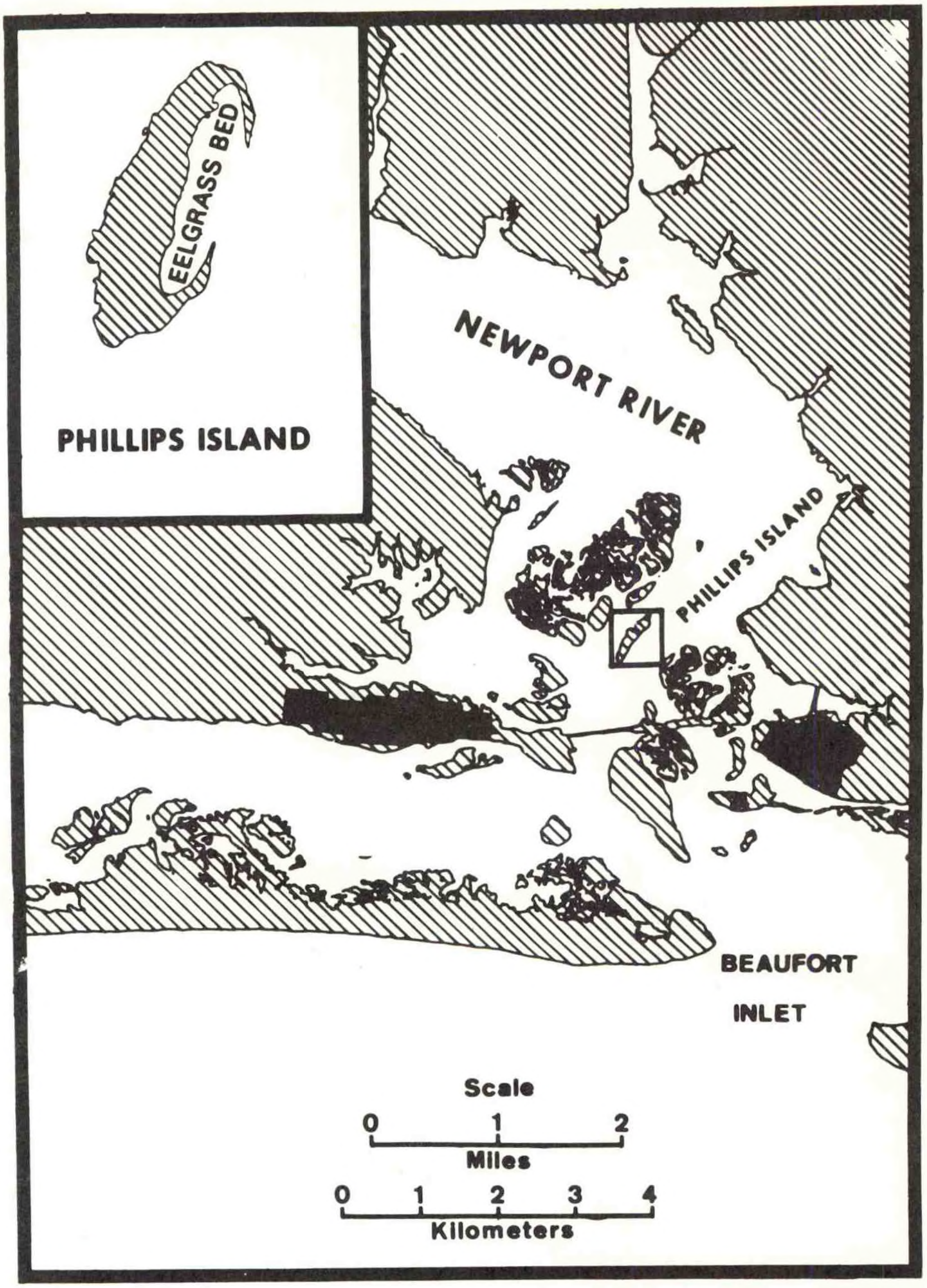

Figure 22.--Map of the Newport River estuary showing location of Phillips Island. Inset of Phillips Island shows the location of the eelgrass bed.

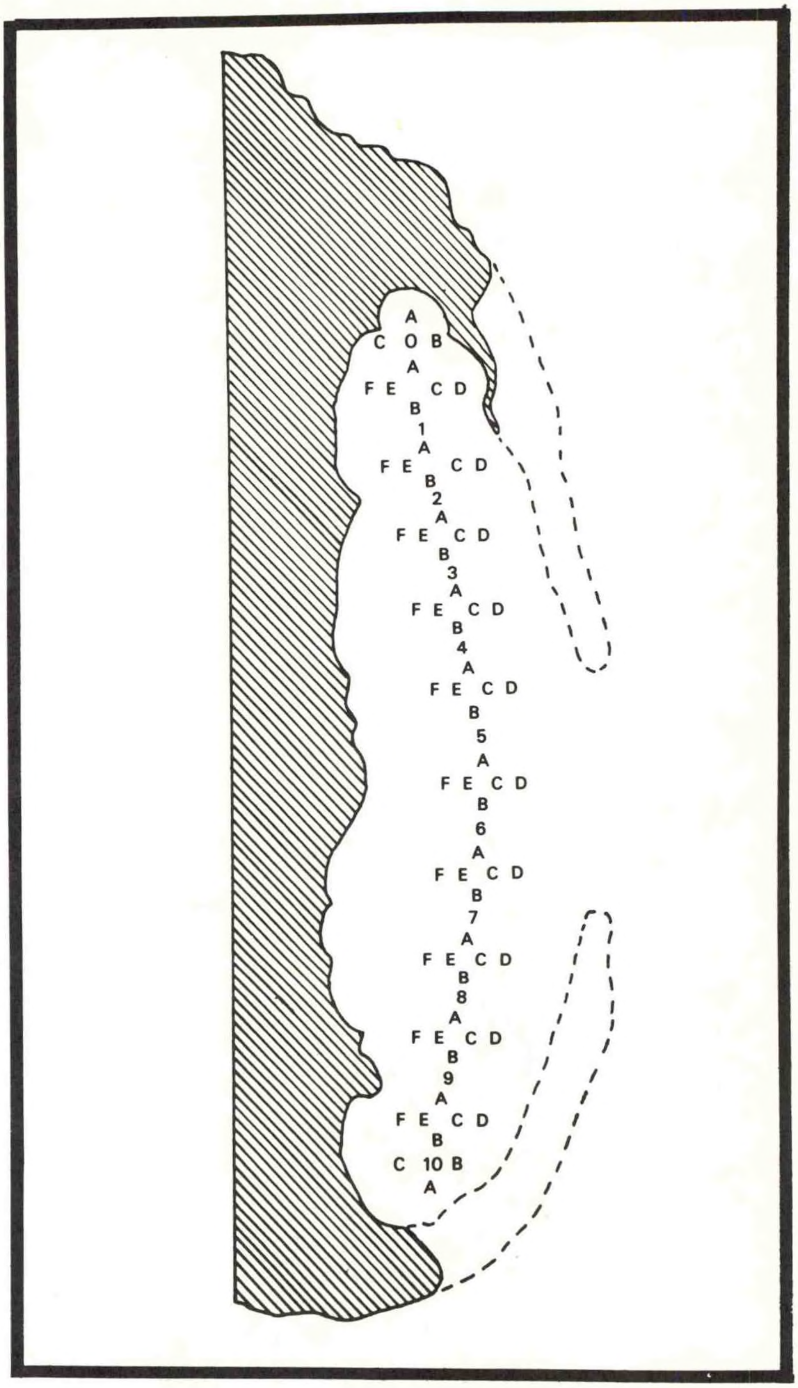

Figure 23.--Diagram of Phillips Island showing location of sampling stations (0-10) and quadrats (A-F).

substrate types present in the embayment. Sampling for the epibenthic and benthic infauna (described elsewhere in this report) are also carried out in this embayment.

The cores are collected with a polyethylene cylinder which is plugged with a vinyl stopper and detached after the core is taken (Fig. 24). The cylinder (inside diameter 3.6 cm) is pushed into the sediment to a depth of 17 cm. The volume thus collected averaged 172.9 cm^3 and had an average wet weight of 288 g and dry weight of 207 g (N = 180). The sediment samples were brought back to the laboratory, weighed and then dried for 7 days at approximately 100 °C. Subsamples were ashed at 500° C for 36 hr. Ash-free dry weight was assumed to be organic matter. Particle size distribution was determined with a hydrometer method and the particle sizes measured were sand (>0.05 mm), coarser silt (0.05-0.025 mm), coarse silt (0.025-0.005 mm), fine silt (0.005-0.002 mm), and total clays (<0.002 mm).

Results and Discussion

The results of this study confirmed our assumption that the physical characteristics of the sediment were essentially similar throughout the embayment and that the eelgrass bed in the embayment could thus be treated as a single community. The sediment was composed preeminently of sand (81.5 percent) and contained small amounts of silt (10.6 percent) and clay (7.9 percent) (tables 16 and 17). Consequently, we feel that

Figure 24.--Photograph of coring device used to collect sediments.

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Table 16.--Mean percentages of sand (>0.05 mm), silt (0.05 - 0.002 mm), clay (<0.002 mm) and ash-free dry weight for each station

Station	Sand	Silt	Clay	Ash-free dry wt
	- - - - - - - - - - - -	Percent	- - - - - - - - - - - -	
0	73.0	16.5	10.5	3.0
1	79.4	12.3	8.3	2.4
2	85.7	7.9	6.4	2.0
3	80.3	11.9	11.8	2.7
4	80.4	11.5	8.1	2.6
5	81.6	11.3	7.1	2.3
6	80.1	10.8	9.1	2.4
7	80.5	11.2	8.3	2.5
8	86.2	7.1	6.7	2.3
9	82.1	10.0	7.9	2.2
10	87.7	6.9	5.4	1.5
Mean	81.5	10.6	7.9	2.3

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Table 17.--Mean percentages for all stations of sand, silt, clay, and ash-free dry weight for each quadrat

Quadrat	Sand	Silt	Clay	Ash-free dry wt
	Percent			
A	82.2	10.0	7.8	2.3
B	81.7	10.7	7.6	2.4
C	78.7	12.0	9.3	2.7
D	78.9	12.2	8.9	2.7
E	84.0	9.1	6.9	2.1
F	84.8	8.7	6.5	1.9

intensive benthic invertebrate sampling at any one location, especially between stations 2-9 (fig. 23) gives a representative picture of the biomass and species composition of the entire embayment.

Sand particles greater than 0.05 mm in diameter comprised the major portion of the sediment and ranged between 73.0 - 97.7 percent; no very coarse particles such as gravel were found in the sediment. The southwest part of the embayment (station 10) had the highest amount of sand in the sediment apparently as a result of washoff from the adjacent beach and sand bar. The sediment at the northeast part (station 0) was lowest in sand and highest in silt due to washoff from the surrounding marsh area. Quadrats near the shore of the island and near the mouth (D and F) of the embayment had generally higher sand and lower silt-clay contents than the central portion of the embayment (table 17).

We obtained an average organic content for these sediments of 2.3 percent (table 16), by assuming that combustion at 500° C destroyed all of the organic material present and nothing else. The sandiest sediments contained the least organic material; those sediments with the highest silt and clay content contained the greatest amount of organic material (tables 16 and 17). Estuarine sediments made up of sand, silt, and clay generally have an organic carbon content between 0.4 and 2.0 percent, but in areas of solid waste pollution the organic carbon content may reach 15.0 percent. We computed that the carbon content of the sediments of this embayment approximated 0.9 percent--an intermediate value for unpolluted estuarine sediments—by assuming that the carbon content of sediment organic matter is similar to the carbon content of cord grass and eelgrass (38 percent).

On a weight basis the sediments of this embayment contained an average 28.3×10^3 g organic material per m^3 (table 18). In addition, the sediment was found to contain 448.7×10^3 g/m^3 of detrital material greater than 1 mm in size; this was primarily fragments of cord grass and eelgrass. Our benthic infauna research suggests that the average biomass of macroinvertebrates in the embayment is 39.2×10^3 g/m^3. Thus, the total organic material in the sediment of this embayment averaged 12.2 times greater than the standing crop of benthic infauna. This suggests that these invertebrates may not be food limited. In addition, if we assume that one-third of the organic material less than 1 mm is living (bacteria, fungi, protozoans and nematodes), there would be an estimated biomass of microfauna of 9.4×10^3 g/m^3 or about one-fourth the biomass of the macrofauna.

These speculative computations suggest that benthic microbes are an important part of the total consumer biomass of this embayment and probably of the entire estuary. In addition, microbes should be extremely important in the energetics of the benthos because bacteria turnover between 5 and 12 times a day. Therefore, since microbes appear at least as important as macroscopic benthic invertebrates in the transfer of energy and radionuclides in benthic systems, their energetics should be studied to obtain a complete picture of the energetics of an estuarine ecosystem.

Table 18.--The mean amount of organic material passing through a 1 mm sieve for each station and quadrat

Station	Organic content	Quadrat	Organic content
	g x $10^3/m^3$		g x $10^3/m^3$
0	33.180	A	30.360
1	25.560	B	29.968
2	24.340	C	30.537
3	32.910	D	29.430
4	31.065	E	24.969
5	28.658	F	24.434
6	26.784		
7	30.050	Mean	28.283
8	29.003		
9	28.534		
10	21.030		
Mean	28.283		

QUANTITATIVE SAMPLING OF THE BENTHOS IN ESTUARIES NEAR BEAUFORT, NORTH CAROLINA

Thomas J. Price, Richard B. Williams, and
Thomas G. Roberts

Benthic infauna and epifauna serve as important links in the transfer of energy and radionuclides from producer and decomposer levels to higher trophic levels. In addition to their role in the energy flow of estuarine ecosystems, benthic organisms support many valuable commercial fisheries. Filter-feeding species remove particulate matter containing pollutants from the water and either assimilate these materials or deposit them on the sediment surface. Burrowing species intermix surface and deeper layers of sediment, thus both burying and exposing pollutants contained in the sediment. Many of these animals concentrate radionuclides and other materials to high levels, thus making them potential excellent indicators for the detection of pollutants since the organisms are either sessile or restricted in their movement.

We are conducting a long term survey of the standing crop and species composition of benthic infauna as part of a general investigation of energy flow and other aspects of the estuarine ecosystem near Beaufort, N. C. The respiration and respiratory energy requirements of organisms collected by our quantitative sampling also are being estimated. A preliminary survey is now completed and is being followed by a survey of seasonal changes in biomass and species composition.

The preceding AEC Annual Report of 1970 contained values from the first 19 stations sampled. This report contains results from the entire survey and estimates for respiration and caloric demand of the benthic infauna population revealed by this sampling.

Methods

Methods were described in detail in the 1969-1970 Annual Reports to the AEC. Five core samples (each $0.073m^2$) were taken at each of the 39 stations (Fig 25). The organisms and coarse debris were separated from mud and sand by washing the samples through screen (opening _ca._ 2 mm square) and organisms separated by floatation from the broken shell which formed most of the coarse debris.

Results and Discussion

A total of 813 organisms of 17 species were extracted from the 14.2 m^2 sampled. Thus, the average abundance was 57.2 organisms/m^2; the average biomass was 4.1 g/m^2 (Table 19). Organisms were obtained at 28 of the 39 stations. The number of organisms ranged up to 558.9/m^2 and the biomass up to 15.2 g/m^2. The numerical abundance of benthic infauna remained low compared to the benthos of Long Island Sound, N. Y. and Puget Sound, Washington, and the biomass estimates remained similar to Bogue Sound, N. C. and Puget Sound and larger than those obtained for Long Island Sound. Animals collected in our investigation averaged

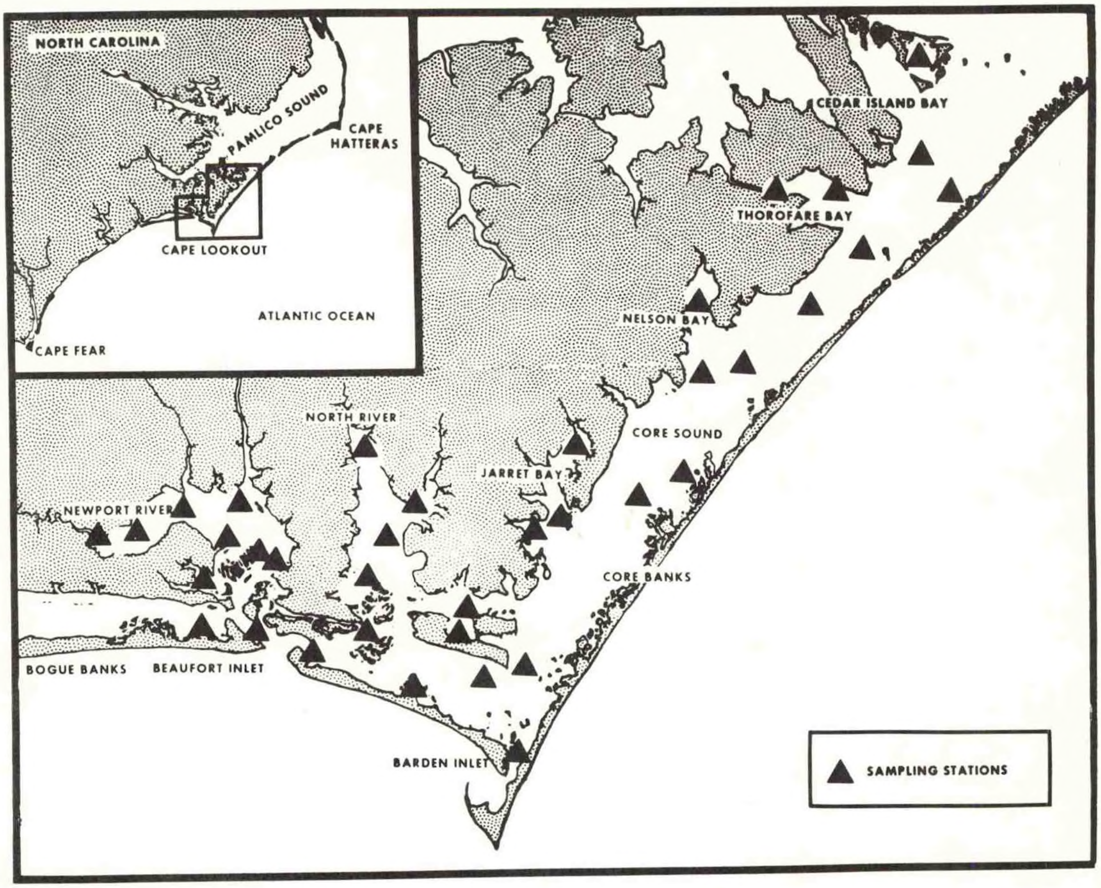

Figure 25.--Location of sampling stations for a survey of the standing crop of benthos in estuaries near Beaufort, N.C.

Table 19.--Summary of substrate and benthos of the shallow estuarine system near beaufort, N.C.

		Numerical abundance				Dry weight			
Station	Sediment type	Deposit Feeders	Filter feeders	Carnivores	Total	Deposit feeders	Filter feeders	Carnivores	Total
		Number/m^2				G/m^2			
1	Mud	--	--	--	--	--	--	--	--
2A	Mud	--	--	--	--	--	--	--	--
2B	Mud	13.7	--	--	13.7	1.3	--	--	1.3
3A	Mud-sand	109.6	13.7	--	123.3	3.4	1.4	--	4.8
3B	Mud-sand	43.8	13.7	--	57.5	2.3	5.7	--	8.0
4A	Sand	2.7	5.5	2.7	10.9	2.3	0.3	0.3	2.9
4B	Sand-mud	9.4	8.2	--	17.6	0.5	3.0	--	3.5
5	Mud-sand	--	8.2	--	8.2	--	12.1	--	12.1
6	Sand-mud	--	--	2.7	2.7	--	--	6.3	6.3
7	Sand-silt	5.5	2.7	--	8.2	0.7	11.0	--	11.7
11	Clay-mud	--	--	--	--	--	--	--	--
12	Clay-mud	49.3	--	--	49.3	3.1	--	--	3.1
13	Clay-mud	65.8	--	--	65.8	8.8	--	--	8.8
14	Sand-mud	43.8	8.2	5.5	57.5	1.2	7.1	0.1	8.4
15A	Sand-shell	--	--	--	--	--	--	--	--
15B	Sand-shell	--	--	--	--	--	--	--	--
15C	Mud	156.1	11.0	--	167.1	12.5	2.7	--	15.2
16	Mud	--	--	--	--	--	--	--	--
17	Sand-shell	--	--	--	--	--	--	--	--
19	Sand-clay	175.4	--	--	175.4	13.7	--	--	13.7
20	Clay-mud	90.4	--	--	90.4	6.4	--	--	6.4
21	Sand	--	--	--	--	--	--	--	--
22	Mud-clay	5.5	--	--	5.5	0.1	--	--	0.1
23	Mud-sand	128.8	5.5	--	134.3	6.3	0.4	--	6.7
24	Mud-clay	--	--	--	--	--	--	--	--
25A	Mud-sand	68.5	11.0	--	79.5	5.7	4.8	--	10.5
25B	Sand	54.8	2.7	--	57.5	4.3	0.1	--	4.4
26A	Mud-sand	185.0	--	--	185.0	10.7	--	--	10.7
26B	Sand-mud	52.0	--	--	52.0	3.6	--	--	3.6
27	Mud	41.1	--	--	41.1	1.8	--	--	1.8
28	Sand	16.4	542.5	--	558.9	2.8	1.7	--	4.5
29	Clay-mud	38.4	--	--	38.4	1.4	--	--	1.4
30	Clay	--	--	--	--	--	--	--	--
31	Mud	35.6	5.5	--	41.1	1.3	1.6	--	8.4
32A	Sand	43.8	--	--	43.8	2.7	--	--	2.7
32B	Sand	35.6	--	--	35.6	2.4	--	--	2.4
33	Sand-mud	46.6	--	--	46.6	1.5	--	--	1.5
34	Detritus	--	--	--	--	--	--	--	--
35	Sand-mud	68.5	--	--	68.5	1.8	--	--	1.8
Mean		40.8	16.3	0.28	57.2	2.6	1.3	.17	4.1

larger in size than those collected from Long Island Sound and Puget Sound. The average biomass found in Kill Bay, Germany was, however, 10 times higher than present in our estuaries.

The benthic infauna were separated into three trophic groups, deposit feeders, filter feeders, carnivores (Table 20). Deposit feeders dominated the benthic infauna. They comprised 71 percent of the population, 63 percent of the biomass and over half of the total species. Deposit feeders averaged 40.8 individuals/m^2 and 2.6 g/m^2. Maximal values were 185 individuals/m^2 and 13.7 g/m^2. The mean weight per individual was 63.7 mg. Filter feeders comprised most of the remainder of the infauna. They averaged 16.3 individuals/m^2 and 1.3 g/m^2, and ranged up to 542.5 individuals/m^2 and 12.1 g/m^2. The mean weight per individual filter feeder was 79.7 mg or slightly greater than that for deposit feeders. Carnivores were an unimportant part of the standing crop. A total of four individual carnivores belonging to three species were obtained in the course of the survey. They represented an average of 0.28 individuals/m^2 and 0.17 g/m^2. The average weight per individual, 614 mg, was nearly an order of magnitude greater than that of the deposit feeders or the filter feeders.

Although the data on numerical abundance and biomass of benthic invertebrates in itself cannot be used to precisely calculate total energy flow through the benthic community, we combined these data with information on the physiology of similar invertebrates inhabiting eel grass beds to estimate the respiration rate and respiratory energy requirements of the benthic population. The data on eelgrass bed invertebrates are presented elsewhere in this Annual Report.

Table 20.--Organisms identified in samples from 39 stations and placed in the following trophic groups.

Filter feeders	Deposit feeders	Carnivores
Bivalves	Polychaetes	Snails
Tagelus divisus	*Nereis pelagica*	*Urosalpinx cinerea*
Tagelus plebeius	*Glymenella torguata*	*Fasciolaris hunteri*
Disinia discus	*Nephthys picta*	Crabs
Mercenaria mercenaria	*Arabella iricolor*	*Libinia dubia*
	Diopatra cuprea	
Amphipods	*Clycera dibranchiata*	
Ampelisca macrocephala	Crabs	
	Panopeus herbstii	
	Hemichordata	
	Saccoglossus kowalevskii	
	Amphipods	
	Amphithoe longimana	

At the mean water temperature during our field work, 21.5^{o} C, the average rates of respiration of deposit feeders, filter feeders, and carnivores were estimated to be 19.6, 28.5, and 30.0 µl O_2/mg dry weight/day respectively. The estimates were multiplied by the biomass per square meter of the respective trophic groups collected at each station (Table 19) to obtain population respiration rates (Table 21). Rates of respiration were multiplied by the oxycaloric equivalent 4.825 cal/ml O_2 to obtain estimates of the respiratory energy requirements of each trophic group per square meter (Table 21). The calculations indicated that the benthic infauna had an average daily respiration of 94.3 ml O_2/m^2/day and an average daily energy requirement of 454.9 cal/m^2/day to supply this respiratory demand. Maximal daily values were 344.9 ml O_2/m^2/day and 1664.1 cal/m^2/day. The respiration of deposit feeders was on the average 55 percent of the total, the respiration of filter feeders 40 percent, and the respiration of carnivores 5 percent. The high respiratory rates of filter feeders and carnivores caused them to contribute a larger percentage to total respiration than to total biomass.

Table 21.--Respiration and respiratory energy requirements at 21.5° C of benthic invertebrate feeding types collected in the shallow estuaries near Beaufort, N.C.

Station	Respiration				Caloric equivalent			
	Deposit feeders	Filter feeders	Carnivores	Total	Deposit feeders	Filter feeders	Carnivores	Total
	Ml O_2/m^2/day				Cal/m^2/day			
1	--	--	--	--	--	--	--	--
2A	--	--	--	--	--	--	--	--
2B	25.5	--	--	25.5	123.1	--	--	123.1
3A	67.7	39.9	--	107.6	326.6	192.5	--	519.1
3B	45.1	144.4	--	189.5	217.6	692.7	--	914.3
4A	45.1	8.6	9.0	62.7	217.6	41.5	43.4	302.5
4B	9.8	85.5	--	195.3	47.3	412.5	--	459.8
5	--	344.9	--	344.9	--	1,664.1	--	1,664.1
6	--	--	189.0	189.0	--	--	911.9	911.9
7	13.7	313.5	--	327.2	66.1	1,512.6	--	1,578.7
11	--	--	--	--	--	--	--	--
12	60.8	--	--	60.8	293.4	--	--	293.4
13	172.5	--	--	172.5	832.3	--	--	832.3
14	22.9	202.4	3.6	228.9	110.5	976.6	17.4	1,104.5
15A	--	--	--	--	--	--	--	--
15B	--	--	--	--	--	--	--	--
15C	245.0	77.0	--	322.0	1,182.1	371.5	--	1,553.6
16	--	--	--	--	--	--	--	--
17	--	--	--	--	--	--	--	--
19	268.5	--	--	268.5	1,295.5	--	--	1,295.5
20	125.4	--	--	125.4	605.0	--	--	605.0
21	--	--	--	--	--	--	--	--
22	2.0	--	--	2.0	9.7	--	--	9.7
23	123.5	11.4	--	134.9	595.9	55.0	--	650.9
24	--	--	--	--	--	--	--	--
25A	111.7	136.8	--	248.5	539.0	660.0	--	1,199.0
25B	84.3	2.9	--	87.2	406.8	14.0	--	420.8
26A	209.7	--	--	209.7	1,011.8	--	--	1,011.8
26B	70.6	--	--	70.6	340.6	--	--	340.6
27	35.3	--	--	35.3	170.3	--	--	170.3
28	54.9	51.0	--	105.9	264.9	246.1	--	511.0
29	27.4	--	--	27.4	132.2	--	--	132.2
30	--	--	--	--	--	--	--	--
31	25.5	45.6	--	71.1	123.0	220.0	--	343.0
32A	52.9	--	--	52.9	255.2	--	--	255.2
32B	47.0	--	--	47.0	226.8	--	--	226.8
33	29.4	--	--	29.4	141.9	--	--	141.9
34	--	--	--	--	--	--	--	--
35	35.7	--	--	35.7	172.3	--	--	172.3
Mean	51.7	37.5	5.1	94.3	249.4	181.1	24.4	454.9

Our calculations suggested that the benthic infauna are very important in the transfer of energy -- and presumably also radionuclides and other pollutants -- in these shallow estuaries. The average respiratory requirement per unit area of this population was ca. 3.4 times larger than that of the eel grass bed invertebrates described elsewhere in this Annual Report. This greater respiratory requirement resulted primarily from a much larger biomass. We estimated the total energy requirement of the benthic infauna by assuming that respiration represented 70 percent of the energy assimilated. The resulting estimate, 650 $cal/m^2/day$ was equivalent to 31 percent of the estimated total plant (phytoplankton, eel grass, and cord grass) net production in this system of shallow estuaries. Zooplankton, in contrast, were estimated to assimilate 3.3 percent of the net phytoplankton production.

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THE ORGANIC CONTENT OF SHELLS, TISSUES, AND PALLIAL FLUID OF SOME ESTUARINE PELECYPODS AND ITS ECOLOGICAL SIGNIFICANCE

T. J. Price, G. W. Thayer, M. W. LaCroix,
and T. G. Roberts

Pelecypods and other molluscs are important both commercially as food for man, and ecologically for their contribution to the biological production and energy flow of aquatic environments. They are major components of the food web and of the animal biomass in estuarine ecosystems. Pelecypods transform energy in phytoplankton and detritus into animal matter acceptable to man and other carnivores (Fig. 26). The soft parts of these pelecypods supply energy and nutrients to terrestrial and aquatic carnivores and to microbes, and within the aquatic system this organic matter is utilized quite rapidly. Much of the total organic matter of pelecypods, however, is in the organic matrix of the shells and thus permanent burial in the sediment of all or some of the organic matter contained in the shell would represent a substantial drainage of organic production from the ecosystem. Even when shells are not buried, utilization of the organic matrix probably is extremely slow. We have begun an investigation of the possible importance of this diversion of energy flow into

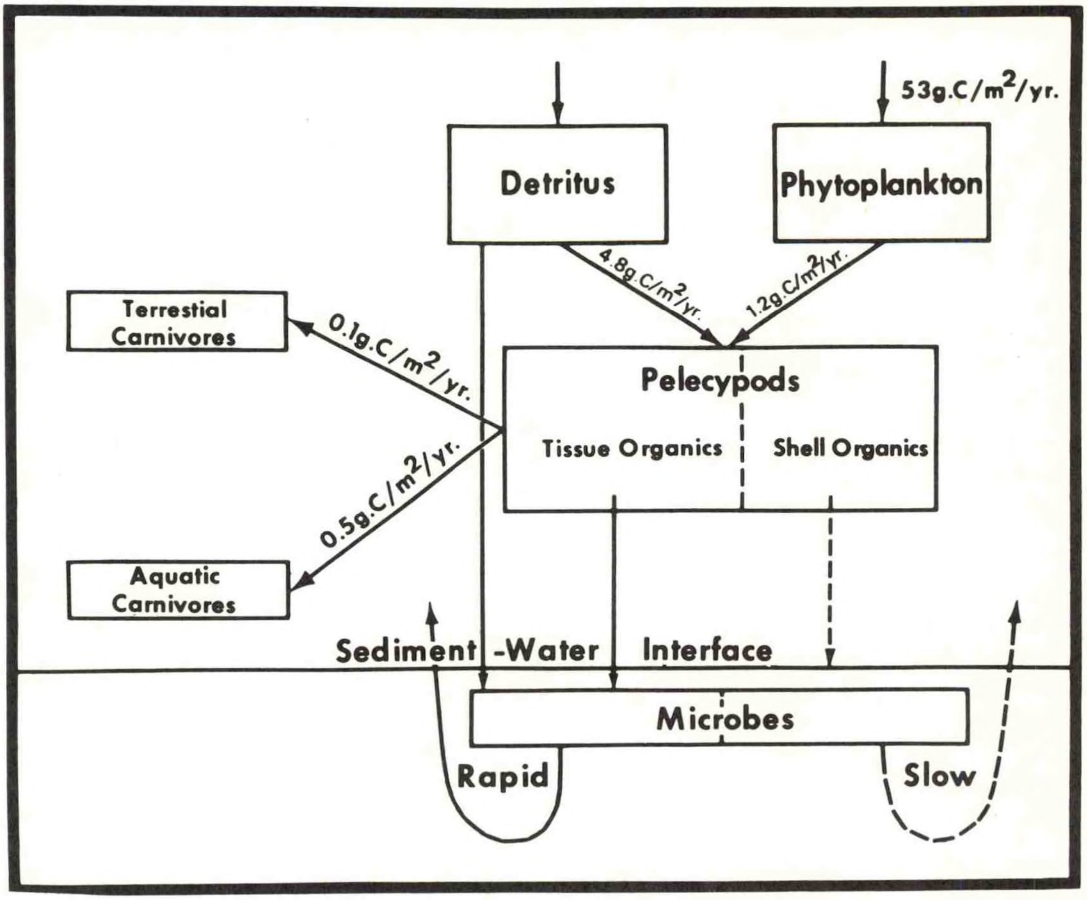

Figure 26.--Diagram for a portion of the food web in the estuaries near Beaufort, N.C. The arrows indicate the flow of energy to and between the different compartments expressed in g $C/m^2/yr$. The input to the plant compartment is net production (g $C/m^2/yr$). The dashed flow indicates slow recycling.

molluscan shells by determining the organic content of shells, meats, and pallial fluids of several estuarine pelecypods.

Methods

Fifty animals of five species: *Argopecten irradians*, bay scallop; *Crassostrea virginica*, American oyster; *Mercenaria mercenaria*, hard clam; *Modiolus demissus*, ribbed mussel; and *Tagelus plebeius*, stout *Tagelus* were collected from the estuaries near Beaufort, N. C.; smaller numbers of *M. demissus* were obtained from New Jersey, Virginia, and Georgia; and *M. demissus granosissima* from Florida. The animals were scrubbed with a soft brush and attached organisms were removed from the shells in such a manner as to minimize the destruction of the organic matter of the shell. Except for *T. plebeius* animals were opened and the pallial fluid drained for 2 minutes into an aluminum weighing dish; pallial fluid was not present in *T. plebeius* because the shells never fully close. After draining, animals were shucked and the meats and shells placed on tared aluminum foil for weighing. Wet, dry, and ash weights were obtained for the components. Dry weights were obtained after heating the samples at 100° C in an oven for 48 hours or until the weight was constant. We determined organic content by ashing at 500 ± 5° C for at least 48 hours. This temperature is sufficient to oxidize organic carbon to carbon dioxide but low enough to preclude the breakdown of calcium carbonate. Organic matter was considered equal to ash-free dry weight, i.e., the loss in weight by ashing.

Results and Discussion

The percent ash-free dry weight, i.e., the percent of the three components which is organic material, was determined for all the organisms. Values for percent organic material for shells, meats, and pallial fluids are summarized in table 22. The meats were largely organic matter (average 82 percent) and the percent of organic matter was fairly uniform (range 72-88 percent) for all species tested. The shells of these animals contained a small percentage of organic matter (average 4 percent) and were quite variable (range 1-6 percent). The organic content of the shell appeared related to shell texture, i.e., the smaller the percentage of organic matter the more brittle the shell. The pallial fluid was intermediate between shell and meats (average 26 percent) in percent organic matter and in variability between species (range 20-35 percent).

The distribution of total organic matter among shell, meat, and pallial fluid is presented in table 23. These values were obtained from data on the composition of shell, meat, and pallial fluid (Table 22). and the distribution of dry weight among these three components in the individual animals. Average values for the distribution of dry weight among shell, meat, and pallial fluid are summarized in table 23. Shell contained 12 percent (*A. irradians*) to 72 percent (*C. virginica*) of the total organic matter, meats from 26 percent (*C. virginica*) to 84 percent (*A. irradians*), and the pallial fluid from 3 percent (*C. virginica*) to 9 percent (*M. demissus*). This fluid seems unimportant in the flow of

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Table 22 . Percent organic matter for dry shell, meats, and pallial fluid of estuarine molluscs (± one standard deviation)

Species	Origin	Shell	Meats	Pallial Fluid
Argopecten irradians	N.C.	1.37 ± 0.15	82.47 ± 1.73	35.15 ± 6.10
Crassostrea virginica	N.C.	3.04 ± 1.16	71.87 ± 8.47	20.01 ± 4.02
Mercenaria mercenaria	N.C.	1.90 ± 0.18	79.79 ± 4.32	26.81 ± 10.47
Tagelus plebeius	N.C.	2.82 ± 0.34	77.80 ± 4.25	---
Modiolus demissus	N.J.	6.16 ± 0.52	84.42 ± 1.98	22.57 ± 4.72
Modiolus demissus	Va.	5.34 ± 0.40	84.79 ± 2.84	21.78 ± 4.44
Modiolus demissus	N.C.	4.63 ± 0.23	81.22 ± 2.33	22.00 ± 2.84
Modiolus demissus	Ga.	5.43 ± 0.63	87.65 ± 3.32	25.20 ± 4.73
Modiolus demissus granosissima	Fla.	5.86 ± 0.42	86.69 ± 1.56	32.69 ± 4.65

Table 23. Percent of the total organic material in the shell, meats, and pallial fluid of estuarine molluscs (± one standard deviation)

Species	Origin	Shell	Meats	Pallial Fluid
Argopecten irradians	N.C.	12.17 ± 1.18	84.27 ± 1.98	3.56 ± 1.43
Crassostrea virginica	N.C.	71.89 ± 9.95	25.55 ± 9.87	2.56 ± 1.07
Mercenaria mercenaria	N.C.	38.60 ± 3.83	54.29 ± 5.27	7.41 ± 2.99
Tagelus plebeius	N.C.	13.00 ± 1.81	87.00 ± 3.36	--
Modiolus demissus	N.J.	40.23 ± 3.20	55.59 ± 3.46	4.11 ± 1.59
Modiolus demissus	Va.	44.54 ± 3.95	50.71 ± 3.81	4.78 ± 1.64
Modiolus demissus	N.C.	47.44 ± 2.96	43.41 ± 3.94	9.14 ± 2.18
Modiolus demissus	Ga.	40.45 ± 4.45	54.02 ± 9.39	4.32 ± 1.59
Modiolus demissus granosissima	Fla.	37.01 ± 4.66	57.91 ± 5.13	4.74 ± 1.96

organic matter to carnivores because it contained a small part of the organic matter and because when released into the environment it would rapidly be diluted and dispersed and thus be unavailable to many carnivores. The pallial fluid might however, be important in contributing some dissolved organic matter to the water.

The large proportion of the total organic matter in the shells of oysters (72 percent) was derived from a combination of a thick shell (98 percent of the total dry weight) and intermediate (3 percent) organic matter in the shell itself. Oyster shells are composed of four distinct layers: periostracum, prismatic layer, calcite-ostracum, and hypostracum. The periostracum is a film of organic material that covers the external surface of the shell. The remaining layers are composed of inorganic crystals deposited in a matrix of conchiolin. The low to intermediate proportions of total organic matter in the shells of the other species (Table 23) were produced by various combinations of shell thickness and organic content. A thin and brittle shell with minimal organic matrix contained only 12 percent of the total organic matter in *A. irradians*; a very thin shell with more organic matrix contained 13 percent of the total organic matter in *T. plebeius*. The high organic content of the shell of *M. demissus* was offset by an intermediate shell thickness so that the proportion of the total organic matter in the shell was only 37 to 47 percent. *M. mercenaria* had a similar proportion, 39 percent, its massive shell had an intermediate organic content.

We found statistically significant difference among populations of M. demissus from different areas in the proportions of total organic matter in the meats and in the shells (Table 24). The proportion of the total organic matter in shell increased significantly southward from New Jersey to North Carolina and northward from Florida to North Carolina. The proportion of the total organic matter in the meat had significant reverse trends. Reasons for these differences in composition were not determined.

Our data (Table 23) indicate that death of the pelecypods and the subsequent burial of the shells would constitute a loss of 12 to 72 percent of the organic material present in the organisms at any one time. This loss of organic production undoubtedly would be less than the fraction of the total organic matter present in the shell because a substantial portion of the organic matter produced by a mollusc during its life is in the form of gametes, mucus, and excretory products which are expelled from the living organism and not included in our estimate of total organic matter. We extrapolated from various data in the literature to estimate the fraction of the total organic production during the life of pelecypods which would be tied up in the organic matrix of their shells and lost upon burial of the shell. These fractions were 50 percent for C. virginica, 30 percent for M. mercenaria and M. demissus, and 5 percent for A. irradians and T. plebeius.

Table 24. Percent of total dry weight in the shell, meats, and pallial fluid of some estuarine molluscs

Species	Origin	Shell	Meats	Pallial Fluid
Argopecten irradians	N.C.	89	11	1
Crassostrea virginica	N.C.	98	1	1
Mercenaria mercenaria	N.C.	96	3	1
Tagelus plebeius	N.C.	83	17	0
Modiolus demissus	N.J.	89	8	3
Modiolus demissus	Va.	91	6	3
Modiolus demissus	N.C.	92	5	4
Modiolus demissus	Ga.	91	7	2
Modiolus demissus granosissima	Fla.	89	9	2

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The few data we have gathered thus far indicated that the organic matrix of shells is lost very slowly after death of the animal. Oyster shells which had lain unburied in an intertidal area, the site of a former oyster shucking house, for 20 to 70 years still had an organic content of 1.2 percent or 40 percent of that initially present in the living animal. Data in the literature of fossil shells indicated that specimens with an estimated age of 360 million years still contained measurable amounts of organic matter. It is thus likely that shells will be buried in the sediment before any appreciable loss of organic matrix occurs and that in general the organic matter in shell represents organic production which will be permanently lost from the ecosystem.

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DISTRIBUTION AND RELATIVE ABUNDANCE OF FISHES IN NEWPORT RIVER, NORTH CAROLINA

William R. Turner, George N. Johnson,
Ronald L. Garner, and Jerry E. Watson

Newport River has been studied over the past 10 years by the National Marine Fisheries Service, Center for Estuarine and Menhaden Research. Major objectives of the studies are construction of a mathematical model describing energy flow within the system and development of research techniques applicable to estuaries in general. Although substantial segments of research essential to developing the model are completed, fishes have received but scant attention.

The present studies were undertaken in 1970 to broaden our knowledge of the ichthyofauna of Newport River. Immediate objectives were obtaining an inventory of the fishes within the system and determining their seasonal distribution and relative abundance. Information obtained from these studies will identify important species and thus enable establishing priorities among planned researches on energy requirements, growth, food habits, and biomass of various fishes.

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Description of Study Area

Newport River originates on the coastal plains of North Carolina in a swampy area near a group of natural lakes in the Croatan National Forest. The northwest prong (6.08 km long) and the southwest prong (14.02 km long) are the two main headwaters and converge to form the river proper. From the confluence of these two prongs, the river courses eastward for 18.57 km then broadens into the Newport estuary. The estuary continues eastward then dips south to join the Atlantic Ocean at Onslow Bay. From the mouth of the river to its juncture with the ocean at Beaufort Inlet, the linear distance along the main channel of the estuary is 19.18 km. The surface area of the estuary has been estimated at 31 km^2; whereas the surface area of the river proper, from the junction of the two prongs to the mouth, is only 0.48 km^2.

The upper section of the river drains hardwood swamps and pine forests. These yield downstream to marshlands. The banks are low but steep, and grade sharply into the channel with very little or no littoral area. Channel depths range from 0.6 m, where the river shoals near the mouth, to 4.6 m in the deepest upstream pocket. Mean channel depth was estimated to be 3.0 m from a series of soundings at low tide.

Newport River estuary is generally less than 1.0 m deep at mean low tide, and the shallow waters are well mixed by wind and tidal action. The intracoastal waterway traverses the lower portion of the estuary and forms a connection with Neuse River through Core Creek (Adams Creek Canal). A second connection with the Neuse River is formed by an abandoned canal linking Harlowe Creek to Clubfoot Creek. Exchange of waters with the Neuse River through these canals may have some effect upon the hydrology and species composition of Newport River.

Methods

To facilitate the description of fish distribution and the location of hydrological observations, the river was divided into six zones, three in the upper river between the forks and the estuary and three in the lower river or estuary (fig. 27). The end of navigable waters, at river km 34.87, determined the upstream boundary of Zone 1. Zone boundaries downstream were located at points with conspicuous land marks and spaced as evenly as possible.

A variety of collecting gear was used to sample the widest possible range of species. A haul seine was used in shallow littoral areas and bottom trawls (2 sizes) and a surface trawl in deeper waters. Anchored gill nets, the only stationary gear employed, were fished from surface to bottom in open waters.

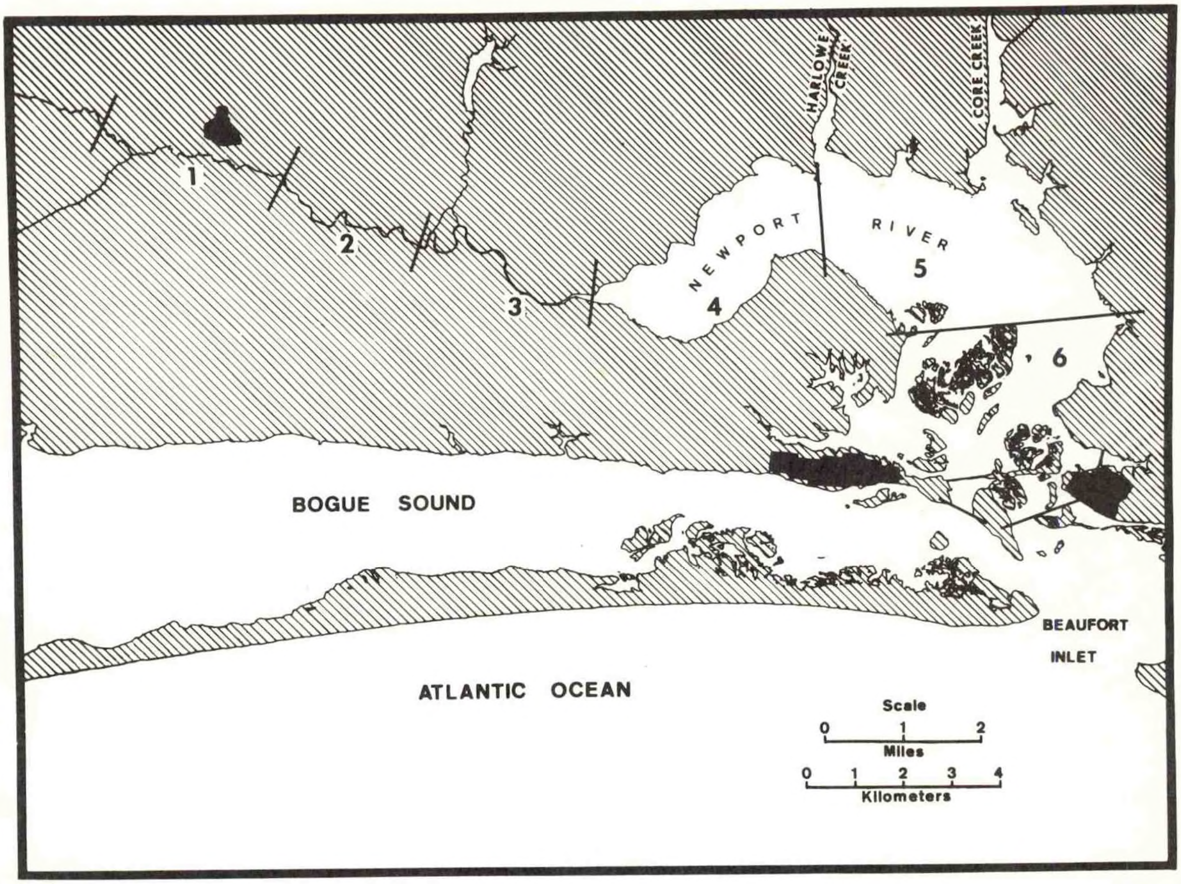

Figure 27.--Zones designated for sampling the fish population of Newport River.

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Hydrography of the system dictated the types of gear fished in each section of the river. The surface trawl (8 stations) and small bottom trawl (4 stations) were fished only in the upper river, while the haul seine (6 stations) and large bottom trawl (5 stations) were fished only in the lower river or estuary. Gill nets were fished in each zone throughout the system (3 stations in the upper river, and 3 regular and 2 alternate stations in the lower river). The surface trawl was limited to fishing in the upper river because of the greater amount of net avoidance encountered in the broader expanse and more transparent waters of the estuary. Steep banks and soft mud bottoms precluded haul seining in the upper river. The total amount of effort expended in each zone during 1970 is summarized in Table 25. Generally, each station was occupied monthly and all samples taken within a 2-week period each month.

Two bottom trawls of similar construction but different sizes were used during the surveys. The smaller net was 2.7 m across the headrope and 3.0 m along the footrope, and the larger 5.8 m across the headrope and 6.1 m along the footrope. A 4.8-mm diameter chain was fastened along the footrope of each trawl for weighting the bottom line. The trawls were made of 19.1-mm bar mesh in the body and wings and 6.3-mm bar mesh in the cod. Otter boards of appropriate size were fastened directly to the ends of the wings.

Table 25.--Monthly distribution of sampling effort in the Newport River, 1970

Fishing gear	J	F	M	A	M	J	J	A	S	O	N	D	Total
						Number hauls							
Surface trawl													
Zone 1	2	2	2	2	2	2	2	2	2	2	2	2	24
2	3	3	3	3	3	3	3	3	3	3	3	3	36
3	3	3	3	3	3	3	3	3	3	3	3	3	36
Bottom trawl (9 m)													
Zone 1	1	1	1	1	1	1	1	1	1	1	1	1	12
2	1	1	1	1	1	1	1	1	1	1	1	1	12
3	2	2	2	2	2	2	2	2	2	2	2	2	24
Bottom trawl (6.1 m)													
Zone 4	1	1	1	1	1	1	1	1	1	1	1	1	12
5	2	2	2	2	2	2	2	2	2	2	2	2	24
6	2	2	2	2	2	2	2	2	2	2	2	2	24
Haul seine													
Zone 4	2	2	2	2	2	2	2	2	2	2	2	2	24
5	2	2	2	2	2	2	2	2	2	2	2	2	24
6	2	2	2	2	2	2	2	2	2	2	2	2	24
						Shackle-hours							
Gill nets													
Zone 1	5	1	1	24	16	25	4	5	6	3	5	5	100
2	5	1	1	24	16	3	4	4	4	3	5	5	75
3	6	1	1	24	17	3	4	19	3	3	4	4	89
4	18	1	1	4	1	6	17	5	38	20	17	18	146
5	17	1	1	4	1	7	18	6	74	20	18	19	186
6	55	-	3	6	7	54	55	10	165	53	53	224	685

A tickler chain (4.8-mm diameter), about 0.5 m shorter than the footrope, was suspended between the otter boards to stir the bottom in front of the trawl. Three 8.9-cm diameter floats were attached to the headropes to open the mouths of the trawls. Nets were towed by two 18.3-m lengths of 16-mm rope attached to separate warps. The small trawl was towed for 5 minutes at each station, and the large trawl for 10 minutes at a station.

The haul seine was 1.2 X 21.3 m with a 1.2 m^2 center bag. The wings of the seine were 5.4-mm and the bag was 3.2-mm (bar measure) woven nylon mesh. The seine was pivoted in a 15.2 m radius around a focal point on the shoreline; one semi-circular sweep covered an area of 182.5 m^2. One haul was usually made at each station, but when fish were not taken a second or third haul was made in an adjacent location.

The surface trawl had a mouth opening 6.7 X 0.9 m and tapered 6.1 m to the cod end. The wings and body consisted of 6.3-mm and the tail bag of 3.2-mm nylon mesh. The trawl was towed downstream between two outboard motorboats for 5 minutes at each station. A chain attached to the footrope and floats attached to the headrope kept the mouth of the trawl open while under tow.

Experimental gill nets were 2.4 m deep by 38.1 m long and consisted of five equal panels of 2.5, 3.8, 5.1, 6.3, and 7.6-cm bar mesh monofilament nylon webbing. Additional nets of 1.9, 3.5, and 10.2-cm mesh were fished occasionally. The nets were anchored at both ends and fished for a recorded period of time at each station. Fishing effort was expressed in units of shackle-hours (table 25); 1 shackle was equivalent to 7.6 m of net.

Fish collections were preserved in 10 percent formalin and brought to the laboratory for processing. In large catches where some species were so numerous that not all specimens could be preserved, only samples of the abundant species were taken. A representation of the species collected was preserved in 40 percent isopropanol and placed in the fish collection at the Center. Processing of fishes included identification, enumeration, and measurement of length (tip of snout to the end of the median caudal ray) and weight. Water temperatures and salinities were taken with a portable induction salinometer during the sampling for fish.

Salinity and Temperature

Salinities in the system ranged from 0.0 o/oo in the upper river to 33.7 o/oo in Zone 6 (table 26). During the summer, salt water penetrated into Zone 1 and during the late winter only to Zone 4. Salinities were lowest throughout the river during the February-April sampling periods; highest salinities in Zones 3 through 6 were recorded in late summer and early fall, and in Zones 1 and 2 in mid-summer. Salinities were most variable in Zone 3, and ranged from 0.0 o/oo during periods of greatest precipitation

Table 26.--Mean monthly salinities and temperatures in each zone of the Newport River during periods of actual biological sampling. Lines denote arbitrary divisions of freshwater (<1.0 o/oo) and low (1-10 o/oo), moderate (10-25 o/oo), and high (>25 o/oo) salinity

Month	Zone						Month	Zone					
	1	2	3	4	5	6		1	2	3	4	5	6
	Salinity (o/oo)							Temperature (°C)					
Jan.	0.1	0.2	4.2	22.3	26.2	30.3	Jan.	6.3	6.3	6.5	6.3	6.5	6.5
Feb.	0.0	0.0	0.0	13.7	17.9	22.7	Feb.	7.1	7.5	7.3	9.1	9.3	9.2
Mar.	0.0	0.0	0.0	15.2	16.3	21.5	Mar.	11.7	11.7	12.3	10.1	11.1	11.3
Apr.	0.0	0.0	0.0	8.3	18.7	30.1	Apr.	11.5	12.3	11.9	13.1	13.9	14.3
May	0.1	0.5	3.3	14.2	28.3	25.9	May	24.5	25.5	27.0	22.9	23.2	22.5
June	0.3	0.7	15.0	24.3	27.8	32.1	June	25.3	25.6	26.1	28.7	23.8	23.9
July	0.5	1.1	9.3	22.9	26.7	31.3	July	26.7	26.3	28.7	25.6	27.5	27.9
Aug.	0.4	0.5	1.3	14.4	30.4	33.1	Aug.	26.4	27.9	29.1	29.0	28.3	28.3
Sept.	0.4	0.5	5.0	16.7	31.4	32.9	Sept.	24.5	26.1	26.5	28.6	29.1	29.6
Oct.	0.1	0.6	19.3	27.0	31.0	33.7	Oct.	18.4	19.7	20.9	22.6	21.6	22.5
Nov.	0.1	0.3	8.3	17.3	25.9	30.6	Nov.	14.9	14.7	13.1	13.5	14.1	15.7
Dec.	0.0	0.5	2.2	23.7	29.7	30.6	Dec.	8.5	8.5	8.5	12.9	13.8	13.9

(Feb.-Apr.) to 19.3 o/oo in October. Zone 3, however, was dominated by estuarine waters (> 1.0 o/oo salinity) during most of the year.

Water temperatures (table 26) were lowest at all sampling stations in January and ranged from 6.3° to 6.5° C. Highest temperatures were reached earlier upriver than downriver. The peak temperature was recorded in Zone 1 during July (26.7° C). Peak temperatures were attained in Zones 2, 3, and 4 during August (27.9° - 29.1° C), and in Zones 5 and 6 during September (29.1° and 29.6° C).

Fish Distribution and Salinity

One hundred and four species of fishes, representing 50 families, were collected during the surveys (table 27). From 22 to 26 species were taken in each of the three zones in the upper river, while in the lower river numbers of species increased in relation to distance downstream; 53 species were collected from Zone 4, 57 from Zone 5, and 69 from Zone 6. Seventeen species were collected in the upper river exclusively, and 64 species were confined to the lower section of the river; the remaining 23 species ranged over both sections of the river or were found throughout the entire system during some stage of their life cycle.

Table 27.--Occurrence of fishes in the Newport River, 1970. Salinity regimes correspond to divisions outlined in Table 26

Species	Zone						Salinity regime
	1	2	3	4	5	6	
Carcharhinidae - requim sharks							
Carcharhinus milberti, sandbar shark						X	HS
Rhizoprionodon terraenovae, Atlantic sharpnose shark					X		HS
Sphyrnidae - hammerhead sharks							
Sphyrna lewini, scalloped hammerhead				X			MS
Dasyatidae - stingrays							
Dasyatis sayi, bluntnose stingray					X		HS
Myliobatidae - eagle rays							
Rhinoptera bonasus, cownose ray				X	X	X	MS-HS
Lepisosteidae - gars							
Lepisosteus osseus, longnose gar	X	X	X				F-LS
Amiidae - bowfins							
Amia calva, bowfin	X						F
Elopidae - tarpons							
Elops saurus, ladyfish					X		HS
Anguillidae - freshwater eels							
Anguilla rostrata, American eel	X		X	X	X		F-HS
Congridae - conger eels							
Conger oceanicus, conger eel						X	HS

Table 27.--Continued

Species	Zone 1	2	3	4	5	6	Salinity regime
Ophichthidae - snake eels							
Myrophis punctatus, speckled worm eel				X	X	X	MS-HS
Clupeidae - herrings							
Alosa aestivalis, blueback herring	X	X	X	X	X		F-MS
Alosa mediocris, hickory shad		X		X			F-MS
Alosa pseudoharengus, alewife				X		X	MS-HS
Alosa sapidissima, American shad	X						F
Brevoortia tyrannus, Atlantic menhaden	X	X	X	X	X	X	F-HS
Dorosoma cepedianum, gizzard shad	X	X	X	X		X	F-HS
Harengula pensacolae, scaled sardine						X	HS
Opisthonema oglinum, Atlantic thread herring				X	X	X	MS-HS
Engraulidae - anchovies							
Anchoa hepsetus, striped anchovy			X	X	X	X	MS-HS
Anchoa mitchilli, bay anchovy	X	X	X	X	X	X	F-HS
Synodontidae - lizardfishes							
Synodus foetens, inshore lizardfish				X	X	X	MS-HS
Cyprinidae - minnows and carps							
Notemigonus crysoleucas, golden shiner	X	X	X				F-LS
Ictaluridae - freshwater catfishes							
Ictalurus catus, white catfish	X	X	X				F-LS
Ictalurus natalis, yellow bullhead	X						F
Noturus insignis, margined madtom	X						F

Table 27.--Continued

Species	Zone						Salinity regime
	1	2	3	4	5	6	
Aphredoderidae - pirate perches							
Aphredoderus sayanus, pirate perch	X						F
Batrachoididae - toadfishes							
Opsanus tau, oyster toadfish				X	X	X	MS-HS
Porichthys porosissimus, Atlantic midshipman					X	X	MS-HS
Gadidae - codfishes							
Urophycis regius, spotted hake				X	X	X	LS-HS
Exocoetidae - flyingfishes and halfbeaks							
Cypselurus heterurus, Atlantic flyingfish						X	HS
Hyporhamphus unifasciatus, halfbeak						X	HS
Belonidae - needlefishes							
Ablennes hians, flat needlefish						X	HS
Strongylura marina, Atlantic needlefish		X	X	X		X	F-HS
Cyprinodontidae - killifishes							
Cyprinodon variegatus, sheepshead minnow				X	X	X	MS-HS
Fundulus confluentus, marsh killifish			X				F
Fundulus heteroclitus, mummichog			X	X	X	X	F-HS
Fundulus majalis, striped killifish				X	X	X	MS-HS
Atherinidae - silversides							
Membras martinica, rough silverside						X	HS

Table 27 .—Continued

Species	Zone 1	2	3	4	5	6	Salinity regime
Menidia beryllina tidewater silverside		X	X	X	X	X	F-MS
Menidia menidia, Atlantic silverside		X	X	X	X	X	F-HS
Syngnathidae - pipefishes and seahorses							
Hippocampus erectus, lined seahorse						X	HS
Syngnathus florida, dusky pipefish					X		MS
Syngnathus fuscus, northern pipefish					X		MS-HS
Syngnathus louisianae, chain pipefish					X	X	MS-HS
Percichthyidae - temperate basses							
Morone americana, white perch			X				F
Serranidae - sea basses							
Centropristis philadelphica, rock sea bass					X	X	HS
Centropristis striata, black sea bass						X	HS
Unidentified serranid (1 species)				X		X	MS-HS
Centrarchidae - sunfishes							
Enneacanthus gloriosus, bluespotted sunfish	X						F
Lepomis gibbosus, pumpkinseed	X	X					F
Lepomis gulosus, warmouth	X						F
Lepomis macrochirus, bluegill	X	X					F
Micropterus salmoides, largemouth bass	X	X					F
Pomoxis nigromaculatus, black crappie	X	X					F-LS
Percidae - perches							
Etheostoma olmstedi, tessellated darter	X						F

Table 27.--Continued

Species	Zone 1	2	3	4	5	6	Salinity regime
Pomatomidae - bluefishes							
Pomatomus saltatrix, bluefish		X	X	X	X	X	LS-HS
Rachycentridae -cobias							
Rachycentron canadum, cobia					X		HS
Carangidae - jacks and pompanos							
Caranx hippos, crevalle jack			X	X		X	MS-HS
Chloroscombrus chrysurus, Atlantic bumper				X			MS
Selene vomer, lookdown				X	X	X	MS-HS
Trachinotus falcatus, permit						X	HS
Lutjanidae - snappers							
Lutjanus griseus, gray snapper				X			MS
Lobotidae - tripletails							
Lobotes surinamensis, tripletail			X				MS
Gerreidae - mojarras							
Eucinostomus argenteus, spotfin mojarra						X	HS
Eucinostomus gula, silver jenny				X	X	X	MS-HS
Pomadasyidae - grunts							
Orthopristis chrysoptera, pigfish				X	X	X	MS-HS
Sparidae - porgies							
Archosargus probatocephalus, sheepshead					X	X	HS
Lagodon rhomboides, pinfish			X	X	X	X	F-HS

Table 27.--Continued

Species	Zone						Salinity regime
	1	2	3	4	5	6	
Sciaenidae - drums							
Bairdiella chrysura, silver perch			X	X	X	X	LS-HS
Cynoscion nebulosus, spotted seatrout			X	X	X	X	LS-HS
Cynoscion regalis, weakfish				X	X	X	LS-HS
Leiostomus xanthurus, spot		X	X	X	X	X	F-HS
Menticirrhus americanus, southern kingfish				X			MS
Menticirrhus saxatilis, northern kingfish				X	X	X	MS-HS
Micropogon undulatus, Atlantic croaker	X	X	X	X	X	X	F-HS
Pogonias cromis, black drum				X	X	X	MS-HS
Ephippidae - spadefishes							
Chaetodipterus faber, Atlantic spadefish					X	X	HS
Mugilidae - mullets							
Mugil cephalus, striped mullet	X	X	X	X	X	X	F-HS
Sphyraenidae, barracudas							
Sphyraena barracuda, great barracuda						X	HS
Gobiidae - gobies							
Gobionellus boleosoma, darter goby				X		X	MS-HS
Gobionellus hastatus, sharptail goby						X	HS
Gobionellus shufeldti, freshwater goby		X		X	X		F-HS
Microgobius thalassinus, green goby				X	X		MS
Trichiuridae, cutlassfishes							
Trichiurus lepturus, Atlantic cutlassfish					X		MS-HS

Table 27.--Continued

Species	Zone						Salinity regime
	1	2	3	4	5	6	
Scombridae - mackerels and tunas							
Scomberomorus maculatus, Spanish mackerel				X	X	X	MS-HS
Stromateidae - butterfishes							
Peprilus alepidotus, harvestfish				X			LS
Peprilus triacanthus, butterfish				X	X	X	MS-HS
Triglidae - searobins							
Prionotus carolinus, northern searobin					X	X	HS
Prionotus evolans, striped searobin					X	X	MS-HS
Prionotus scitulus, leopard searobin						X	HS
Prionotus tribulus, bighead searobin				X		X	MS-HS
Bothidae - lefteye flounders							
Ancylopsetta quadrocellata, ocellated flounder					X	X	MS-HS
Citharichthys spilopterus, bay whiff				X		X	MS-HS
Etropus crossotus, fringed flounder				X	X	X	MS-HS
Paralichthys albigutta, Gulf flounder						X	HS
Paralichthys dentatus, summer flounder			X	X	X	X	LS-HS
Paralichthys lethostigma, southern flounder	X	X	X	X	X	X	F-HS
Scopthalmus aquosus, windowpane					X	X	MS-HS
Soleidae - soles							
Trinectes maculatus, hogchoker	X	X	X	X	X	X	F-HS

Table 27.--Continued

Species	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Salinity regime
Cynoglossidae - tonguefishes							
Symphurus plagiusa, blackcheek tonguefish				X	X	X	LS-HS
Balistidae - triggerfishes and filefishes							
Monacanthus hispidus, planehead filefish					X	X	LS-HS
Tetraodontidae - puffers							
Sphoeroides maculatus, northern puffer					X	X	HS
Diodontidae - porcupinefishes							
Chilomycterus schoepti, striped burrfish					X	X	HS

Thirteen of the 17 species exclusive to the upper river were collected in freshwaters only, <1.0 o/oo salinity, while four species (longnose gar, Lepisosteus osseus, golden shiner, Notemigonus crysoleucas, white catfish, Ictalurus catus, and black crappie, Pomoxis nigromaculatus) showed a tolerance for low salinity or brackish waters, 1-10 o/oo. The longnose gar is a well-known invader of moderate to high salinity waters, but was not taken in the Newport River estuary. Of the 13 species taken only in freshwaters, three are known to occur in saline waters, but their scarcity in the collections reflected a limited distributional pattern. They were the anadromous American shad, Alosa sapidissima, and white perch, Morone americana, and the marsh killifish, Fundulus confluentus. Consequently, only 10 species were regarded as strictly freshwater forms.

The fish population of the lower river or estuary was essentially marine fauna. The only species of freshwater origin that invaded the estuary were gizzard shad, Dorosoma cepedianum, and the catadromous American eel, Anguilla rostrata. On the other hand, 12 of the marine forms were considered as euryhaline and penetrated into tidal fresh waters of the upper river. Seven other marine species tolerated waters within the low salinity range (1-10 o/oo); four were collected from brackish waters of the upper river and three from the low salinity waters (8.3 o/oo) encountered in Zone 4 of the lower river during the April sampling period.

Eighty-six different species were collected in moderate to high salinity waters (i.e. over 10 o/oo) of the estuary. Twenty-six of these species gave evidence of preferring high salinity since they were collected only from waters greater than 25 o/oo. Five of these species, however, have been recorded from freshwaters by other workers and, are therefore considered euryhaline: these species are ladyfish, *Elops saurus*; rough silverside, *Membras martinica*; sheepshead, *Archosargus probatocephalus*; sharptail goby, *Gobionellus hastatus*; and northern puffer, *Sphoeroides maculatus*.

Relative Abundance

A total of nearly 129,000 fishes were collected from Newport River in 1970. Moveable gear (trawls and haul seine) accounted for 98 percent of the total catch, and stationary gear (anchored gill nets) the remainder. Gill nets were fished for 1,281 shackle-hours over the 12-month period, whereas the actual fishing time for all other gears was estimated at 28.5 hours. The surface trawl netted 66 percent of the total catch and was the most successful gear employed in terms of catch per unit of effort, 884 fish per haul. The haul seine took 19 percent of the total catch and 335 fish per haul, the large bottom trawl 13 percent of the total catch and 284 fish per haul, and the small bottom trawl less than 1 percent of the total

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catch and 23 fish per haul. Gill nets were the least efficient of the various gears, yielding only 1.4 fish per shackle-hour.

A general picture of the utilization of each zone and the different habitats within the system can be gained by examining the relative abundance of species in the catches by various gears. Each species representing 1 percent or more of the total catch by a particular gear for the entire year was considered a dominant form.

Surface trawls captured 29 species of fishes from pelagic waters of the upper river, but just two species made up nearly 98 percent of the total catch (Table 28). Atlantic menhaden (*Brevoortia tyrannus*), predominantly young of the year, was the most abundant species and was followed by bay anchovy (*Anchoa mitchilli*). Both of these species, marine euryhaline fishes, moved upstream into Zone 1, but their numbers decreased in a direct relation to distance upstream, Golden shiner ranked next in abundance, but made up less than 1 percent of the total catch.

Twenty-six species were taken in the upper river by bottom trawl, and the seven dominant species constituted about 94 percent of the catch. Spot (*Leiostomus xanthurus*) was the predominant species in the samples, and was followed in order of decreasing abundance by Atlantic croaker (*Micropogon undulatus*), hogchoker (*Trinectes maculatus*), white catfish, pinfish (*Lagodon rhomboides*), bay anchovy, and pirate perch

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Table 28.--Relative abundance of the principal fishes taken by surface trawl and bottom trawl in upper Newport River, 1970

	Catch per haul in Zone			Composition of total catch
	1	2	3	
	Surface trawl			Percent
Brevoortia tyrannus	7	138	1,758	80.57
Anchoa mitchilli	17	24	369	17.14
	Bottom trawl			Percent
Leiostomus xanthurus	-	1	17	39.15
Micropogon undulatus	1	5	6	19.57
Trinectes maculatus	1	1	7	17.53
Ictalurus catus	1	1	2	7.33
Lagodon rhomboides	-	-	3	6.31
Anchoa mitchilli	-	-	1	2.32
Aphredoderus sayanus	1	-	-	1.67

(Aphredoderus sayanus). Atlantic croaker and hogchoker occurred as far upstream as Zone 1, but were more numerous downstream. Spot was taken as far upstream as Zone 2, but was more abundant in Zone 3. White catfish was distributed rather evenly throughout the upper river, while the other freshwater species, pirate perch, was found only in Zone 1. Pinfish and bay anchovy were collected in Zone 3 only. Of the nine predominant fishes in samples from the upper river, six were marine euryhaline species and three freshwater species.

Samples from bottom trawling in the lower river contained 58 different species, but four of these made up 95 percent of the total catch (table 29). Spot was again the most abundant species and was followed successively by bay anchovy, pinfish, and Atlantic croaker. All of the latter were also among the dominant species of the upper river. Spot (mostly adult) was most numerous in Zone 6, bay anchovy in Zone 4, pinfish in Zone 6 and Atlantic croaker in Zone 5. Pinfish and Atlantic croaker were sparse in Zones 4 and 6 , respectively.

Thirty-seven species were represented in samples from littoral waters of the estuary, and seven of these accounted for nearly 96 percent of the total catch by haul seine. These samples consisted principally of young-of-the-year fishes. Young spot predominated in these samples. Atlantic silverside (Menidia menidia) and young striped mullet (Mugil cephalus) ranked next in importance

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Table 29.--Relative abundance of the principal fishes taken by bottom trawl and haul seine in lower Newport River, 1970

Species	Catch per haul in Zone 4	5	6	Composition of total catch
	Bottom trawl			Percent
Leiostomus xanthurus	74	107	129	38.44
Anchoa mitchilli	281	61	65	37.52
Lagodon rhomboides	2	24	45	9.91
Micropogon undulatus	31	45	2	8.79
	Haul seine			Percent
Leiostomus xanthurus	273	129	116	51.53
Menidia menidia	41	40	89	16.87
Mugil cephalus	50	37	63	14.92
Anchoa mitchilli	25	9	11	4.50
Brevoortia tyrannus	25	16	1	4.17
Lagodon rhomboides	5	4	11	1.98
Membras martinica	-	-	19	1.87

but were each less than a third as numerous as spot. Bay anchovy and post-larval Atlantic menhaden ranked next and were followed by post-larval pinfish and rough silverside. Unlike the adults, young spot were most abundant in the upper reaches of the estuary indicating an upstream movement similar to that of Atlantic menhaden. Both species of Atherinids, Atlantic and rough silversides, were most numerous in the lower reaches of the system. The distribution of bay anchovy and pinfish in littoral waters paralleled their distribution in samples from benthic waters.

Gill nets, fished in open waters throughout the river, took a greater variety of fishes than any other gear, 59 different species. Because of their selectivity, however, gill nets showed relative abundance of the moderate-to-large-sized fishes only. Eight species comprised about 93 percent of the total catch by gill nets (table 30). Atlantic menhaden (chiefly yearling fish) was by far the dominant species in the open waters. Yearling menhaden were especially abundant in catches in the estuary but small numbers were taken upstream into Zone 2. Juvenile and adult pinfish ranked second in abundance and occurred only in samples from the estuary. Spot was the third most abundant species and was captured as far upstream as Zone 2, but in smaller numbers than in the estuary. Longnose gar ranked next in abundance and was limited to samples from the upper river. This species appeared the most abundant of the

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Table 30.--Relative abundance of the principal fishes taken by gill nets in the Newport River, 1970

Species	Catch per 100 shackle-hours in Zone--						Percent of total catch
	1	2	3	4	5	6	
Brevoortia tyrannus	-	1.3	1.1	173.3	198.4	34.2	54.93
Lagodon rhomboides	-	-	-	24.7	55.4	15.3	12.83
Leiostomus xanthurus	-	2.7	2.2	5.5	6.5	34.2	6.87
Lepisosteus osseus	9.0	25.3	14.6	-	-	-	6.58
Pomatomus saltatrix	-	-	-	12.3	17.2	12.7	5.68
Dorosoma cepedianum	2.0	9.3	7.9	0.7	-	1.0	2.81
Opisthonema oglinum	-	-	-	9.6	1.1	0.3	1.48
Micropogon undulatus	-	-	-	0.7	3.2	6.3	1.37

large freshwater fishes. Bluefish (*Pomatomus saltatrix*), mostly yearlings, also were taken in large numbers in the estuary; young-of-the-year bluefish were taken by surface trawl in the upper river but in relatively smaller numbers. Gizzard shad were gill netted throughout the system, but were most abundant in the upper river. Atlantic thread herring (*Opisthonema oglinum*) and Atlantic croaker were taken only in the estuary, the former species being most abundant in the upper reaches and the latter species in the lower reaches.

The seven dominant species in the total collections from the system were Atlantic menhaden, bay anchovy, spot, Atlantic silverside, striped mullet, pinfish, and Atlantic croaker. All seven are marine euryhaline species and their combined numbers formed 97 percent of the total catch. The first five species alone accounted for more than 93 percent of the total catch. The remaining 97 species each contributed less than 1 percent to the total catch, nevertheless some were taken in considerable numbers. The three next most common species were golden shiner, rough silverside, and tidewater silverside (*Menidia beryllina*). Only one freshwater species ranked among the 10 most numerous fishes. Other species occurring in substantial numbers were blueback herring (*Alosa aestivalis*), hogchoker, and bluefish. Because of their abundance, all of these species are very important components of the estuary (Zones 2 through 6). Since the major emphasis of the ecosystem research is on Zones 3 through 6,

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the dominant species of fishes which should be given detailed physiological and ecological study appear to be Atlantic menhaden, bay anchovy, spot, Atlantic silverside, striped mullet, pinfish, Atlantic croaker, and bluefish.

Seasonal Distribution of Major Species

Numerically, the fish population within the river system was of course dominated by small fishes, larvae, and juveniles. All of the dominant species used the system as a nursery area and two of these species, bay anchovy and Atlantic silverside, apparently resided within the system throughout their lives. The capacity to which most of the dominant species utilized the system was inferred from their seasonal and areal distribution, sizes, and numbers in the collections.

Atlantic menhaden

Samples collected by haul seine in the estuary and surface trawl in the upper river best describe the cyclic distribution of menhaden within the system (table 31). Menhaden spawn off the North Carolina coast from November to March. The larvae enter the estuary where they transform into juveniles and spend most of their first year of life. Larval and postlarval menhaden were first taken in samples from within the estuary in February. Some fishes attained juvenile proportions (about 35 mm total length) by March, and at that time many had moved into the upper portion of the river. No

Table 31.--Monthly distribution and length range (mm in parentheses) of young-of-the-year Atlantic menhaden in samples collected by haul seine in the lower river and surface trawl in the upper river

Month	Zone						Total
	6	5	4	3	2	1	number
Jan.	-	-	-	-	-	-	0
Feb.	4 (23-27)	1 (31)	8 (22-31)	-	-	-	13
Mar.	-	326 (22-34)	420 (22-37)	2,287 (24-35)	4 (24-26)	-	3,037
Apr.	34 (26-30)	18 (24-35)	84 (26-35)	808 (24-34)	-	-	944
May	-	2 (25-28)	3 (25-27)	31,276 (22-48)	183 (25-34)	1 (28)	31,465
June	-	12 (35-62)	50 (41-57)	20,191 (29-52)	4,397 (29-42)	161 (33-45)	24,811
July	-	-	16 (34-61)	8,190 (37-78)	388 (32-73)	4 (29-32)	8,598
Aug.	-	-	-	2 (62-67)	-	-	2
Sept.	-	-	-	486 (61-95)	-	-	486
Oct.	-	-	-	32 (65-115)	-	-	32
Nov.	-	-	-	-	-	-	0
Dec.	-	-	-	-	-	-	0

traces of salt were detected throughout the upper river at the time of menhaden influx into that area. Menhaden moved well upstream and into Zone 1 by May and remained until August. Peak numbers were encountered in May and June and most of the population was centered in Zone 3 of the upper river. During these two months the population of young menhaden in the system was spread along a very wide salinity gradient, ranging from a mean of 0.1 o/oo in Zone 1 to a mean of 28.3 o/oo in Zone 5. After July the number of menhaden in collections diminished abruptly. By August the juveniles had emigrated from Zones 1 and 2, but some remained in Zone 3 at the mouth of the river until November. After departing from the upper river, juveniles probably stayed in open waters of the estuary and thus were not available to seining efforts in the littoral areas. The majority of these young menhaden left the estuary and returned to the ocean as waters began to cool. Some lingered in the system for a greater period of time, however, as attested by the catches of yearlings in gill nets throughout the year.

Bay anchovy

Bay anchovy was distributed throughout the system and occurred in collections each month (table 32). They were taken in the upper portion of the river from June through December.

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Table 32.--Monthly distribution and length range (mm in parentheses) of bay anchovy collected in samples from all gears combined in the upper and lower river

Month	Zone						Total number
	6	5	4	3	2	1	
Jan.	-	9 (36-45)	4 (45-53)	1 (50)	-	-	14
Feb.	2 (34-35)	10 (55-61)	548 (37-55)	-	-	-	560
Mar.	19 (43-57)	319 (42-83)	176 (38-82)	4 (33-78)	-	-	518
Apr.	89 (43-82)	87 (47-81)	9 (53-73)	-	-	-	185
May	26 (45-78)	194 (53-69)	22 (58-70)	21 (38-73)	-	-	263
June	39 (48-65)	186 (17-65)	87 (17-68)	-	-	1 (25)	312
July	12 (43-64)	333 (18-72)	413 (22-82)	945 (19-72)	61 (21-31)	398 (25-35)	2,162
Aug.	693 (37-63)	278 (47-72)	368 (24-72)	276 (22-46)	-	-	1,615
Sept.	224 (31-77)	224 (33-53)	1,415 (19-100)	10,102 (18-50)	9 (32-46)	-	11,974
Oct.	678 (41-61)	-	696 (40-55)	1,711 (25-53)	764 (23-42)	1 (87)	3,850
Nov.	2 (28-32)	25 (41-61)	250 (41-62)	220 (22-42)	6 (26-37)	-	503
Dec.	39 (40-69)	19 (30-62)	-	33 (26-67)	13 (37-68)	-	104

Small anchovies entered the catches in June, indicating that spawning began in May. Young fishes persisted in the catches during the remainder of the year, suggesting a prolonged breeding season extending well into fall. The bay anchovy was most numerous from July - October with a peak of abundance in September, suggesting that spawning intensity was greatest in mid-summer.

Spot

Postlarval spot were first taken in collections from the estuary during February and appeared in samples from the upper river, Zone 3, in March (table 33). During April they occurred as far upstream as Zone 2 in waters that were completely fresh at the time of sampling. By July young spot had emigrated from the upper river, but young-of-the-year were taken from the estuary through October.

Adult spot containing well-developed roe were taken from gill nets in Zone 6 during October. They apparently left the estuary after October and moved offshore to spawn. The cyclic distribution of spot paralleled that of Atlantic menhaden, the chief differences being that spot attained peak abundance in the catches during March and did not move upstream to as great an extent as menhaden. Disparity in peaks of abundance of these two species probably reflects the high vulnerability of juvenile menhaden to the surface trawl.

Atlantic silverside

This species was also widely distributed in the system and occurred in samples throughout the year (table 34). Although

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Table 33.--Monthly distribution and length range (mm in parentheses) of young-of-the-year spot in samples collected by haul seine in the lower river and bottom trawl in the upper river

Month	Zone						Total
	6	5	4	3	2	1	number
Jan.	-	-	-	-	-	-	0
Feb.	266 (11-22)	269 (12-23)	1,418 (12-22)	-	-	-	1,953
Mar.	1,842 (16-31)	1,904 (19-27)	3,168 (14-26)	335 (14-24)	-	-	7,249
Apr.	710 (20-29)	655 (18-32)	2,185 (20-33)	22 (31-48)	11 (31-44)	-	3,583
May	59 (17-51)	391 (21-47)	190 (12-50)	-	-	-	640
June	27 (41-49)	55 (16-73)	70 (48-64)	1 (59)	-	-	153
July	-	5 (70-83)	6 (60-101)	-	-	-	11
Aug.	6 (88-106)	1 (93)	4 (82-88)	-	-	-	11
Sept.	6 (97-106)	-	5 (96-118)	-	-	-	11
Oct.	1 (112)	5 (95-110)	1 (120)	-	-	-	7
Nov.	-	-	-	-	-	-	0
Dec.	-	-	-	-	-	-	0

Table 34.--Monthly distribution and length range (mm in parentheses) of Atlantic silverside in samples collected by haul seine and surface trawl

Month	Zone 6	 5	 4	 3	 2	 1	Total number
Jan.	2 (70-75)	188 (45-102)	14 (31-90)	2 (42-55)	-	-	206
Feb.	1 (65)	285 (66-110)	46 (53-103)	-	-	-	332
Mar.	88 (48-100)	58 (53-104)	211 (47-105)	2 (47-77)	-	-	359
Apr.	11 (70-105)	9 (73-94)	56 (50-108)	1 (68)	-	-	77
May	39 (72-110)	8 (80-100)	128 (21-102)	7 (41-62)	6 (52-54)	-	188
June	906 (24-81)	613 (23-40)	328 (25-47	1 (31)	2 (47-58)	-	1,850
July	-	4 (40-82)	110 (23-60)	36 (37-39)	2 (54-63)	-	152
Aug.	375 (45-60)	7 (35-54)	12 (48-60)	2 (34-41)	-	-	396
Sept.	9 (66-74)	-	186 (46-72)	5 (43-69)	6 (34-47)	-	206
Oct.	582 (65-78)	4 (60-75)	7 (65-71)	131 (42-85)	-	-	724
Nov.	274 (72-103)	-	4 (41-62)	111 (51-95)	-	-	389
Dec.	242 (61-93)	40 (58-91)	1 (41)	159 (41-89)	3 (53-54)	-	445

Atlantic silverside has been recorded from fresh waters on many occasions, the species was never taken in Zone 1 and was collected only in limited numbers in Zone 2. Collections indicated that spawning occurred in April and May, and the species reached peak abundance in the collections in June.

Striped mullet

Postlarval striped mullet first appeared in samples from the estuary in November and were taken in Zone 3 in December (table 35). The species apparently spawns over an extensive period as larvae persisted in samples through April. Striped mullet penetrated well upstream, and was taken in Zone 1 in July.

Pinfish

Postlarval pinfish (11 mm) first appeared in the estuary in November and small specimens (<18 mm) persisted in the samples from the lower river until early May. This suggests a prolonged spawning period, probably from October to April, coincident with the Atlantic menhaden and striped mullet spawning seasons in this area. Spawning appears to occur offshore.

Atlantic croaker

An insufficient number of young-of-the-year croaker was collected to accurately infer spawning time in this area, however there is evidence of spawning off the South carolina coast from October to January. Most of the croakers taken in Newport River were yearlings and adults collected by bottom trawls and gill nets. The species occurred throughout the system.

Table 35.--Monthly distribution and length range (mm in parentheses) of young-of-the-year striped mullet in samples collected by haul seine and surface trawl

Month	Zone						Total
	6	5	4	3	2	1	number
Jan.	24 (21-24)	3 (21-27)	17 (25-29)	-	-	-	44
Feb.	31 (21-27)	97 (22-31)	1,434 (16-33)	-	-	-	1,562
Mar.	497 (19-34)	31 (22-33)	141 (25-28)	-	-	-	669
Apr.	967 (21-34)	784 (21-38)	136 (22-34)	11 (19-27)	-	-	1,898
May	-	-	2 (30-34)	-	-	-	2
June	-	10 (34-39)	-	-	1 (52)	-	11
July	-	1 (78)	6 (83-104)	15 (45-97)	4 (55-70)	1 (84)	27
Aug.	8 (91-123)	2 (104-108)	3 (40-107)	2 (72-87)	-	-	15
Sept.	4 (107-123)	4 (96-134)	41 (59-126)	1 (84)	-	-	50
Oct.	-	11 (82-118)	4 (101-133)	14 (92-114)	1 (118)	-	30
Nov.	1 (80)	3 (21-80)	11 (88-120)	5 (86-106)	-	-	20
Dec.	15 (114-131)	-	13 (20-102)	110 (22-83)	-	--	138

Bluefish

The majority of bluefish collected were yearling fish taken by gill nets from the lower river. Small numbers of young-of-the-year, however, were collected by surface trawl in the upper river. Yearling bluefish were taken in Zone 6 from march-December, in Zone 5 from April-November, and in Zone 4 from may-November. Young-of-the-year (45-72 mm) occurred sporadically in collections from the upper river in May, July, and October. They moved upstream into Zone 2 in July, but were more abundant in Zone 3. A winter spawning offshore is indicated by size and time of appearance of young fish in the collections. The absence of bluefish in collections with the bottom trawls was probably indicative of their habitat preferences and in no way reflected population size.

Other fishes

In addition to the above major species, many other marine fishes utilized the system as a nursery area. Most notable among these were speckled worm eel (*Myrophis punctatus*), blueback herring, inshore lizardfish (*Synodus foetens*), spotted hake (*Urophycis regius*), Atlantic needlefish (*Strongylura marina*), mummichog (*Fundulus heteroclitus*), rock sea bass (*Centropristis philadelphica*), black sea bass (*C. striata*), crevalle jack (*Caranx hippos*), Atlantic bumper (*Chloroscombrus chrysurus*), lookdown (*Selene vomer*), gray snapper (*Lutjanus griseus*), silver perch (*Bairdiella chrysura*), spotted seatrout (*Cynoscion nebulosus*), weakfish (*C. regalis*), black drum (*Pogonias cromis*), Atlantic cutlassfish (*Trichiurus lepturus*), Spanish mackerel (*Scomberomorus maculatus*), bay whiff (*Citharichthys spilopterus*), fringed flounder (*Etropus crossotus*), summer flounder (*Paralichthys dentatus*), southern flounder (*P. lethostigma*), hogchoker (*Trinectes maculatus*), blackcheek tonguefish (*Symphurus plagiusa*), and planehead filefish (*Monocanthus hispidus*).

Other marine species that occurred incidentally in the catches from the estuary and regarded as transient forms were sandbar shark (*Carcharhinus milberti*), Atlantic sharpnose shark (*Rhizoprionodon terraenovae*), scalloped hammerhead (*Sphyrna lewini*), scaled sardine (*Harengula pensacolae*), Atlantic flyingfish (*Cypselurus heterurus*), flat needlefish (*Ablennes hians*), lined seahorse (*Hippocampus erectus*), tripletail (*Lobotes surinamensis*), spotfin mojarra (*Eucinostomus argenteus*), and great barracuda (*Sphyraena barracuda*).

Biomass of Fishes

The wide variety of sampling gear employed during the fish inventory studies identified the dominant species, their habitat preferences, relative abundance, and distribution within the river system. Of the array of gears used, however, the haul seine provided the only satisfactory estimates of biomass because the area covered by the seine could be replicated with little variability, and because the littoral regions in which the haul seine was used are generally frequented by young or small fishes that are more susceptible to capture.

Average biomass (wet weight) of fishes in the littoral waters of the estuary was estimated to be 1.85 g/m^2 for the entire year of sampling (table 36). Monthly biomass did not appear related to the influx of any species during a particular time of the year, but rather the estimates were erratic and ranged from 0.92 to 3.66 g/m^2 with peak catches occurring in March, August, September, and November. Atlantic silverside made up 39.0 percent of the total biomass in littoral waters and was followed by striped mullet, 17.4 percent, spot, 15.0 percent, and pinfish, 6.5 percent. The remaining 20 percent of the biomass was made up of a mixture of 33 other species.

Biomass and standing crop estimates will be obtained from the deeper areas of the estuary by a portable drop net that samples fishes throughout the water column. The drop net -- now under construction -- is made of 6.3-mm mesh nylon and is suspended from a floating aluminum frame by a series of 24 electromagnets (Figure 28). A timer is used to break the circuit and release the net at a designated time. The net is enclosed on four sides and the top, and the opening at the bottom is 6 m square. The bottom of the net is heavily weighted with chain, 1.59 kg per running meter. The weighted open end of the net plunges to the bottom when released, thereby trapping organisms throughout 36 m^2 of the water column. The net is closed by pursing the bottom and retrieved by winching aboard the work boat, chain line first. Catches are removed by opening a draw-string in top of the net. By sampling with the drop net in open waters and haul seine in littoral waters, estimates of fish biomass will be obtained throughout the estuary.

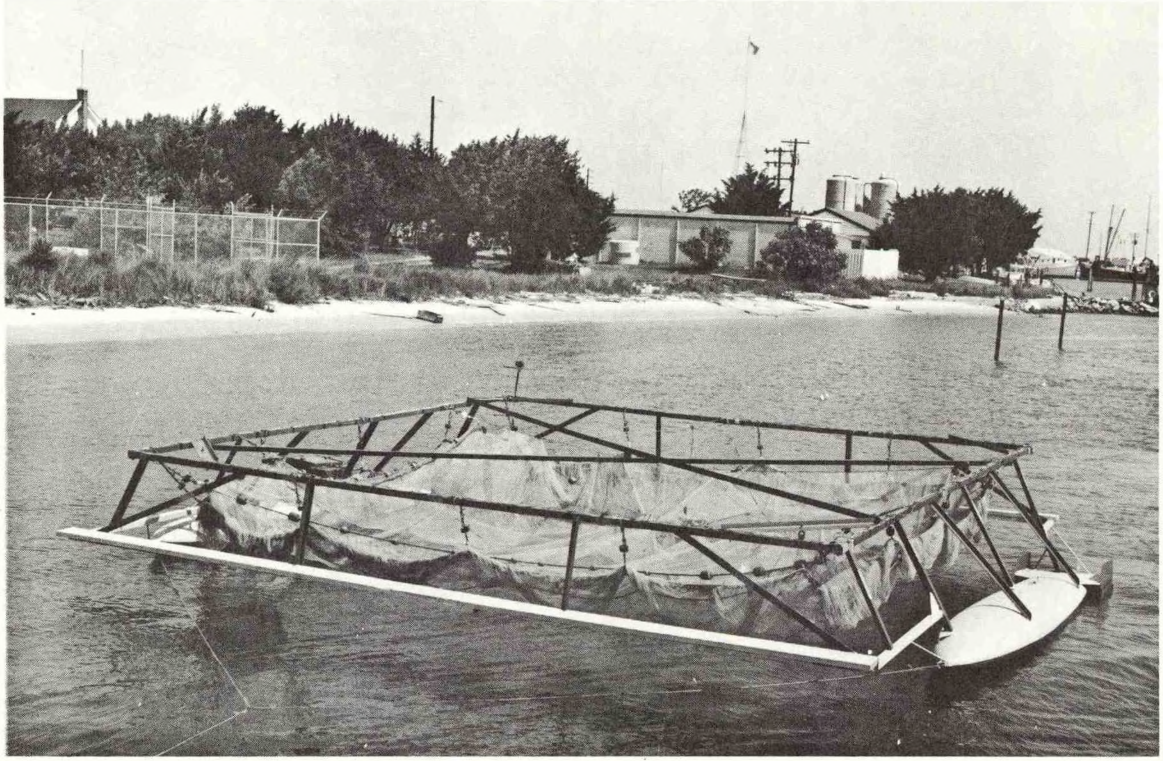

Figure 28.--Drop-net for sampling biomass of fishes in Newport River.

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Table 36.--Biomass (g/m^2) of fishes collected from littoral waters of Newport River, 1970

Month	Zone			Mean
	4	5	6	
January	1.29	1.43	0.04	0.92
February	0.82	3.35	0.08	1.42
March	7.48	1.61	1.90	3.66
April	1.64	0.94	1.18	1.25
May	2.98	0.85	1.47	1.77
June	2.04	0.87	1.42	1.44
July	2.53	0.25	0.23	1.00
August	2.12	1.71	5.00	2.94
September	3.36	0.96	2.36	2.23
October	0.70	1.38	2.52	1.53
November	0.63	0.92	5.49	2.35
December	0.44	0.49	4.18	1.70
Totals	26.03	14.76	25.87	22.21
Means	2.17	1.23	2.16	1.85

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METABOLISM, BIOMASS, AND ENERGY REQUIREMENTS OF A POPULATION OF PINFISH (Lagodon rhomboides) IN THE NEWPORT RIVER ESTUARY, N.C.

Donald E. Hoss and Curtis W. Lewis

Studies on the metabolism, population size, biomass and energy requirements of the Newport River pinfish population were concluded this year and the data have now been analyzed. Background information on this study was reported in previous annual reports to the AEC.

Metabolism

Routine metabolism

Fish metabolism was measured in the laboratory by the indirect method of oxygen consumption. We measured the routine oxygen consumption of pinfish which was defined as the oxygen consumed by fish whose only movements are spontaneous (Beamish and Mookherjii, 1964). For juvenile and adult pinfish we used a recirculating water respirometer (Hoss, 1968) modified from a type described by Keys (1936) and by other investigators (Fig. 29). The basic respirometer consisted of a reservoir with heating, cooling, and aeration apparatus, a respirometer tank, a constant-level tank, flow meters and respiration chambers. Water from the reservoir was pumped into the elevated constant level tank and then flowed by gravity to the respiration tank and respiration chambers. Water flowing from

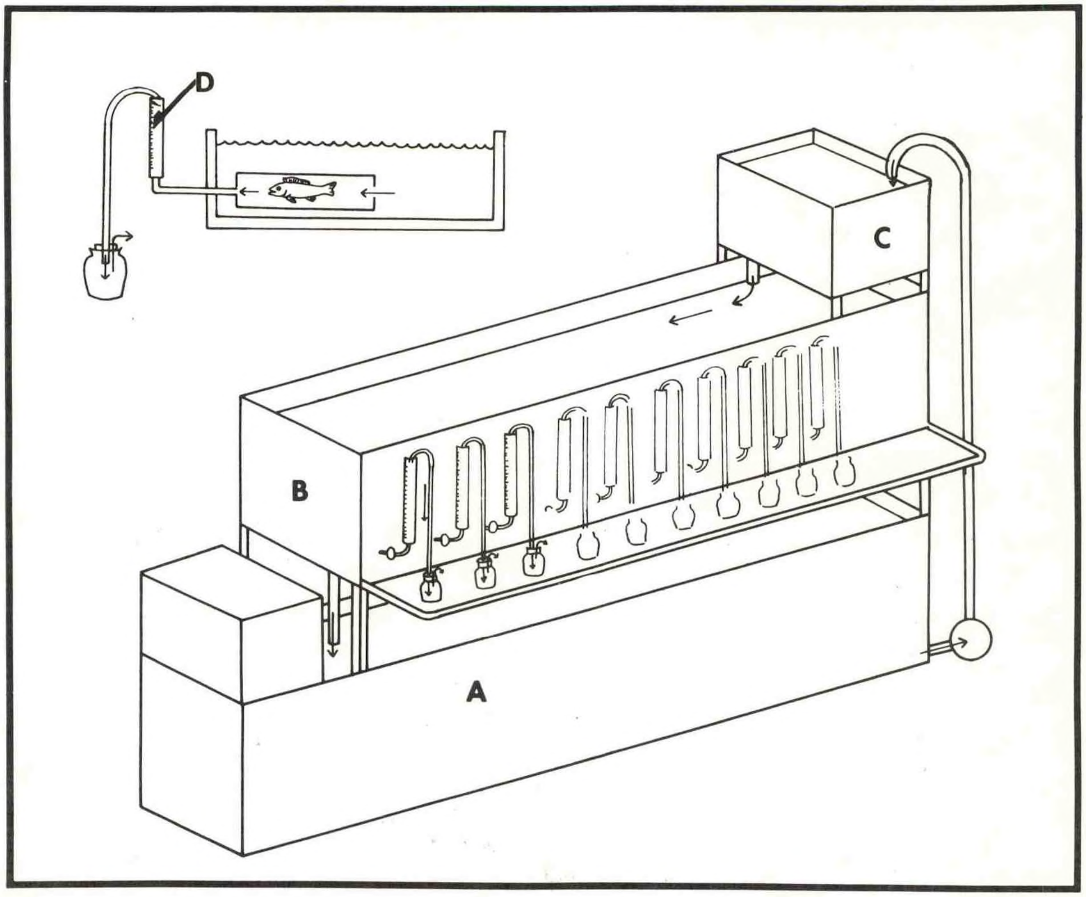

Figure 29.--Recirculating water respirometer used to measure respiration in fish. The insert is a transverse section through one of the 10 respiration chambers. (A) Reservoir with heating, cooling, and aeration apparatus. (B) Respirometer tank. (C) Constant level tank. (D) Flow meter.

the respiration chamber passed through the flow meter and sample jar and returned to the reservoir. The rate of flow of water through each respiration chamber was regulated by a flow meter and the oxygen content of the water was measured polarographically. The amount of oxygen used by each fish was calculated by multiplying the difference between inflowing and outflowing water by the flow rate.

In our respiration experiments the experimental fish were not fed for 24 hours before being placed in the respiration chamber and were acclimated to the respiration chamber for 24 hours before the first oxygen measurement was made. The volume of the respiration chamber was at least ten times the displacement volume of the fish in all cases. We made five consecutive measurements of oxygen consumption at 1 hour intervals on each fish and no fish was used more than once in an experiment. Wet weights of the fish were obtained after the last oxygen measurement.

Because of their small size routine oxygen consumption of postlarval fish was measured in a differential respirometer. Again the test fish were not fed for 24 hours before being placed in the respiration chamber. The postlarvae were acclimated to the differential respirometer flasks for 2 hours, then four consecutive measurements of oxygen consumption were made at 1 hour intervals. As in the juvenile-adult experiments, wet weights were obtained after the last oxygen measurement.

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Seasonal measurements of routine oxygen consumption were made at temperatures of 10° and 15° C for postlarval fish and at 10°, 15°, 20°, and 25° for juvenile-adult fish. In addition, a number of summer measurements were made at 33° C and a number of winter measurements were made at 5° C even though temperatures in the Beaufort, N.C. area do not stay at these extremes for any length of time.

Logarithms of oxygen consumption per fish were plotted against logarithms of weight of the fish and least squares regression lines were calculated to obtain the slope of the line ("k") and the intercept ("a") The relationship between body weight and metabolic rate was then used to calculate energy of metabolism for fish of different weights. The relationship is expressed as $Q = aW^k$, where; "Q" is the rate of metabolism, "W" is the weight of the fish and "a" and "k" are constants for the species (Winberg, 1956).

Values for "a" and "k" in the metabolism equation $Q = aW^k$ are given in table 37 along with the number of fish, the weight range of the fish and the temperature at which the measurements were made. Using the values for "a" and "k" obtained in these experiments, regression lines were calculated for 0.02 and 0.10 g postlarval fish and for 10 and 100 g juvenile-adult fish (Fig. 30). Except for the two extreme temperatures of 5° and 33° C the routine oxygen consumption measurements were made at temperatures corresponding to the average environmental temperature for that time of the year. We considered the fish to be naturally acclimated to the temperature at which their oxygen consumption was measured. The problems associated with acclimating fish to unnatural temperature regimes were thus avoided.

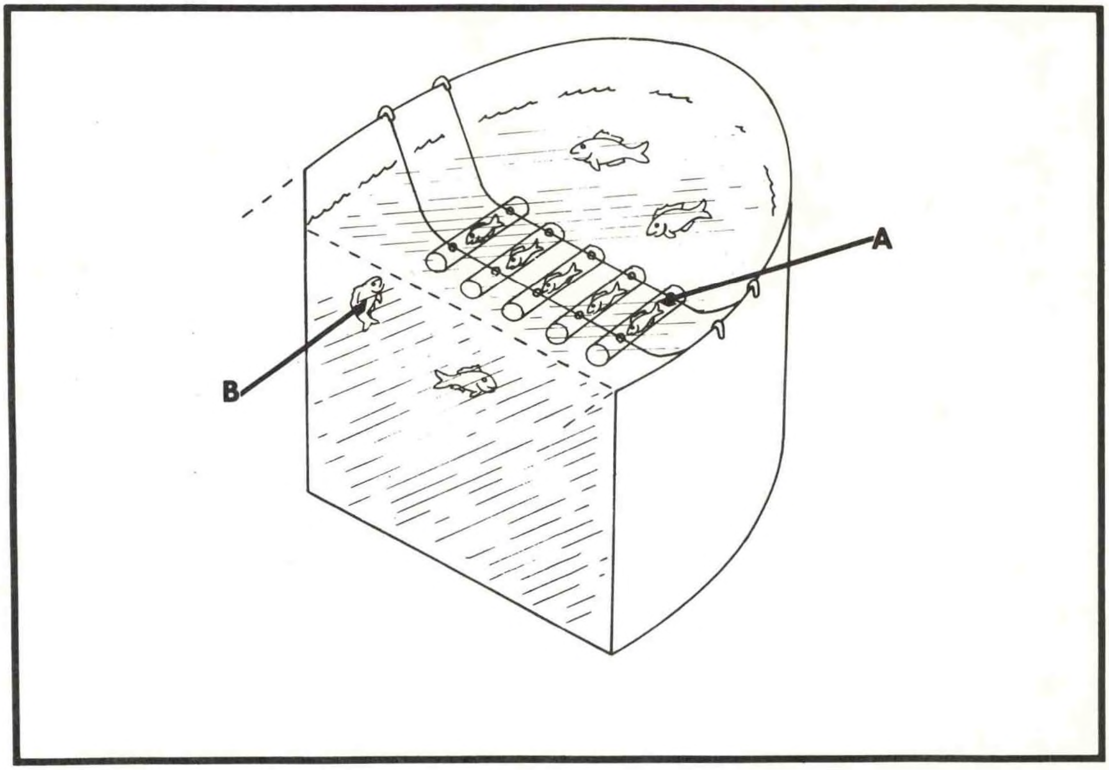

Figure 30.--Diagram showing fish confined in modified respiration chambers (A) and fish free in tanks (B).

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Table 37.--Summary of oxygen consumption experiments on postlarval, juvenile and adult pinfish

Temperature (°C)	Number of fish	Weight range (g)	"a"	"k"	Standard error of "k"
33	35	7-40	1.185	0.634	0.0855
25	65	5-63	0.944	0.589	0.0419
20	42	5-67	0.201	0.833	0.0582
15[1]	55	.02-.10	0.264	0.865	0.0826
15	40	5-98	0.552	0.434	0.0526
10[1]	54	.02-.05	0.393	1.122	0.1235
10	69	5-59	0.297	0.614	0.0519
5	26	5-48	0.203	0.661	0.1042

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[1] Postlarval fish

The "k" values for juvenile-adult fish ranged from 0.43 at 15° C to 0.83 at 20° C and averaged 0.6. The values obtained at 15° C and 20° C may be due in part to the variable environmental conditions that occur in the spring and fall of the year.

At Beaufort the 15° and 20° C temperatures are in fact transition temperatures that gradually decrease in the fall to the winter normal of 10° C and gradually increase in the spring to the summer normal of 25° C. To illustrate this point we have broken down the 12 month period from October 1969 to September 1970 into average temperature, regimes (Table 38). During the fall and spring of the year, temperatures either decreased or increased at a fairly constant rate. During the summer and winter months, however, temperatures tended to be more stable for longer periods of time. The number of consecutive days at either 15° or 20° C is much less than at 10° or 25° C and therefore the fish has much less time to fully acclimate to these temperatures.

Except for larval stages, metabolism-weight coefficients "k" have now been published for many species of fish including pinfish (Winberg, 1956; Fry, 1957, 1964; Cameron, 1969; Wohlschlag, Cameron, and Cech, 1968). Metabolism-weight coefficients for juvenile-adult fish generally fall in the range of 0.67 to 0.8 (Winberg, 1956). The values we obtained for the metabolism-weight coefficient for juvenile-adult pinfish are, in general, lower than those obtained by Cameron (1969), working with the same species of fish and the same temperature range. They also are lower than the overall value for all fish given

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Table 38.--Temperature regimes in the Newport River Estuary from October 1969 to September 1970

Temperature (° C)	Season	Days
10 ± 2.5	Winter	87
15 ± 2.5	Spring	25
20 ± 2.5	Spring	27
25 ± 2.5	Summer	73
20 ± 2.5	Fall	17
15 ± 2.5	Fall	25

by Winberg (1956). On the other hand, our values for postlarval pinfish are higher than Winberg's overall value but correspond with published data for larval and postlarval stages of other species.

The weight range of fish used to determine the metabolism-weight coefficient could be one reason why our values for juvenile-adult fish are lower than Cameron's. The fish used in his oxygen consumption experiments range in weight from 1.54 g to 34.91 g with an overall average of 9.5 g. The fish we used in our calculations range in weight from 5 g to 98 g with an overall average of 24.8 g. In previous work with croaker (Micropogon undulatus) and pinfish we found that the slope of the calculated regression line was in part dependent on the weight range of the fish used in the calculation. Thus, for croakers the slope of the line for 0.01 to 0.4 g/fish was 1.12 and the slope for 10-100 g fish was 0.57. However, when the data were pooled and a single line calculated for a weight range of 0.01 to 100 g we obtained a value of 0.78 which is fairly close to the universal metabolism-weight coefficient of 0.80 calculated by Winberg (1956).

Other reasons for the differences in the metabolism-weight coefficient might include the type of respirometer used and the length of the acclimation period. Cameron (1969) suggested that in part his higher than expected metabolism-weight coefficients for fall and winter runs of pinfish may have been due to the size of the container in relation to the size of the fish. In our experiments the volume of the respiration chamber was held at approximately ten times the displacement volume of the fish so that size of the container should have had no effect on respiration (Hickman, 1959). In addition, juvenile-adult fish had a 24-hour period to acclimate to the respiration chambers whereas Cameron's had only 1 hour. Mann (1965), Hickman (1959), Keys (1930), and others have reported that when a fish is first placed in a respirometer its oxygen consumption increases. Over a period of time the oxygen consumption will decrease until a relatively steady level is reached. Because of this, oxygen consumption measurements made in a closed system, where only a short acclimation period is possible, may tend to give higher oxygen consumption rates because the fish is in an excited state.

Normal metabolism

The amount of oxygen consumed by a fish in its natural habitat has been called normal metabolism and some estimate of normal metabolism is needed to calculate the energy requirements of fish under natural conditions. At present, however, there are no direct methods of measuring normal metabolism. Winberg (1956) proposed doubling the routine oxygen consumption of fish to give an estimation of their metabolic rate in nature.

The use of radioisotopes has been proposed as an indirect method for measuring metabolism under natural conditions (Odum, 1961; Mishima and Odum, 1963). The method consists of following the retention of a radioisotope under relatively natural conditions and comparing it to retention under standard or routine conditions. Edwards (1967) used this method to estimate the respiratory rate of plaice under natural conditions.

We labeled groups of pinfish with ^{65}Zn and attempted to relate the rate of loss of this isotope to oxygen consumption. Zinc-65 was selected as the label because it was easily detectable even when incorporated into a fish, had a relatively long half-life of 245 days, was required in trace amounts by the fish in their normal metabolism, and was used by previous investigators as a label (Edwards, 1967; Mishima and Odum, 1963; Shulman et al., 1961; Rhodes, 1969; Odum, 1961; and Odum and Golly, 1963).

Two experiments were conducted to determine if metabolism could be correlated with the loss of ^{65}Zn. In the first experiment one group of pinfish labeled with ^{65}Zn in sea water (.004μCi/ml) was placed in modified respiration chambers suspended on lines in a large (2,000 l) tank of flowing sea water. A second group of fish labeled in the same manner were released into the same tank to swim freely (Fig. 31). At weekly intervals the fish were removed from the tank and their radioactivity measured. Twice each week the fish were placed in small containers of sea water and allowed to feed on a commercial fish food for 4 hours. An excess amount of food was given to both groups of fish during the feeding period so that feeding rate would not be a factor in the experiment.

In the second experiment two large tanks were used (Tanks A and B). The experimental procedure was the same as in the previous experiment except that stable zinc was added to the food in tank B while food in tank A was identical to that used in the previous experiment.

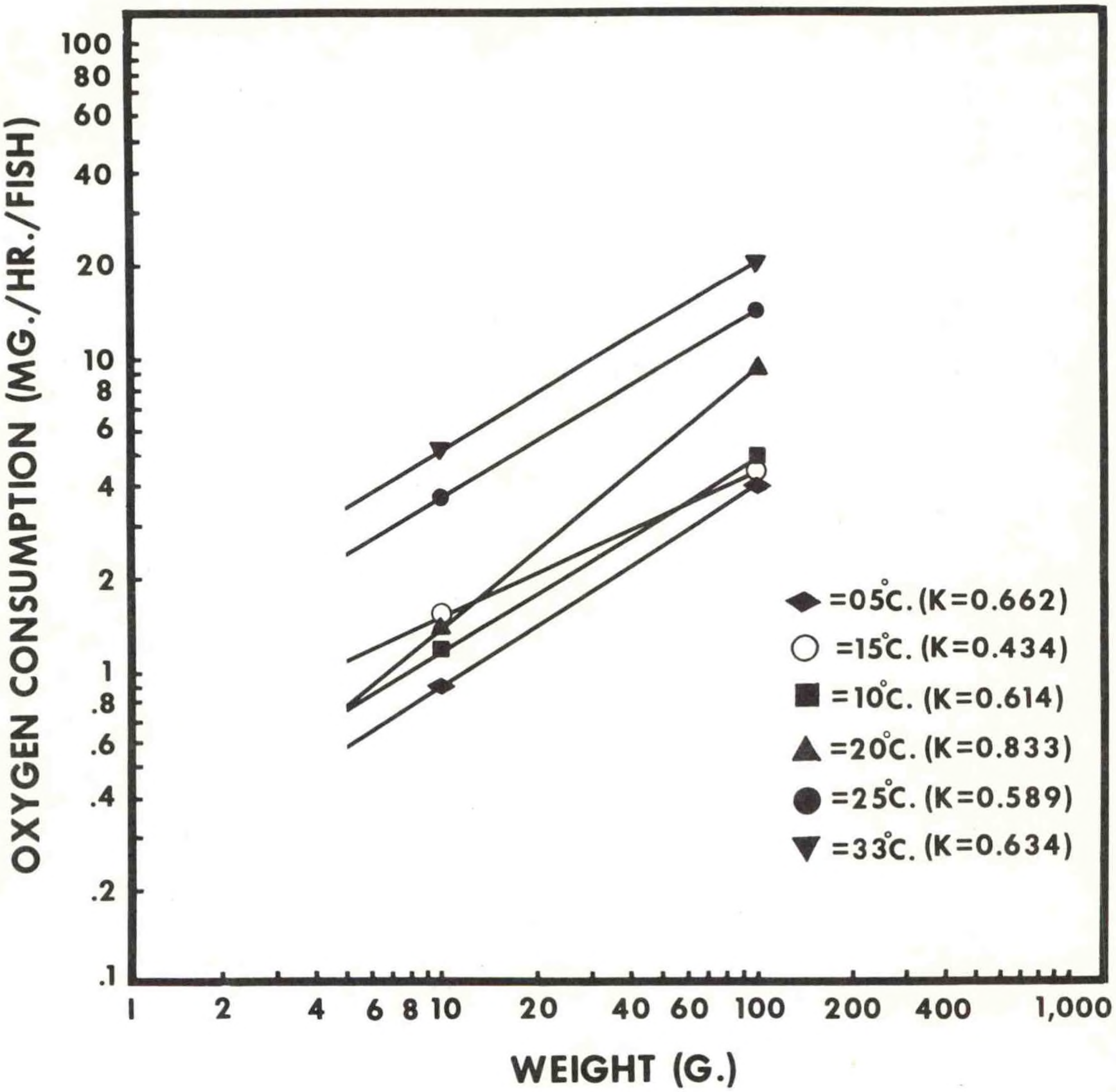

Figure 31.--Linear regressions for oxygen consumption versus weight of juvenile-adult pinfish at various temperatures, on a log/log scale. Each line is based on numerous fish throughout the weight range.

The amount of stable zinc in the food was increased by adding 1.387 g ZnCl dissolved in 1,000 ml of distilled water to 500 g of fish food, then drying the food in an oven at 90° C. After drying the labeled food was broken into crumbs with a mortar and pestle. The food with the normal level of zinc was treated in the same way, except that the 1,000 ml of distilled water did not contain additional ZnCl. Levels of zinc in the food were measured with an atomic absorption spectrophotometer.

Loss of ^{65}Zn by pinfish held in modified respiration chambers and by pinfish free in the tank is shown in Fig. 32. The shape of the retention curves were similar to that obtained in the preliminary experiment and to that obtained by Edwards (1967). Because of the initial rapid loss of ^{65}Zn the percent retained was calculated and plotted using day seven rather than day zero as 100 percent. During the experiment the rate of loss of ^{65}Zn from the fish held free in the tank appeared to be slightly faster than that of the fish held in the respiration chambers. If the loss of ^{65}Zn is related to metabolism (oxygen consumption) this is what one would expect. However, a t-test for difference between means at both 48 and 111 days (Table 39) indicated that there was no significant difference between fish held in the respiration chamber and those free in the tank.

Variation in ^{65}Zn content between fish was high in both the confined and the free fish and this variation may have masked any difference between means. A second experiment was conducted in which an attempt was made to reduce individual variation by fin clipping each fish so that retention of ^{65}Zn by individual fish rather than groups of fish could be

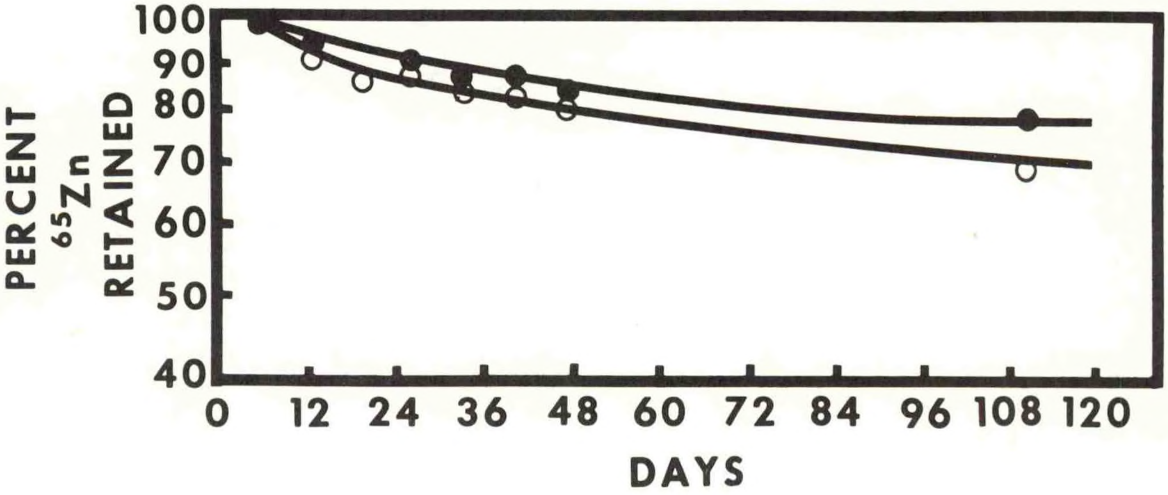

Figure 32.--Loss of ^{65}Zn by pinfish held in modified respiration chambers (●) and by pinfish free in tank (○).

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Table 39.--Comparison of the retention of ^{65}Zn between fish confined in respiration chambers and fish free in a large tank

Days	Treatment	Number of fish	Mean counts per minute ^{65}Zn retained	t
48	Free	13	8,681	0.881 n.s.*
	Confined	9	11,309	
111	Free	13	6,123	1.749 n.s.*
	Confined	5	10,426	

* Not significant at .05 level

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followed. In addition, the effect of increased levels of stable zinc in the fishes' food on retention of ^{65}Zn was measured. The experimental design was a 2 X 2 factorial. The two levels of activity (A) were confined fish and free fish and the two levels of food (B) were normal stable zinc (148 µg/g wet weight of zinc) and increased stable zinc (2,798 µg/g wet weight of zinc).

An analysis of variance of the mean percent ^{65}Zn retained after 21 days indicated no significant difference in the retention rates by the four groups of fish (Table 40). The rate of loss of ^{65}Zn by free swimming fish was not significantly different from confined fish and the rate of loss of ^{65}Zn by fish fed food with increased levels of stable zinc was not significantly different from fish fed normal food.

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Table 40.--Analysis of variance of the data using percent ^{65}Zn retained at 21 days (day seven considered 100 percent)

Source	df	SS	MS	F
Activity (A)	1	.065	.065	3.66 n.s.*
Food (B)	1	.006	.006	0.33 n.s.
A x B	1	.006	.006	0.33 n.s.
Residual	26	.466	.018	
Total	29	.543		

* Not significant at .05 level

One possible interpretation of the results is that retention of ^{65}Zn cannot be correlated with activity (metabolism) in the pinfish. This interpretation is directly opposite to that reached by Edwards (1967) who found that retention of ^{65}Zn could be correlated with metabolism in the plaice (Pleuronectes platessa L.). It is also contrary to the conclusion reached by Rhodes (1969) who found a significant correlation between oxygen consumption rate and biological half life in the wood roach (Cryptocercus punctulatus). An alternative interpretation is that activity of the fish (metabolism) in the respiration chambers is approximately the same as activity of the fish free in the tank. This would explain why the rate of loss of ^{65}Zn was the same in all groups of fish, i. e., why the metabolic rates were approximately the same.

Recent preliminary investigations by Hettler and Hoss (1971 and this report) tend to substantiate the second interpretation that there is no difference between the respiration of the pinfish in the respiration chambers and the pinfish free in the tank. In their experiments the amount of oxygen consumed by pinfish held in the flowing water respirometer described in this paper was compared to the amount of oxygen consumed by a group of pinfish swimming in a sealed 200 l circular tank. The salinity, temperature, flow rate, percent oxygen saturation and treatment of the fish was the same for both systems. Comparisons were made at 15° and at 19° C and in both cases oxygen consumption per unit weight was approximately the same.

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Edwards, Finlayson, and Steele (1969) concluded that higher metabolic rates measured in July in large tanks were due to higher rates of food intake rather than increased physical activities. In our experiments the feeding rates were the same for all groups of fish. Therefore, increased activity due to feeding would be the same in confined and free fish.

While these experiments are preliminary in nature they do suggest that the normal oxygen consumption by pinfish may be the same or nearly the same as the routine oxygen consumption as measured in my experimental system. Therefore, I did not feel justified in doubling the routine rate to estimate the normal rate as proposed by other investigators for different species of fish.

Biomass and Energy Requirements

Estimations of the biomass, energy content, and energy requirements of the Newport River pinfish population collected in a 2-year period are given in table 41. The total biomass and energy content was greatest during March-April when both postlarval fish and juvenile-adult fish were at peak numbers. Energy required for metabolism was greatest during the May-June period, however, when the total number of fish had decreased but the water temperature had increased from an average of 14.9° C to an average of 24.0° C causing an increase in the

Table 41.--Bimonthly estimate of the biomass, energy content, and energy requirements of the Newport River pinfish population. (Data collected over a 2-year period)

Date and life stage	Biomass (Kg wet wt)	Energy content (cal wet wt)	Energy requirement (cal per day)
July-Aug.			
Postlarval	0	0	0
Juv.-adult	13.4×10^3	14.7×10^9	244×10^6
Sept-Oct.			
Postlarval	0	0	0
Juv.-adult	9.7×10^3	10.7×10^9	195.8×10^6
Nov.-Dec.			
Postlarval	3.3×10^2	2.2×10^8	6.4×10^6
Juv.-adult*	2.4×10^3	2.7×10^9	23.9×10^6
Jan.-Feb.			
Postlarval	3.2×10^3	2.1×10^9	65.8×10^6
Juv.-adult*	2.4×10^3	2.7×10^9	23.9×10^6
Mar.-April			
Postlarval	3.3×10^3	2.2×10^9	116.4×10^6
Juv.-adult	68.9×10^3	75.9×10^9	466.8×10^6
May-June			
Postlarval	0	0	0
Juv.-adult	37.0×10^3	40.8×10^9	690×10^6

*Calculated from the September-October population estimate oxygen consumption of the fish. During July-August and September-October, biomass, energy content, and routine metabolism decreased. The seasonal low in numbers of fish was measured in September-October but we estimated that the minimum in biomass, energy content, and energy required for routine metabolism should occur in November-December. During this period the water temperature reaches a seasonal average low of 10° C and juvenile-adult fish are greatly reduced in numbers and generally less than 10 cm total length. Postlarval fish are just starting to enter the estuary at this time and will not reach their peak for another 2 months. The average pinfish biomass for the year was 754 kg wet weight/m^2.

We calculated the yearly energy requirements of the pinfish population and compared them to the estimated yearly primary production in the estuary. The pinfish population required 111.7×10^9 calories for routine metabolism for 1 year (Table 42). Using data collected by Williams (1966) we estimated that the average annual production of the phytoplankton in the Newport River was 35.0×10^{12} calories per year and the total available primary production was 79.5×10^{12} cal/yr.

Pinfish are omnivorous (Caldwell, 1957; Darnell, 1958) and therefore difficult to assign to a specific trophic level based on feeding habits. However, based on previous investigations and on observations made on pinfish collected at Beaufort, we assigned them to the second consumer level of the food chain. Assuming that the Newport River

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Table 42.--Energy requirements for juvenile-adult and postlarval pinfish in the Newport River

Period	Juvenile-adult (cal)		Postlarval (cal)
July-Aug.	15.1 X 10^9		0
Sept.-Oct.	11.9 X 10^9		0
Nov.-Dec.	1.4 X 10^9		3.9 X 10^8
Jan.-Feb.	1.4 X 10^9		3.8 X 10^9
Mar.-April	28.4 X 10^9		7.1 X 10^9
May-June	42.0 X 10^9		0
Total	100.4 X 10^9		11.3 X 10^9
Grand Total		111.7 X 10^9	

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ecosystem has a net growth efficiency of 10 percent (10 g of plant production is required to produce 1 g of herbivore at trophic level 1.0, and 100 g of plant production is required to produce 1 g of carnivore at trophic level 2.0) the secondary consumers, including pinfish would have 10 percent of the total primary production (79.5×10^{12} cal) available to them as a source of energy (Phillipson, 1966). Thus for routine metabolism, the Newport River pinfish population would require 1.39 percent of the total yearly energy available to secondary consumers, or about .139 percent of the total primary production.

Calculations made by Williams however, suggest that the ecosystem in the Beaufort area must be more than 10 percent efficient because the plant production demanded by a 10 percent efficiency is unreasonably large. Williams feels that the overall efficiency of an estuarine ecosystem quite likely lies between 10 and 30 percent with 20 percent being a reasonable average. If the net growth efficiency is 20 percent instead of 10 percent then the pinfish would have 2 percent of the total primary production available to them as a source of energy. In this case the pinfish would require .69 percent of the total yearly energy available to secondary consumers.

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References

Beamish, F. W. H., and P. S. Mookherjii. 1964. Respiration of fishes with special emphasis on standard oxygen consumption I. Influence of weight and temperature on respiration of goldfish, Carassius auratus L. Can. J. Zool. 42: 161-175.

Caldwell, D. K. 1957. The biology and systematics of the pinfish, Lagodon rhomboides (Linnaeus). Bull. Fla. St. Mus. Biol. Sci. 6(2): 77-173.

Cameron, James N. 1969. Growth, respiratory metabolism and seasonal distribution of juvenile pinfish (Lagodon rhomboides Linnaeus) in Redfish Bay, Texas. Contr. Mar. Sci. Univ. Tex. 13: 89-104.

Darnell, Rezneat M. 1958. Food habits of fish and larger invertebrates of Lake Pontchartrain, Louisiana, an estuarine community. Inst. Mar. Sci. Univ. Tex. 5: 353-416.

Edwards, R. R. C. 1967. Estimation of the respiratory rate of young plaice (Pleuronectes platessa L.) in natural conditions using zinc-65. Nature 216(5122): 1335-1337.

Edwards, R. R. C., D. M. Finlayson, and J. H. Steele. 1969. The ecology of 0-group plaice and common dabs in Loch Ewe. II. Experimental studies of metabolism. J. Exp. Mar. Biol. Ecol. 3: 1-17.

46/7

Fry, F. E. J. 1957. The aquatic respiration of fish, p. 1-63. In M. E. Brown [ed.] The Physiology of fishes. Academic Press, New York.

Fry, F. E. J. 1964. Animals in aquatic environments: Fishes, p. 715-728. In D. B. Dill [ed.] Handbook of physiology, Sect. 4: Adaptation to the environments. Am. Physiol. Soc., Washington, D.C.

Hettler, W. H., Jr., and D. E. Hoss. 1971. A comparison of two flowing respirometers for measuring fish oxygen consumption. Ass. Southeastern Biol. Bull. 18(2): 38.

Hickman, C. P., Jr. 1959. The osmoregulatory role of the thyroid gland in the starry flounder, Platichthys stellatus. Can. J. Zool. 37: 1006-1023.

Hoss, Donald E. 1968. Rates of respiration of estuarine fish. Proceedings of the 21st Annual Conference of the Southeastern Association of Game and Fish Commissioners, 1967, p. 416-422.

Keys, A. B. 1930. The measurement of the respiratory exchange of aquatic animals. Biol. Bull. (Woods Hole). 59: 187-198.

Mann, K. H. 1965. Energy transformations by a population of fish in the river Thames. J. Anim. Ecol. 34: 253-275.

Mishima, J. and E. P. Odum. 1963. Excretion rate of ^{65}Zn by Littorina irrorata in relation to temperature and body size. Limnol. Oceanogr. 8: 39-44.

46/8

Odum, E. P. 1961. Excretion rate of radio-isotopes as indices of metabolic rates in nature; biological half-life of zinc-65 in relation to temperature, food consumption, growth and reproduction in arthropods. (abstr.). Biol. Bull. (Woods Hole) 121 (2): 371-372.

Odum, E. P. and F. B. Golley. 1963. Radioactive tracers as an aid to the measurement of energy flow at the population level in nature, p. 403-410. In V. Schultz and A. W. Klement, Jr. [eds.], Radioecology. Reinhold, New York.

Phillipson, John. 1966. Ecological Energetics. St. Martin's Press, New York. 57 p.

Rhodes, Samuel T. 1969. Zinc-65 excretion as an indirect means of measuring metabolism in the wood-feeding roach Cryptocercus punctulatus Scudder. M.S. thesis. Auburn University, Auburn, Alabama. 28 pp.

Schulman, J., I. L. Brisbin, and W. Knox. 1961. Effects of temperature, salinity and food intake on the excretion of ^{65}Zn in small marine fish. (abstr.). Biol. Bull. (Woods Hole) 119(2): 378.

Williams, Richard B. 1966. Annual phytoplankton production in a system of shallow temperate estuaries, p. 699-716. In Harold Barnes [ed.], Some contemporary studies in marine science. George Allen and Unwin Ltd., London.

46/9

Winberg, G. G. 1956. Rate of metabolism and food requirements of fishes. (Transl. from Russian) Fish. Res. Bd. Can., Transl. Ser. 194. 239 p.

Wohlschlag, D. E., J. M. Cameron, and J. J. Cech. 1968. Seasonal changes in the respiratory metabolism of the pinfish (*Lagodon rhomboides*). Contr. Mar. Sci. Univ. Tex. 13: 89-104.

SUMMER FOODS OF THE LADYFISH, *Elops saurus*, FROM LOUISIANA COASTAL STREAMS

Glenn B. Sekavec

The ladyfish, *Elops saurus*, is commercially unimportant and comprises only a small percentage of the fish population in most waters where it occurs. It is, however, a recognized sportfish in many areas along the southeastern coast of the United States and exhibits characteristics similar to those of the closely related tarpon, *Megalops atlantica*, and bonefish, *Albula vulpes*. Little is known concerning the food, feeding habits, and general ecology of the ladyfish.

This study on feeding habits was undertaken to augment our present meager knowledge of the ecology of the ladyfish. Feeding habits are an important aspect of nutrition and the nutritional state influences growth rates, physiological condition, and ultimately the population size of a species. This research is part of an overall study by the Center for Estuarine and Menhaden Research on energy flow in estuarine ecosystems.

During the summers of 1968 and 1969 fish were collected by trawling in estuaries along the northern coast of the Gulf of Mexico from Galveston Bay, Texas to Apalachee Bay, Florida. These collections were made to determine year-class strength of Gulf menhaden, Brevoortia patronus. In these collections ladyfish were taken between Sabine Pass, Texas and Pearl River, Mississippi.

Materials and Methods

Samples were taken by two different-sized surface trawls. During the day, a small trawl (6.3 mm (bar measure) knotted nylon mesh, 6.1 m long and 6.7 X 0.9 m mouth opening) was towed between two outboard motorboats in the mid-channel at each station over a distance of about 740 m (0.4 nautical mile). The tows began upstream in or near freshwater and were evenly spaced to the mouth of the streams. A larger trawl (9.1 m long with a 10.1 X 0.9 m mouth opening) was used both day and night. The wings and body were made of 9.5 mm and the tail bag of 6.3 mm (bar measure) knotted nylon mesh. The collected ladyfish were preserved in 10 percent formalin and transported to the laboratory where the stomachs were excised, wrapped in cheesecloth, and stored in 40 percent isopropanol.

Fork length and weight of each fish were measured and the fish were separated into 25 mm length groups prior to stomach content analysis. The stomachs were weighed, and the contents analyzed under a dissecting microscope. Organisms were identified to the highest taxon possible, and the total contents as well as each prey species were counted and weighed. Since there were no important differences in the stomach contents of ladyfish collected during 1968 and 1969 (see Results and Discussion), the collections were combined and percents of total weight and frequencies of occurrence of food items were calculated for the different length groups (Table 43) and for the total sample (Table 44).

Results and Discussion

Stomach contents of 222 ladyfish, ranging from 71 to 201 mm in length, collected in June of 1968, and 73 ladyfish, ranging from 45 to 196 mm, collected in June of 1969, were examined. Nearly 78 percent of the stomachs contained food items. Fish made up 92.4 percent and decapods 7.6 percent of the food items, one mysid also was found (Tables 43 and 44). Stomach contents gave no evidence of bottom feeding because benthic organisms, sediment, and detritus, were lacking. The only species present in the stomachs were pelagic forms, suggesting that ladyfish are surface and mid-water feeders. There were no obvious differences in the stomach contents of individuals collected during the 2 years of study, nor were there any significant differences in the stomach contents of fish collected during day and those collected at night. Apparently, there was no change in feeding habits or patterns with growth (age ?) since the stomach contents were similar for all size groups collected (Table 43).

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Table 43.--Number, frequency and weight of food items contained in stomachs of various size classes of ladyfish from Louisiana streams during June of 1968 and 1969

Size class** and number of stomachs examined	Food item	Number	Frequency	Percent frequency	Weight (grams)	Percent weight
45 - 71 mm	*Brevoortia patronus*	2	1	25.0	0.2	40.0
n = 4	*Gambusia affinis*	4	1	25.0	0.3	60.0
	Dorosoma petenense	1	1	25.0	*	*
	Acetes americanus	6	1	25.0	*	*
	Empty stomachs	1				
72 - 97 mm	*Brevoortia patronus*	46	24	39.3	5.8	63.0
n = 61	*Gambusia affinis*	11	7	11.5	0.8	8.7
	Astroscopus y-graecum	1	1	1.6	*	*
	Anchoa hepsetus	3	3	4.9	0.6	6.5
	Anchoa mitchilli	3	3	4.9	0.2	2.2

Table 43.--Continued

Size class** and number of stomachs examined	Food item	Number	Frequency	Percent frequency	Weight (grams)	Percent weight
	Anchoa spp.	6	6	9.8	0.3	3.3
	Poecilia latipinna	1	1	1.6	0.1	1.1
	Unidentifiable fish	9	5	8.2	0.1	1.1
	Palaemonetes pugio	2	2	3.3	0.3	3.3
	Sicyonia spp.	1	1	1.6	0.2	2.2
	Mysidacea	1	1	1.6	*	*
	Unidentifiable decapods	4	4	6.6	0.8	8.7
	Empty stomachs	16				
98 - 123 mm	*Brevoortia patronus*	96	46	44.2	19.8	71.2
n = 104	*Gambusia affinis*	5	3	2.9	0.3	1.1
	Anchoa hepsetus	5	3	2.9	0.7	2.5

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Table 43.--Continued

Size class** and number of stomachs examined	Food item	Number	Frequency	Percent frequency	Weight (grams)	Percent weight
	Anchoa mitchilli	8	3	2.9	0.5	1.8
	Anchoa spp.	5	5	4.8	0.4	1.4
	Poecilia latipinna	2	2	1.9	0.8	2.9
	Poecilia spp.	1	1	1.0	0.5	1.8
	Membras martinica	9	1	1.0	0.9	3.2
	Fundulus grandis	1	1	1.0	*	*
	Unidentifiable fish	19	16	15.4	2.6	9.4
	Palaemonetes pugio	2	2	1.9	0.8	2.9
	Penaeus setiferus	2	1	1.0	0.1	0.4
	Macrobrachium ohione	1	1	1.0	0.1	0.4
	Unidentifiable decapods	5	5	4.8	0.3	1.1
	Empty stomachs	26				

Table 43.--Continued

Size class** and number of stomachs examined	Food item	Number	Frequency	Percent frequency	Weight (grams)	Percent weight
124 - 149 mm	*Brevoortia patronus*	72	31	40.8	19.7	56.4
n = 76	*Gambusia affinis*	7	3	4.0	1.1	3.2
	Anchoa hepsetus	3	3	4.0	0.2	0.6
	Anchoa mitchilli	10	10	13.1	1.6	4.6
	Anchoa spp.	5	3	4.0	0.9	2.6
	Poecilia latipinna	4	2	2.6	1.2	3.4
	Poecilia spp.	1	1	1.3	0.2	0.6
	Cyprinodon variegatus	10	4	5.3	5.3	15.2
	Cynoscion spp.	1	1	1.3	0.4	1.1
	Mugil cephalus	1	1	1.3	0.5	1.4
	Menidia spp.	1	1	1.3	0.2	0.6
	Unidentifiable fish	17	14	18.4	3.2	9.2
	Palaemonetes pugio	1	1	1.3	0.1	0.3

Table 43.--Continued

Size class** and number of stomachs examined	Food item	Number	Frequency	Percent frequency	Weight (grams)	Percent weight
	Penaeus spp.	1	1	1.3	0.2	0.6
	Unidentifiable decapods	2	2	2.6	0.1	0.3
	Empty stomachs	17				
150 - 175 mm	*Brevoortia patronus*	43	15	44.1	14.0	58.1
n = 34	*Poecilia latipinna*	2	1	2.9	0.8	3.3
	Cyprinodon variegatus	1	1	2.9	2.0	8.3
	Menidia menidia	1	1	2.9	1.3	5.4
	Unidentifiable fish	16	11	32.3	4.2	17.4
	Palaemonetes pugio	2	1	2.9	0.6	2.5
	Unidentifiable decapods	5	2	5.9	1.2	5.0
	Empty stomachs	5				

Table 43.---Continued

Size class** and number of stomachs examined	Food item	Number	Frequency	Percent frequency	Weight (grams)	Percent weight
176 - 201 mm	*Brevoortia patronus*	40	15	93.8	13.4	73.2
n = 16	*Poecilia latipinna*	2	1	6.3	1.6	8.7
	Menidia menidia	1	1	6.3	1.3	7.1
	Unidentifiable fish	1	1	6.3	0.1	0.5
	Palaemonetes pugio	5	1	6.3	1.9	10.4
	Empty stomachs	1				

* Less than 0.1 gram.
** Sizes given in fork length.

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Table 44.--Total number, frequency and weight of food items utilized by ladyfish from Louisiana streams during June of 1968 and 1969

Size class** and number of stomachs examined	Food item	Number	Frequency	Percent frequency	Weight (grams)	Percent weight
45 - 201 mm	*Brevoortia patronus*	299	132	44.7	72.9	62.9
n = 295	*Gambusia affinis*	27	14	4.7	1.6	1.4
	Anchoa hepsetus	11	9	3.1	2.4	2.1
	Anchoa mitchilli	21	16	5.4	2.3	1.9
	Anchoa spp.	16	14	4.7	1.6	1.4
	Poecilia latipinna	11	7	2.4	4.5	3.9
	Poecilia spp.	2	2	0.7	0.7	0.6
	Cyprinodon variegatus	11	5	1.7	7.3	6.3
	Mugil cephalus	1	1	0.3	0.5	0.4
	Dorosoma petenense	1	1	0.3	*	*
	Astroscopus y-graecum	1	1	0.3	*	*
	Membras martinica	9	1	0.3	0.9	0.8
	Fundulus grandis	1	1	0.3	*	*
	Cynoscion spp.	1	1	0.3	1.1	0.9

Table 44.--Continued

Size class** and number of stomachs examined	Food items	Number	Frequency	Percent frequency	Weight (grams)	Percent weight
	Menidia spp.	1	1	0.3	0.6	0.5
	Menidia menidia	2	2	0.7	2.6	2.2
	Acetes americanus	6	1	0.3	*	*
	Palaemonetes pugio	12	7	2.4	3.7	3.2
	Sicyonia spp.	1	1	0.3	0.2	0.2
	Penaeus setiferus	2	1	0.3	0.1	0.1
	Macrobrachium ohione	1	1	0.3	0.1	0.1
	Penaeus spp.	1	1	0.3	0.2	0.2
	Mysidacea	1	1	0.3	*	*
45 - 201 mm	Unidentifiable fish	62	47	15.9	10.2	8.8
	Unidentifiable decapods	16	13	4.4	2.4	2.1
	Empty stomachs	66				

* Less than 0.1 gram.
** Sizes given in fork length.

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Preliminary data from the surface trawls indicated that Gulf menhaden constituted approximately 85 percent of the fish population in pelagic waters where ladyfish were collected. Accordingly, juvenile Gulf menhaden occurred in 72 percent of the stomachs containing fish (not including unidentified fish), table 44.

To determine whether ladyfish are selective feeders, I used the modified formula of Ivlev (1961):

$$E = \frac{ri - pi}{ri + pi} ,$$

where E is the selectivity or "electivity" of ladyfish for a food species, ri is the quantity of that particular food species in the ration expressed as a percent of the total ration, and pi is the quantity of the food species in the environment expressed as a percent of the total environment. The positive selection of one fish species for another as a food source is indicated by values from +1 to 0 and non-selectivity by index values between 0 and -1.

I used the percentages of Gulf menhaden in the stomachs of ladyfish and in the environment to compute the selectivity of ladyfish for menhaden. This computation was:

$$E = \frac{72 - 85}{72 + 85} ,$$

and yielded an index of -0.08. An E value of -0.08 indicated that ladyfish do not select menhaden as a food source. Even assuming that the 62 unidentified fish (Table 44) are menhaden the E value would be only -0.05. Thus, I conclude that ladyfish are opportunists rather than selective feeders and consume what is available.

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Reference

Ivlev, V. S. 1961. Experimental ecology of the feeding of fishes. (Trans. from Russian). Yale University Press, New Haven. 302 p.

INTERACTION OF ENVIRONMENTAL STRESSES ON ESTUARINE ORGANISMS

INTERACTION OF ENVIRONMENTAL STRESSES ON ESTUARINE ORGANISMS

Meeting the challenge of planning in a technological society requires information needed for predicting the effects of man's altering the environment. Man's modifications and additions to the estuarine environment are many and varied, and organisms in the environment respond to these changes in combination with their responses to wide natural fluctuations of the environmental variables. We are actively gathering information on the physiological responses of estuarine organisms to natural environmental fluctuations and the effects of superimposing additional stresses from environmental changes.

A principal contemporary problem is the effect of large scale additions of heated water to aquatic environments. Increasing demand for electrical power and increasing use of nuclear powered generating plants to fill that demand will make the acute and chronic effects of elevated water temperatures matters of ubiquitous concern. Four studies reported here--those on flounder growth, fish respiration, thermal shock and on blue crab respiration--are of direct pertinence to problems of thermal additions.

A second problem engendered by nuclear generating plants is that of emission of radioactive by-products into the aquatic environment. While the record of generating plants in controlling their emissions has been excellent, the potential danger can not be ignored. Our study on effects of low level radiation on marine microcosms is relevant to this subject.

Besides the completed work reported here, our group has several current projects which will supply information useful in predicting the effects of adding heat or radioactivity to aquatic systems. Among these are experiments designed to duplicate temperature changes in water passed through the cooling system of a generating plant and to assess the effects of those changes on larval and juvenile fishes entrained in the cooling water. For experimental animals we are using spots, croakers, mullets, menhaden, silversides, and pinfish. We consider these to be the ecologically most important fishes in our local estuaries. Studies of respiration of these same six species in schools in response to temperature stress are continuing. Measuring respiration of fishes while they are in groups in relatively large containers should give the most realistic respiration values available. The two respirometers we have constructed for grouped fish are very reliable and easy to use.

Also we are currently examining growth of another important estuarine species, the hog choker, in relation to salinity, feeding rate, and most importantly, temperature. An adjunct study is of the natural feeding rate of hogchokers as measured from field observations.

A prime requisite for survival in estuaries is an adaptable osmoregulatory system. We are presently evaluating the effect of both radiation and elevated temperature on the osmoregulatory ability of the blue crab.

The contribution of our research, including that completed, that being conducted, and that planned, will help form a basis for rational planning for environmental protection. Our progress during fiscal year 1971 is demonstrated in the following papers.

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COMPARISON OF SCHOOL VS.
INDIVIDUAL FISH RESPIRATION

William F. Hettler, Jr. and Donald E. Hoss

A flowing-water respirometer was developed initially to measure the metabolism of juvenile and adult menhaden. These fish are highly active swimmers that must move continually to irrigate their gills. They also possess a strong drive to school. Hence, they cannot be held or studied in small conventional aquaria or isolated in respiration chambers. If this is attempted, their activity is elevated to a state where they eventually beat themselves to death attempting to escape confinement.

To measure the metabolism of a school of menhaden, we used a circular fiberglass tank 1.2 m in diameter, with a 200-liter volume. A floating lid with an air tight seal was used to isolate the water from the air above the chamber. A light source and viewing port were in the lid. Water of controlled salinity and temperature, 100 percent saturated with air, flowed into the respirometer from a distribution ring around the bottom of the tank. Used water flowed out a central drain. A polaragraphic oxygen analyzer and a strip-chart recorder were used to measure the difference in oxygen content of the inlet and outlet water. A unique feature of the system was that continuous measurements could be made while variables, such as salinity, temperature, or photoperiod, were manipulated.

This system, as presently used, does not drive the fish to specific levels of activity, but rather is dependent upon spontaneous movements of the fish. They are isolated from external stimuli as much as is practical. The metabolic rate measured at steady state conditions is called routine metabolism and is intermediate between the two extremes of metabolism, active and standard.

Measurements made on fish in the large respirometer were compared with measurements made on single fish in a respirometer system described by Hoss (1968). Three species of estuarine fish were compared in the two respirometers. In all measurements, the fish were permitted to acclimate to the respirometer 24 hours prior to the beginning of the measurements. The fish were not fed during the acclimation period. The fish were anesthetized with MS-22- for weighing and transferring. The results are presented in table 45.

Menhaden were difficult to keep alive in the small plexiglass cylinders of the single-fish respirometer; 50 percent of the fish died before the end of the acclimation period. The surviving fish used about twice as much oxygen per gram of wet weight as did a school of 42 fish swimming freely in the large tank. This elevated metabolism is attributed to the stress imposed on the fish by confinement and isolation. Spot used slightly more oxygen as individuals than as an unrestricted group. Pinfish were similar to spot in their oxygen consumption. The difference in the two respirometers for pinfish was 36 mg O_2 per kilogram of wet body weight at 14 1/2° C and only 12 mg at 19° C.

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Table 45.--Comparison of group vs. individual respiration

Species	Respirometer system	Temp °C	Sal o/oo	No. observations	No. fish	$\bar{X}$ wt fish (g)	$\bar{X}$ O_2 used (Mg/g/hr)
Brevoortia tyrannus	Group	15.3	29.2	4	42	95.1	0.137
	Individual	15.6	31.0	5	5	92.6	0.302
Leiostomus xanthurus	Group	15.0	28.5	9	100	24.0	0.130
	Individual	15.6	29.0	5	10	22.4	0.149
Lagodon rhomboides	Group	14.8	28.8	9	128	7.7	0.125
	Individual	14.5	30.8	5	10	7.5	0.161
	Group	19.7	29.4	5	75	34.5	0.162
	Individual	18.7	30.8	5	10	31.3	0.150

Measurements of routine metabolism are probably the best estimates of the metabolic needs at a given temperature. These measurements reflect the energy required to meet the stimulus for spontaneous activity at that temperature, as well as the cost of cell maintenance.

Windberg (1956) proposed doubling the routine oxygen consumption of fish to give an estimation of their metabolic rate in nature. However, based on the similarity in oxygen consumption of the restrained fish compared with the fish permitted to swim unrestricted and, in the case of pinfish to even set up territories, the measurement of routine metabolism gives a good estimate of the normal non-feeding state of energy expenditure for spots and pinfish.

Complicating the estimation of metabolism in a natural habitat is the elevated 0_2 consumption noted in feeding and recently fed fish. Schools of menhaden in the large respirometer double their oxygen consumption above the routine rate during and following feeding. For pinfish, respiration was up to 30 percent higher after feeding than the routine rate. Spots increased metabolism by 20 percent following feeding. From these initial observations, it can be anticipated that the best estimation of total daily normal metabolism will have to include routine metabolism and active metabolism (resulting from feeding activity or excited swimming behavior) components in proportion to the daily behavioral activity patterns of the particular species under study. The effects of food and feeding, as well as the effects of temperature, salinity, and photoperiod, on the respiration of selected estuarine fish is a study to be continued during the next year's research.

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References

Hoss, D. E. 1968. Rates of respiration of estuarine fish. Proceedings of the 21st Annual Conference of the Southeastern Association of Game and Fish Commissioners, 1967, p. 416-422.

Winberg, G. G. 1956. Rates of metabolism and food requirements of fish. (Transl. from Russian) Fish. Res. Bd. Can., Transl. Ser. 194. 239 p.

EFFECTS OF THERMAL SHOCK ON ESTUARINE FISH

Donald E. Hoss, Linda C. Coston,

and

William F. Hettler, Jr.

We initiated a study this year to experimentally measure the physiological effect of thermal shock on three species of postlarval fish (menhaden, Brevoortia tyrannus, pinfish, Lagodon rhomboides, and spot, Leiostomus xanthurus). Our purpose in conducting these experiments was to determine the possible effects that thermal additions from electric generating stations might have on estuarine species of fish. We selected postlarval fish to start our experimental work on because they are not able to avoid thermal additions and they may be more susceptible to changes in temperature than larger fish of the same species.

We are, at the present time, evaluating two methods for measuring the effects of thermal shock on the fish. These are: Measurement of the critical thermal maximum (CTM) and measurement of changes in routine oxygen consumption or metabolism.

Critical Thermal Maximum

The CTM may be defined as the thermal point at which locomotory activity becomes disorganized and the animal loses its ability to escape from conditions that will promptly lead to its death.

In our experiments the postlarval fish were maintained in the laboratory for a period of 3-5 days at temperatures and salinities approximating that of the water in which they were caught (15° C and 30 o/oo). To determine the CTM a fish was taken directly from the acclimation container and placed in a 500 ml three-necked distillation flask containing 300 ml of water. The distillation flask was then placed in a hemispherical mantle heater connected to a variable transformer adjusted to obtain a rate of heating of 1° C per minute. The water in the distillation flask was aerated and stirred by air introduced through a tube.

When first placed in the flasks the fish were usually relatively quiet (except for menhaden). However, as the temperature increased the activity of the fish increased; periods of rapid swimming were followed by spasms and finally by a fanning out of the opercula. Death predictably followed these symptoms.

After several preliminary runs we chose the fanning out of the opercula to indicate the CTM, and recorded the temperature at this point. Results obtained to date are summarized in Table 46. Of the three species tested menhaden had the lowest CTM when acclimated to 15° C.

Table 46.--CTM values for three species of fish acclimated at 15° C

Species	Number of fish	Average wet weight (mg)	Average CTM (°C)
Menhaden	18	47.2	29.4
Spot	32	25.2	31.1
Pinfish	24	29.4	31.0

Routine Metabolism

The routine metabolism of postlarval fish was measured with a differential respirometer. Four consecutive measurements of oxygen consumption were made at hourly intervals on each fish, and no fish was used more than one time. Wet weights were obtained after the fourth oxygen measurement. Postlarval fish used in these experiments were acclimated to the same conditions as those used in the CTM experiments (15° C and 30 o/oo).

We transferred the postlarval fish from the acclimation container to 3 ml of sea water at acclimation temperature (15° C) in a 15 ml respiration flask. The flask was then attached to the respirometer and immersed instantly into a water bath at the acclimation temperature (15° C) or at a temperature 5°, 10°, or 15° C above acclimation. A temperature probe was inserted into one of the respiration flasks to determine the time for the water in the flask to reach the temperature of the water in the bath (Table 47).

Table 47.--Average time for water in respiration flask to reach temperature of water bath

Increase °C	Average time (min) 3 ml	5 ml
15 - 20	1.76	2.35
15 - 25	3.13	3.80
15 - 30	3.82	4.22

Least squares regressions were calculated for logarithms of respiration as a function of logarithms of weight, and values for the metabolism-weight coefficients in the respiration equation are summarized in table 48 along with the temperature, the numbers of fish at the start and at the end of the experiment and the weight range of the fish used in the experiments. For each species of fish the mean oxygen consumption per fish was plotted against total body weight on a double logarithmic scale for each temperature (Fig. 33 and Fig. 34).

At temperatures of 15° C above the acclimation temperature (15° C) all of the fish tested died within 5-10 minutes after being placed in the respiration flasks. At 10° C above the acclimation temperature, 67 percent of the menhaden (12 of 18), 50 percent of the spot (9 of 18), and 17 percent of the pinfish (3 of 18) died during the experiment (Table 48). As one would expect the increased temperatures caused an increase in oxygen consumption by all three species.

These results are preliminary but they indicate that under our experimental conditions a rise in temperature of 15° C occurring in a 3-4 minute period is lethal to the three species of postlarval fish tested when they are acclimated at 15° C. A thermal shock of 15° C is a severe stress but not a completely unrealistic one. The average rise in temperature through condensers is 10.8° C and the range is 5.6° C to 18° C (Auerbach et al., 1971). This elevated temperature may be maintained for several minutes in the outlet and discharge canal.

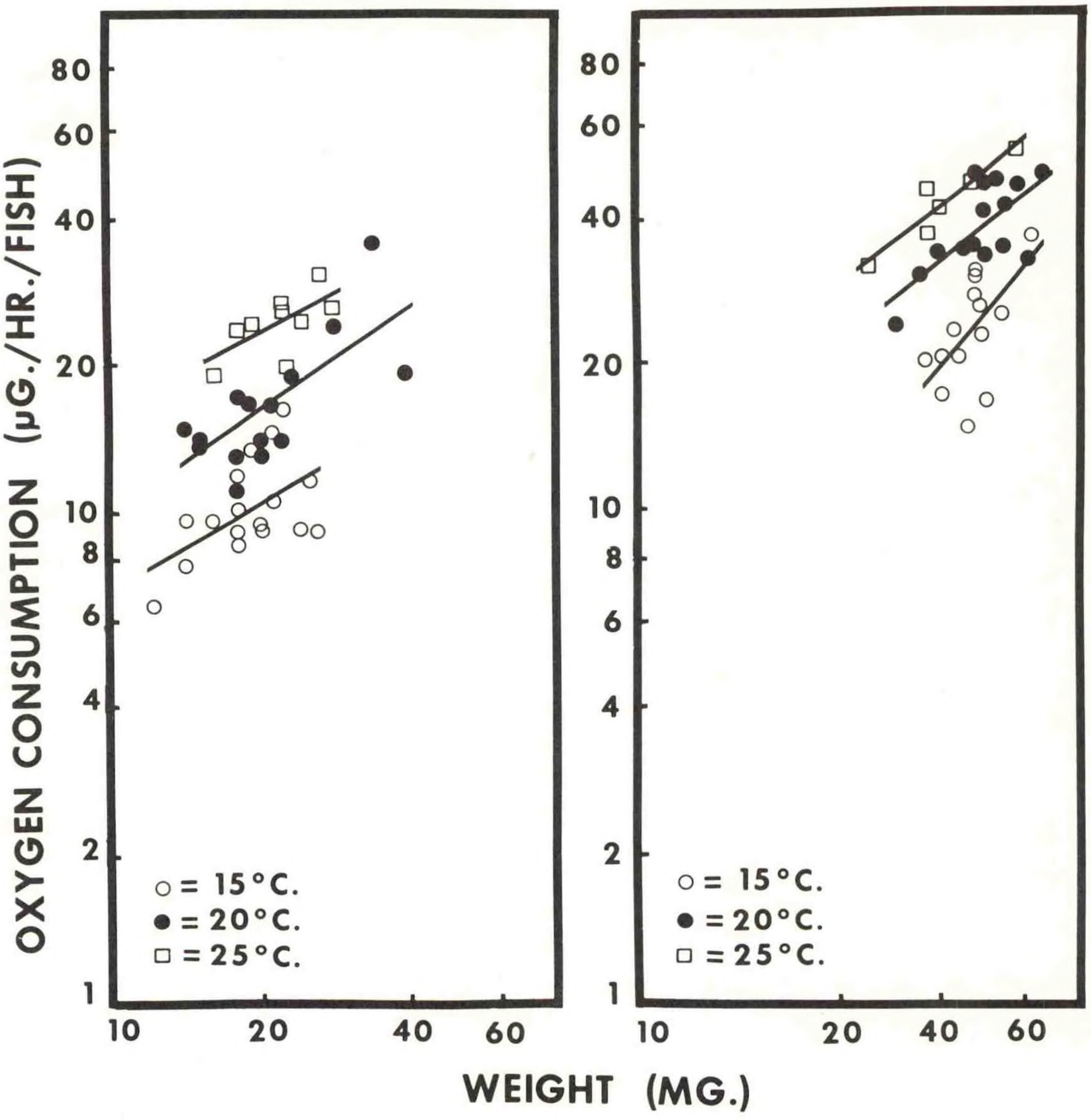

Figure 33.--Effects of temperature on rates of respiration of postlarval spot (left) and menhaden (right).

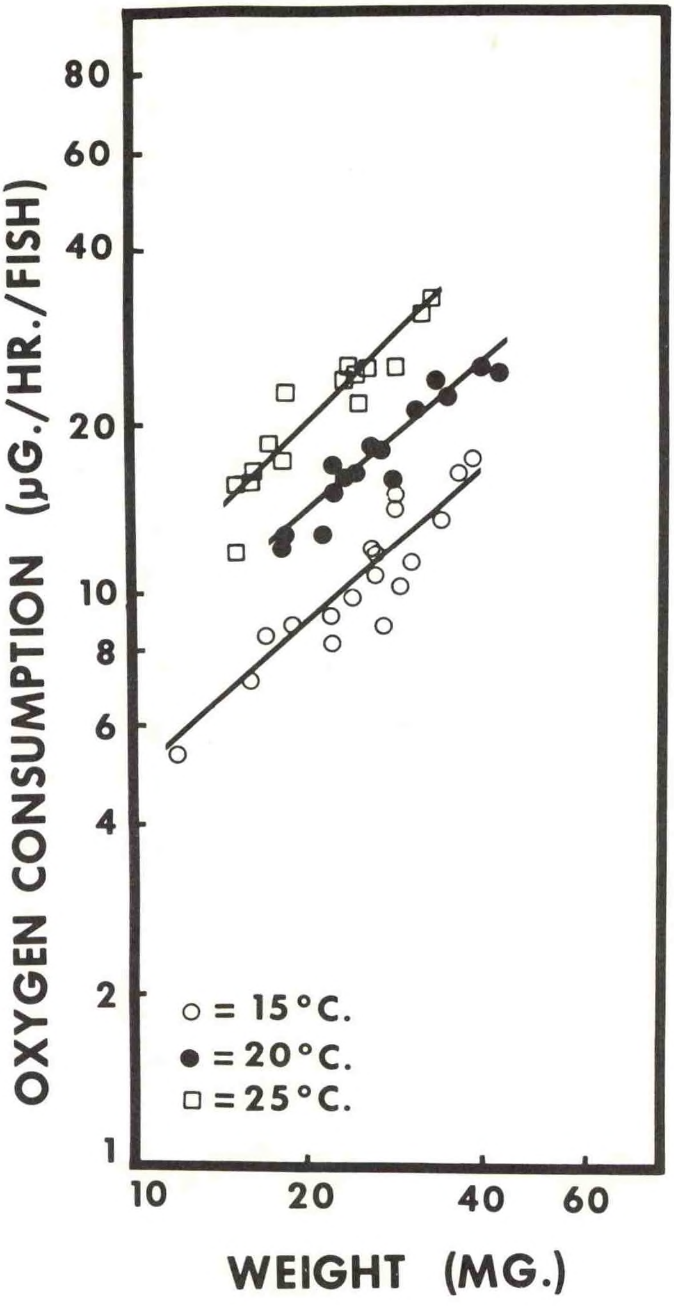

Figure 34.--Effects of temperature on rates of respiration of postlarval pinfish.

Table 48.--Effects of sudden increases in temperature on survival and oxygen consumption by three species of postlarval fish

Species	Acclimation Temp	Measurement Temp (°C)	Number of fish start	Number of fish end	Weight range (mg)	Coefficients* a	Coefficients* k
Menhaden	15	15	18	15	38-62	-.6205	1.1882
	15	20	18	16	33-65	.2516	.7781
	15	25	18	6	29-58	.3839	.7688
	15	30	18	0	--	--	--
Spot	15	15	17	17	12-26	.2786	.5724
	15	20	16	15	13-39	.3227	.6819
	15	25	18	9	16-28	.7149	.5013
	15	30	18	0	--	--	--
Pinfish	15	15	17	17	12-38	-.2320	.9100
	15	20	15	12	18-42	.0278	.8621
	15	25	18	15	10-32	.0009	1.0024
	15	30	18	0	--	--	--

Reference

Auerbach, S. I., D. J. Nelson, S. V. Kaye, D. E. Reichler, and C. C. Coutant. 1971. Ecological considerations in reactor power plant siting, p. 803-820. _In_ Environmental aspects of nuclear power stations. International Atomic Energy Agency, Vienna.

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THE EFFECT OF TEMPERATURE, SALINITY, AND FEEDING RATE ON GROWTH RATE AND GROWTH EFFICIENCY OF JUVENILE FLOUNDER, *Paralichthys dentatus* and *P. lethostigma*

David S. Peters

Determinations of the rates and pathways of energy utilization give an indication of the ability of animals to thrive under various environmental conditions. How well they thrive is indicated by their growth rate and efficiency of transforming food to body tissue. The consecutive processes of ingestion, digestion, absorption, and oxidation of assimilated materials may be modified by the environment and will be manifested in the rate and efficiency of growth. Few studies have recorded the effect of the three environmental variables--temperature, salinity, and food availability--most important for estuarine fish.

Early work on fish growth rates and efficiencies was not as useful as more recent studies. Dawes (1930) and Pentelow (1939) measured growth as change in live weight. More recently change in dry weight has been determined (Kinne, 1960), and caloric growth has been measured (Pandian, 1970, and Edwards, et al., 1970). Caloric determinations are best as they eliminate any differences due to variations in water or fat content. Some energy values have been estimated by indirect calorimetry (Pandian, 1967, and Edwards, et al., 1970); however, much recent work has been directly with a bomb calorimeter, e.g., Menzel (1960), Davis and Warren (1965), and Pandian (1970).

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Some effects of environmental factors on growth are known but much information is still lacking. Temperature and salinity have a significant effect on the rate and pattern of energy utilization; but the precise effect depends on the species. Whether interactions between temperature, salinity, and feeding level affect growth or growth efficiency has not been adequately investigated. In spite of Brown's often cited statement (1957) that "Food is probably the most potent factor affecting the growth of fishes," few studies have been conducted at various feeding level restrictions. In the studies on food and growth of fish reanalyzed by Paloheimo and Dickie (1966), feeding rates varied mainly as a result of different physiochemical conditions, not as a result of limited food availability. Growth was most efficient at low feeding levels and efficiency decreased with increasing ration. Warren and Davis (1967) raised fish under various limitations of food availability and found most efficient growth at slightly more than 2/3 *ad libitum* feeding. More information will be needed before these conflicting views on the relationship between feeding level and growth efficiency can be reconciled.

Information of practical value can be gained from studies of fish metabolism. For example, fishery managers and culturists are interested in getting high growth rates and efficiencies. Currently, however, there is little information on the best temperatures, salinities, and feeding levels for most species. A second use for growth studies is in predicting affects of thermal enrichment. Discharge of cooling waters into coastal areas may increase or decrease fish growth by altering the natural temperature and salinity regimes. The amount of change due to altered conditions and whether it will be harmful or beneficial are still undetermined.

This report describes how energy utilization is affected by temperature, salinity, and feeding level in economically important estuarine fish, summer flounder, *Paralichthys dentatus*, and southern flounder, *Paralichthys lethostigma*. It includes the effect of temperature and salinity on feeding rate and the combined effect of temperature, salinity, and feeding rate on growth rate and growth efficiency.

Materials and Methods

Fish were caught, maintained in natural temperature and salinity conditions, and fed crustaceans until they grew past the postlarval stage. Experimental fish were caught in February in a tidal net (Lewis, et al., 1970) as they entered the estuary at night. *Paralichthys dentatus* and *P. lethostigma* were separated as postlarvae by the characteristics of Deubler (1958) and Woolcott, Beirne and Hall (1968). Before experimentation began they were grown through the postlarval stage. Food consisted of natural zooplankton

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plus Artemia salina nauplii. The fish were maintained in unheated running seawater with temperature and salinity naturally varying from 10-15° C and 25-35 ppt.

During the feeding and growth experiments, fish were maintained so that effects of variables other than temperature, salinity, and feeding level would be low and constant. Fish were held individually in clear plastic containers, 100 mm in diameter with 10 two-millimeter holes in the side of each. These individual containers were placed on stands in 30 liter tanks at appropriate depths so that each contained 300 ml of water. Up to 10 containers were placed in each tank. Aerators maintained circulation between the containers and the surrounding water. Fluorescent light provided a 12-hour photoperiod at an intensity of 275 lux. Following Kinne (1960, 1962), and Edwards, et al., (1970) the terrestrial white worm, Enchytraeus sp. was used as food. It could be fed whole and even submerged would remain alive at least 24 hours; thus, any uneaten food could be easily and completely removed the next day.

The experimental design used in this study is factorial in that the effects of three factors are investigated simultaneously, each treatment consisting of a combination of these factors. Combinations were chosen to conform to a central composite rotatable design as described by Cochran and Cox (1957). In my study 15 different treatment

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combinations were tested (Fig. 35) with one, the center point, being replicated six times for a total of 20 different measurements. Since feeding rate could not be accurately preset, the actual treatment combinations approached, but were not exactly the same as, those desired.

Data on growth of P. dentatus were obtained from unreplicated treatment combinations while information on P. lethostigma came from two replications of each treatment. Six fish were grown in each of the unreplicated treatments and three in the replicated ones.

Temperature and salinity were closely monitored in all experiments. The tanks were set up in constant temperature rooms where water temperature fluctuated ± 1° C. The desired salinities were obtained using artificial seasalt (Seven-Seas Marine Mix from Utility Chemical Company) and distilled water. Each day the tanks were checked for evaporation and distilled water added to return the water to its original level.

The desired feeding rates were calculated separately prior to each experiment with rates actually obtained being determined later. Maximum food consumption, ad libitum feeding rate, was determined for three fish under each temperature salinity combination and was expressed as the average proportion of body weight consumed each day. This required information on the weight of each fish every day. Those weights were calculated assuming a constant growth rate from the formula:

$$W_t = W_{t-1} (W_n/W_o) \exp (1/n)$$

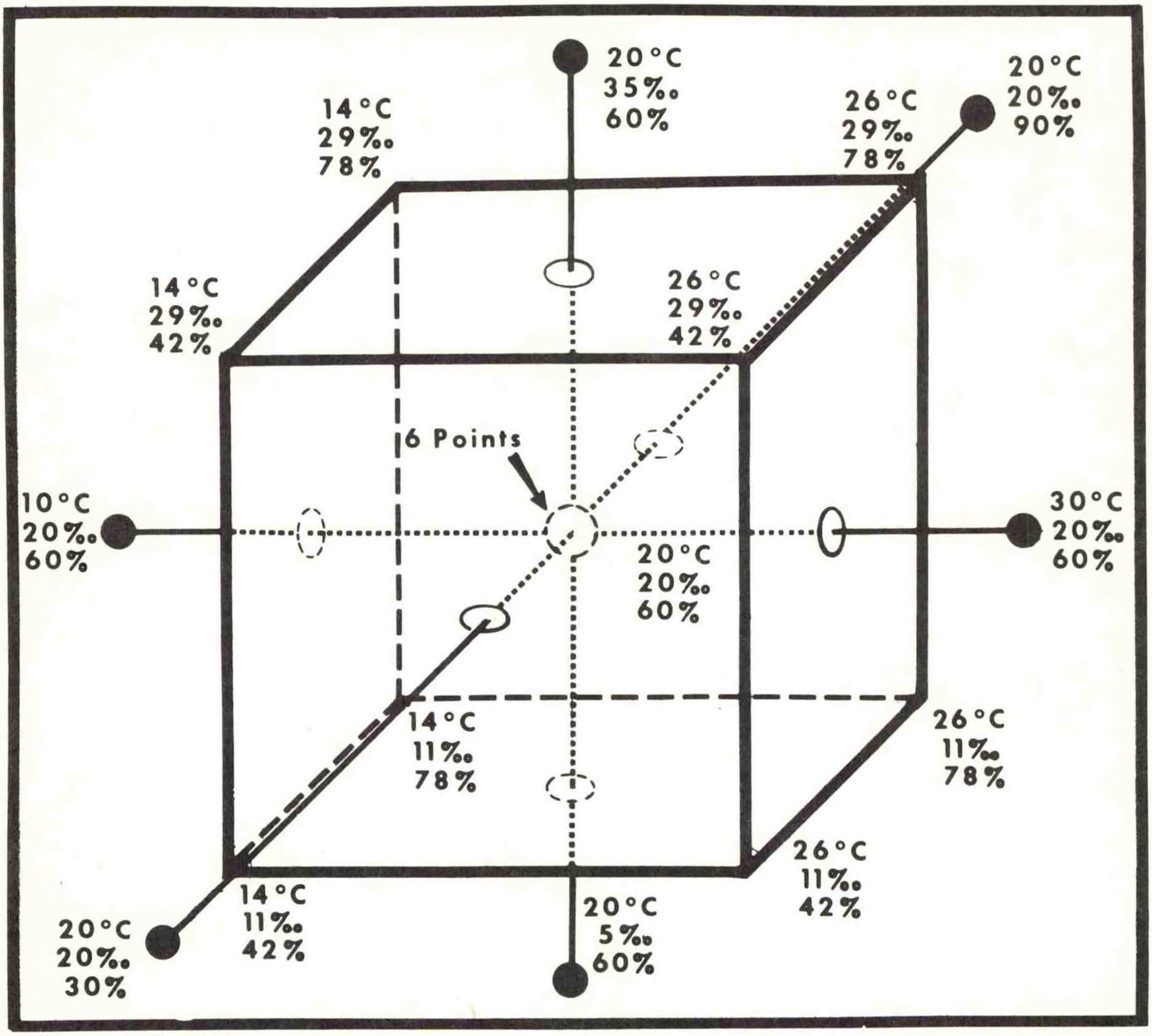

Figure 35.--A central composite rotatable design in three variables.

where W_o = original weight, W_n = final weight, t = any day, and n = the number of days over which growth occurred. The amount of food given to fish on restricted rations was the product of: the maximum feeding rate x desired fraction of maximum feeding rate x weight of fish. After the first feeding the weights of the fish were not known and were therefore estimated based on the amount of food consumed and preliminary estimates of growth efficiency. In the few instances when not all food was consumed, the amount actually eaten was recorded. At the termination of each experiment, the actual diet restriction was calculated as:

$$\frac{\text{average proportion of body wt consumed daily}}{\text{maximum feeding rate}} \quad \times \quad 100$$

Although it might seem appropriate to acclimate fish to the experimental conditions, this was not attempted. Acclimation is a physiological adjustment which may take days (Prosser and Brown, 1961), during which time differential growth would occur in the various treatments. With the rapidly growing fish used in this experiment, I had the choice of using unacclimated fish or ones of different sizes. Since growth is related to body size (Paloheimo and Dickie, 1966), the first alternative was chosen.

All experiments were conducted in the following manner. Pre-experimental weights were measured 24 hours after fish had been introduced to the experimental temperature salinity combinations.

Randomly chosen fish were removed to show caloric content per gram prior to growth. Feeding of remaining fish was begun several hours later and continued daily for 4 to 7 days at which time final weight was determined and the fish preserved for caloric determination.

Caloric content was measured in a microbomb calorimeter (Phillipson, 1964). Two different bombs were used and four different measurements were averaged for each calroic value. After every fourth measurement the accuracy of each bomb was checked with benzoid acid. Fish of each species from any one treatment combination were ground together, then analyzed to give one value for caloric content.

Caloric growth rates and efficiencies were calculated on a daily basis and averaged for each treatment combination. Growth rates were expressed as a proportional increase per day from the formula:

$$\text{rate} = (W_n/W_o) \exp (1/n) -1.$$

Growth efficiencies were calculated as growth rate divided by average daily proportion of body weight consumed. When growth was negative, efficiencies were arbitrarily set at zero.

Regression analysis and response surface diagrams were used to summarize the data. Growth rates and efficiencies were used to calculate regression equations of the form:

$$y = b_o + b_1T + b_2S + b_3F + b_{11}T^2 + b_{22}S^2 + b_{33}F^2 + b_{12}TS + b_{13}TF + b_{23}SF$$

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where y = growth rate or efficiency, T = temperature (°C), S = salinity (ppt), and F = percent *ad libitum* feeding rate; b_o is a constant and the other b values are regression coefficients pertaining to the various linear quadratic and interaction effects. *Ad libitum* feeding rates were summarized by the equation:

$$y = b_o + b_1T + b_2S + b_{11}T^2 + b_{22}S^2 + b_{12}TS$$

where y = average daily percentage of body weight consumed. Even though some appeared unimportant, all of the terms in the regression equations (Table 49) were used in response surface plotting.

Results and Discussion

Temperature is the main factor affecting feeding rate of *P. dentatus* (Fig. 36). The salinity effect is slight but at higher temperatures higher salinities resulted in greater food consumption. The regression equation relating feeding rate to temperature and salinity was:

$$y = -0.29187 + 0.03602T - 0.00046T^2 + 0.00014S + 0.00002S^2 + 0.00001TS$$

Most of the variation in feeding rate could be explained by the regression ($R^2 = 0.97$).

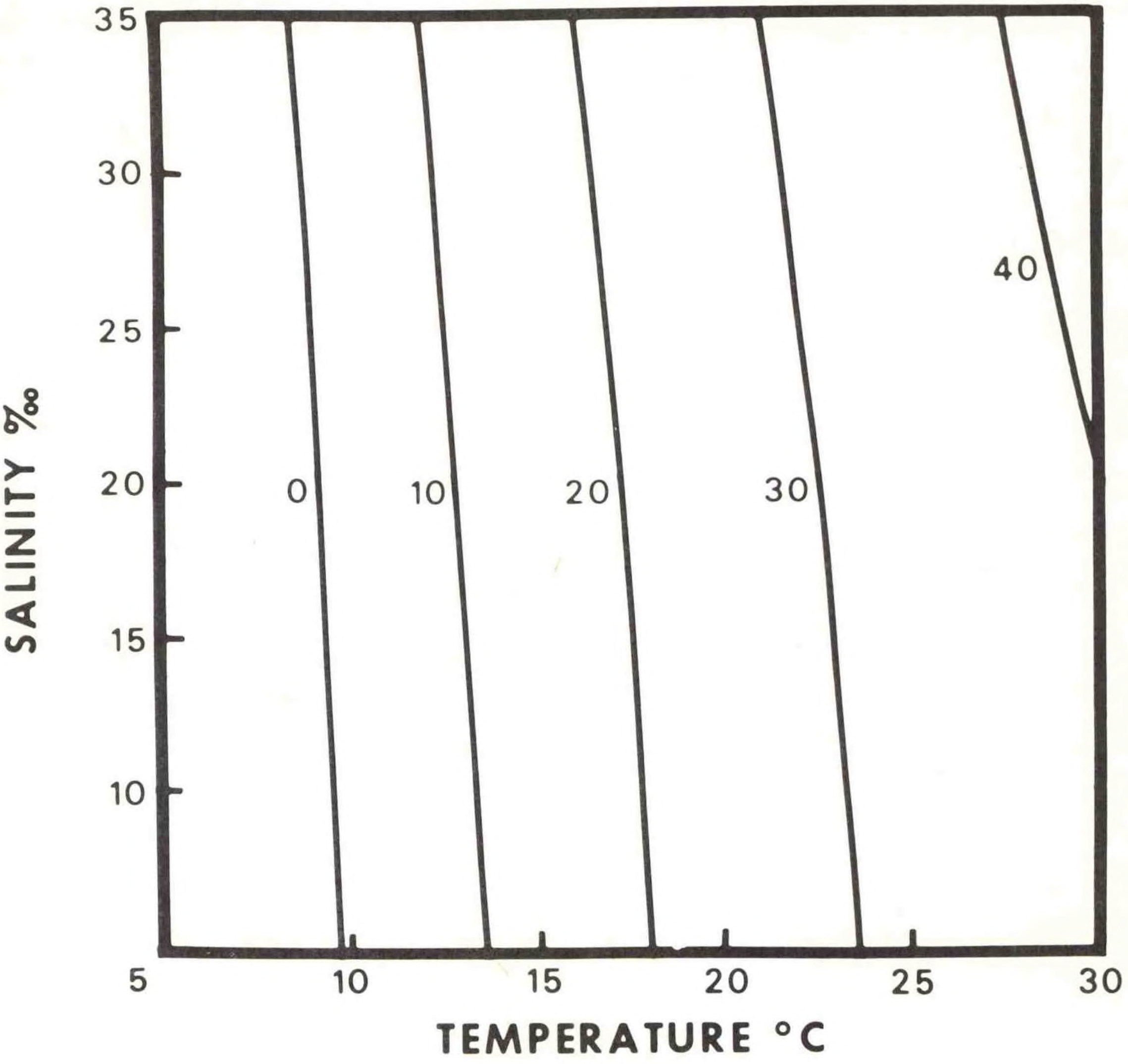

Figure 36.--Estimation of percent body weight ingested per day by *Paralichthys dentatus* at *ad libitum* feeding based on the fitted response to nine observed combinations of temperature and salinity.

Like *ad libitum* feeding rate growth efficiency is strongly influenced by temperature. Efficiency is low at cooler temperatures and increases to a maximum in the 20-25° C range (Fig. 37). The feeding level apparently has little effect on the temperature for optimum efficiency. Salinity, however, has a slight effect on food conversion with intermediate salinities producing slightly more efficient food use. Thus, food is converted to growth more efficiently at temperatures and salinities below those favoring highest food consumption.

Feeding rate and food conversion efficiency combine to give growth rate which is dependent primarily on temperature and feeding rate (Fig. 38). The highest growth occurs at high temperatures, salinities and feeding levels. However, as the feeding rate is reduced the temperature for maximum growth approaches 20-25° C which corresponds to maximum efficiency. This means the temperature feeding interaction is important and a determination of the effect of thermal effluents on the growth rate of fish requires information on the amount of food which will be available under the altered conditions.

Feeding rate of *P. lethostigma* was also dependent primarily on temperature (Fig. 39). The salinity effect was again slight and important mainly at higher temperatures where it acted differently than in *P. dentatus*. That is, in warm water low salinities resulted in greater food consumption. The calculated regression,

$$y = -0.3890 + 0.04584T - 0.0041T^2 + 0.00089S + 0.00008S^2 - 0.00025TS$$

could explain most of the variation ($R^2 = 0.93$)

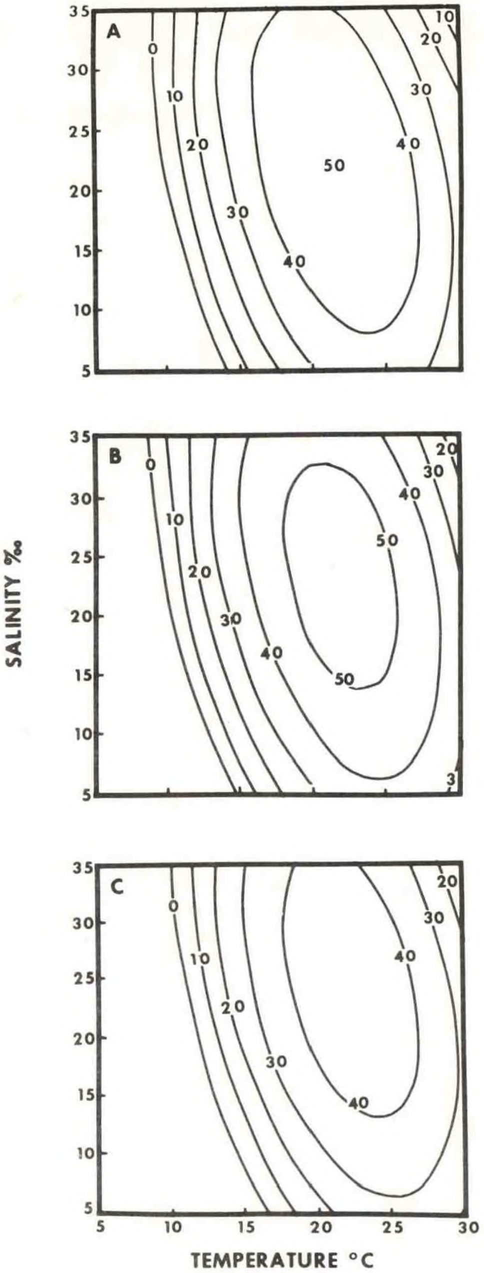

Figure 37.--Estimation of caloric growth efficiency of P. dentatus (percent of food converted to body substance) based on the fitted response to observed efficiency under 15 different combinations of temperature, salinity, and feeding level (A is 60 percent, B is 80 percent, and C is 100 percent ad libitum feeding).

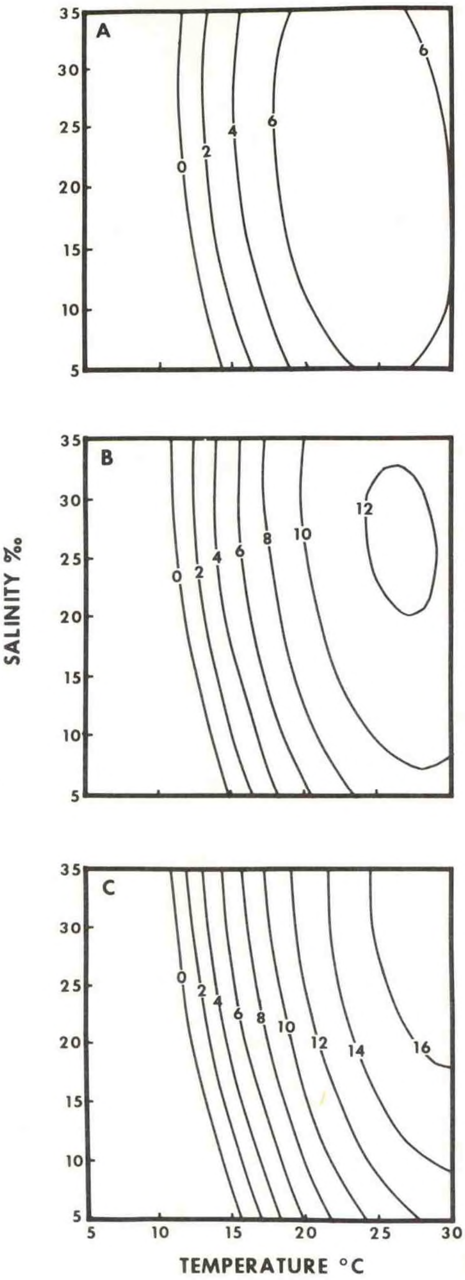

Figure 38.--Estimation of caloric growth rate of P. dentatus (percent daily increase) based on the fitted response to observed growth under 15 different combinations of temperature, salinity, and feeding level (A is 60 percent, B is 80 percent, and C is 100 percent *ad libitum* feeding).

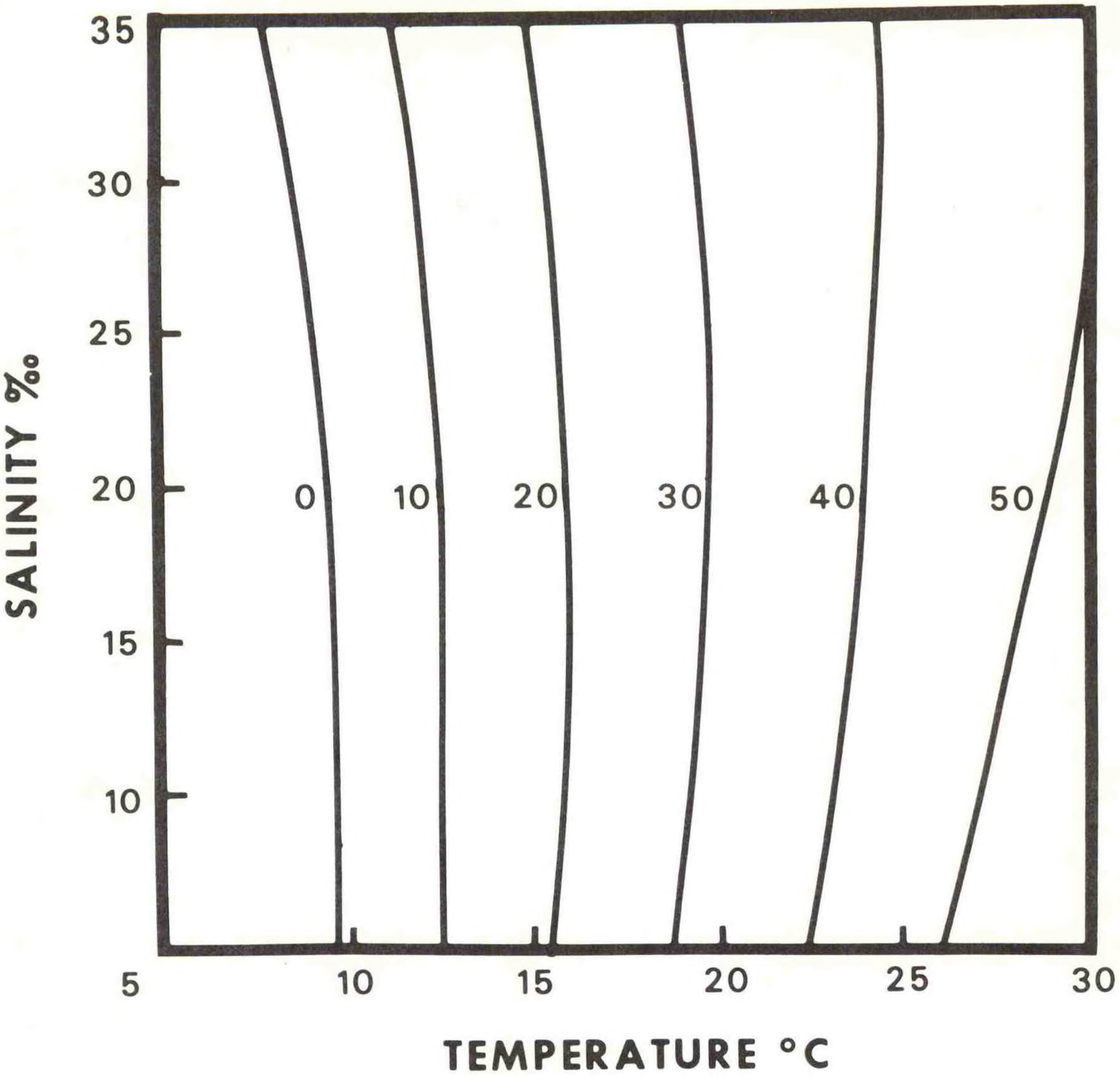

Figure 39.--Estimation of percent body weight ingested per day by *P. lethostigma* at *ad libitum* feeding based on the fitted response to nine observed combinations of temperature and salinity.

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An optimum temperature does not exist for growth efficiency of southern flounder (Fig. 40). Instead the temperature producing greatest efficiency increases as the salinity decreases.

Growth of P. lethostigma was highest at low salinities and high temperature and feeding level with maximum growth rate probably slightly above 30° C. In this species optimum temperature for growth is evidently not affected by the feeding level. This is somewhat different than summer flounder in which reduced feeding levels resulted in lower temperatures for fastest growth.

The effect of salinity on growth rate is also different in the two species. In P. dentatus at low temperature, greatest growth occurred at high salinity. In P. lethostigma, the salinity affect may be the same at low temperatures but it was always different at high temperature where maximum growth was always at low salinities.

The effects of temperature and salinity as seen on growth rate are also evident in the natural pattern of fish distribution. At high temperatures greatest growth rate and efficiency for summer flounder were at high to intermediate salinities and for southern flounder at low salinities. Unpublished distributional data (W. Turner personal communications) indicate that during the summer, when water is 25°-30°, each species is most abundant in areas with salinities which this data indicate will result in fastest growth.

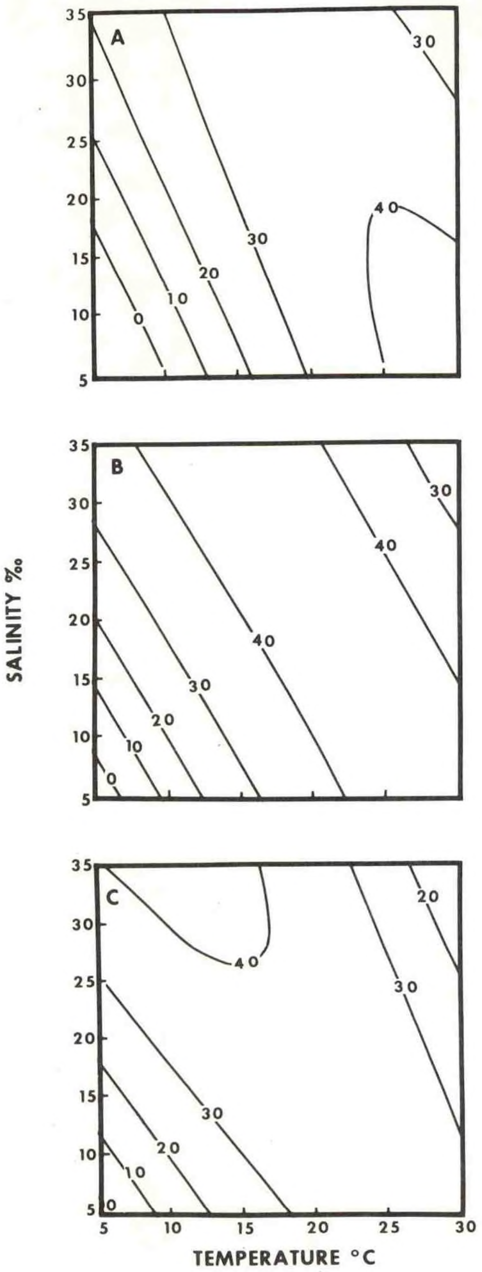

Figure 40.--Estimation of caloric growth efficiency of *P. lethostigma* (percent of food converted to body substance) based on the fitted response to observed efficiency under 15 different combinations of temperature, salinity, and feeding level (A is 60 percent, B is 80 percent, and C is 100 percent *ad libitum* feeding).

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In addition to the distributional difference, there is a species adaptation of growth to temperature. Growth of P. dentatus (Fig. 38), the more northern species, is slower at high temperature than growth of P. lethostigma (Fig. 41). P. lethostigma eats more at higher temperatures and also uses it more efficiently than the P. dentatus. It is not surprising that these two closely related species react differently to increased temperature when you consider that they have different latitudinal distribution and that the southern flounder is the one which functions best at high temperature.

In conclusion, the data indicate that the level of food availability may alter the effects of temperature on fish growth, that temperature salinity interactions exist and are important, and that each species must be considered separately if we want to predict the change in growth due to anticipated thermal alteration.

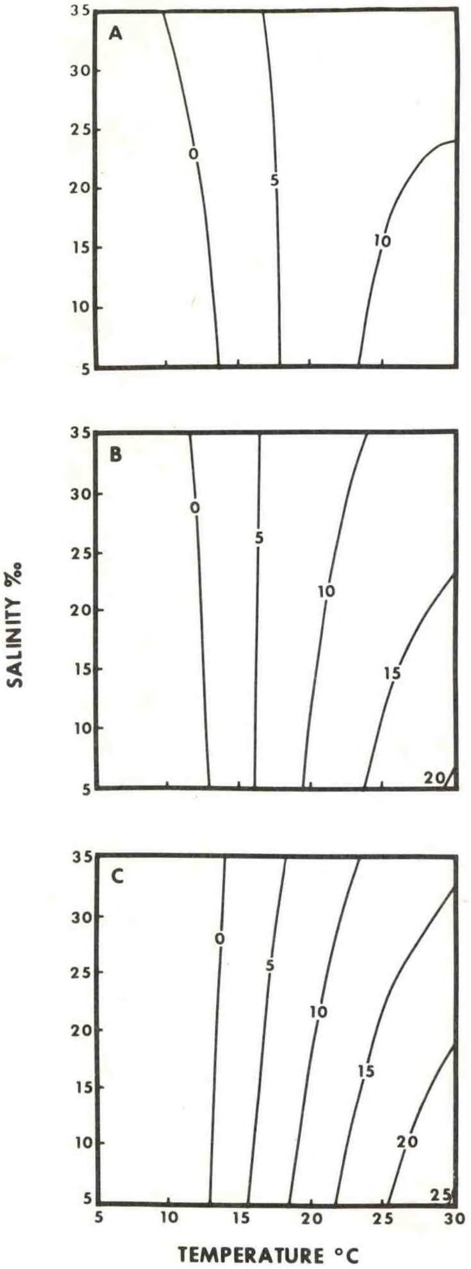

Figure 41.--Estimation of caloric growth rate of *P. lethostigma* (percent daily increase) based on the fitted response to observed growth under 15 different combinations of temperature, salinity, and feeding level (A is 60 percent, B is 80 percent, and C is 100 percent *ad libitum* feeding).

Table 49.--Prediction equations from flounder growth data

P. dentatus			*P. lethostigma*		
Term	Growth rate	Growth efficiency	Term	Growth rate	Growth efficiency
b_0	-0.17861612	-2.45174877	b_o	-0.26757977	-1.84972544
b_1	0.01762818	0.16622773	b_1	0.01190012	0.08128449
b_{11}	-0.00051993	-0.00366278	b_{11}	-0.00027215	-0.00090891
b_2	0.00249264	0.04408608	b_2	0.00577794	0.02689929
b_{22}	-0.00006881	-0.00060104	b_{22}	0.00000742	-0.00019050
b_{12}	-0.00008658	-0.00112342	b_{12}	-0.00019316	-0.00087424
b_3	-0.00134484	0.01812773	b_3	0.00175287	0.02933646
b_{33}	-0.00000863	-0.00016282	b_{33}	-0.00002005	-0.00014265
b_{13}	0.00014780	0.00021536	b_{13}	0.00015400	-0.00031726
b_{23}	0.00004345	0.00010662	b_{23}	-0.00004157	-0.00001183

THE EFFECT OF RADIATION, SALINITY, AND TEMPERATURE ON THE IONIC REGULATION OF THE BLUE CRAB, *Callinectes sapidus*

D. W. Engel, E. M. Davis, J. W. Angelovic
and D. E. Smith[1]

In an estuary, temperature and salinity largely characterize the physicochemical properties of the water and to a large extent determine the species diversity. Estuarine waters and the waters entering estuaries are being used increasingly by the nuclear power industry and other industries for discharges of waste heat and radioactive materials; temperatures, salinities, and levels of radioactivity in these estuaries are changing. Thus, the interactions of salinity, temperature, and radiation may materially affect the ecology and species diversity of an estuarine system.

In the study of effects of radiation on estuarine organisms, the influence of the environment must be evaluated carefully. Since osmoregulatory ability is necessary for survival in the estuary, any additional stress which causes alterations in the ability to regulate the internal environment in relation to the external one will reduce survival. Reduced survival occurs when the environmental factors,

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radiation, temperature, and salinity, interact to have either a synergistic or antagonistic effect on the organisms (Angelovic, White, and Davis, 1967; Angelovic and Engel, 1967; and Engel, 1967). The interactions of these variables have been demonstrated vividly with the mummichog (Angelovic, et al., 1967) where they affected mortality, LD_{50}, and sodium efflux. At the upper limit of their temperature range, mummichog tolerated more radiation at low salinity, and at the lower limit of their temperature range the pattern was reversed. Salinity and temperature also affect the survival of irradiated and unirradiated brine shrimp (Angelovic and Engel, 1971).

The blue crab, Callinectes sapidus, used in these experiments is a euryhaline and eurythermal estuarine decapod crustacean, known to be a good hyperosmotic regulator at low salinity and hyposmotic at full strength sea water (34-36 o/oo) (Ballard and Abbot, 1969; Tan and Van Engel, 1966; Mantel, 1967; and Grifford, 1962). The osmoregulatory abilities of the blue crab follow the patterns which have been established for other euryhaline crustaceans such as Eciocheir sinenis (Potts and Parry, 1964), Rhithropanopeus harrisi (Smith, 1967), Pachygrapsus crassipes (Rudy, 1966), and Ocypode albicans (Gifford, 1962). In these species the ionic concentration of the blood determines the osmotic pressure, because in the blood of these crabs the major osmotic effectors are ions rather than organic molecules such as free amino acids. In the tissues however, the free amino acids play a major role in osmoregulation while the inorganic ions are less important.

The purpose of this investigation was to determine the effect of a single acute dose of gamma radiation along with different salinities and temperatures on the ionic regulation of the blue crab, *Callinectes sapidus*. The experiments involve three temperatures and two salinities which give information on the effects of salinity and temperature and salinity-temperature-radiation interactions on ionic regulation of the hemolymph of the blue crab.

Methods and Materials

The blue crabs were collected in the Newport River estuary of North Carolina. All crabs used were immature ranging in size from 6 to 10 cm carapace width to minimize sex-linked physiological differences which may occur following maturation. After capture the crabs were maintained in the laboratory in flowing sea water until they were used in an experimental series.

Experiments were performed with sea water at two salinities (5 and 35 o/oo) prepared with commercial sea salt and three temperatures (12°, 20°, and 28° C). Salinity measurements were made with an induction salinometer with an accuracy of ± 1.5 o/oo. Temperature was regulated to within ± 2° C in constant-temperature rooms.

Acclimation of crabs required 2 weeks for temperature and 1 week for salinity. The crabs were placed in individual containers at 20° and 28° C to protect against cannibalism but at 12° C cannabalism did not occur due to the slower metabolic rate, and the crabs were maintained in groups. Salinity acclimation of the crabs at low temperature required 3 weeks instead of the usual 1 week because rapid downward shifts in salinity resulted in death, presumably due to osmotic failure.

Crabs were irradiated in a ^{60}Co irradiator which had a dose rate of 200 Rad/min ± 10 percent and an irradiation chamber 6" X 6" X 12", in which the dose varied 10 percent. During irradiation the crabs were held in a lucite container supplied with aerated sea water at the appropriate salinity and temperature. The experimental crabs were given a dose of 10,000 Rad which is in the sublethal range (Engel, 1967). The control animals were treated in a similar fashion, but were not irradiated. After irradiation, the crabs were returned to their containers and held at the prescribed salinity and temperature.

Crabs were chosen at random for sampling of hemolymph at 1, 4, 7, 14, and 28 days after irradiation. Hemolymph samples were obtained by severing the pleopod or the modified fourth leg at the merus. The hemolymph was collected in a clean, 3-ml, centrifuge tube, allowed to clot, and then centrifuged in a Sorvall RC-2 centrifuge at 16,000 X g for 20 minutes at 4° C. The supernatant serum was then used for the determination of ions (Na^+, K^+, Cl^-, and Mg^{++}) and free amino acids.

To prepare for the analysis of ions, the hemolymph was diluted 500 fold (0.1 ml of hemolymph into 50 ml of dionized water) to achieve levels of ions which could be measured accurately. The dilution for the extraction of free amino acids from the hemolymph was 4 fold in 95 percent ethyl alcohol (0.1 ml hemolymph into 0.3 ml 95 percent ethyl alcohol) with the final dilutions dependent upon the levels of amino acid present in the hemolymph samples.

Hemolymph samples were analyzed for Na^+, K^+, and Mg^+ ions using a modified clinical procedure and an atomic absorption spectrophotometer (Perkin-Elmer, model 303). The diluted hemolymph samples were compared to a set of appropriate standards and the results are reported as mEq (milliequivalents) per liter of hemolymph. The chloride concentration of the hemolymph was measured with a chloride titrator. Here the measurement was done with undiluted serum, and the results are reported as mEq per liter of hemolymph.

Total free amino acid content or, more correctly, ninhydrin positive substance (NPS) was measured in the hemolymph using the method of Lee and Takahashi (1966). The free amino acids were extracted with 95 percent ethonol, and the resultant extractant was subjected to colorimetric analysis. The resultant values were compared against an alanine standard, and the values are reported as μ M/liter of hemolymph.

There were significant effects of radiation, temperature, and salinity on the ionic regulation and free amino acid content of the hemolymph of the blue crab, Callinectes sapidus. In general temperature and radiation caused significant effects as shown by two way analyses of variance at each salinity. At the high salinity of 35 p.p.t. both temperature and radiation had effects significant at the 99 percent level of confidence for Na^+, K^+, and Mg^{++} with no significant interactions. Chloride and free amino acids also showed significant temperature and radiation effects but had significant interactions. A one way analysis of variance of Cl^- and free amino acids showed radiation to be significant at each of three temperatures. At the low salinity, 5 p.p.t., there were significant radiation induced changes in the hemolymph of crabs for some temperatures. There were significant effects for Na^+, K^+, Cl^-, and Mg^{++}, but not for the total free amino acids.

The regulation of the Na^+ ion concentration in the hemolymph of irradiated blue crabs was affected by salinity as well as temperature (fig. 42). The differences in Na^+ concentration between the crabs maintained at 5 and 35 p.p.t. remained constant throughout the period of the experiment. The effects of irradiation on Na^+ concentration

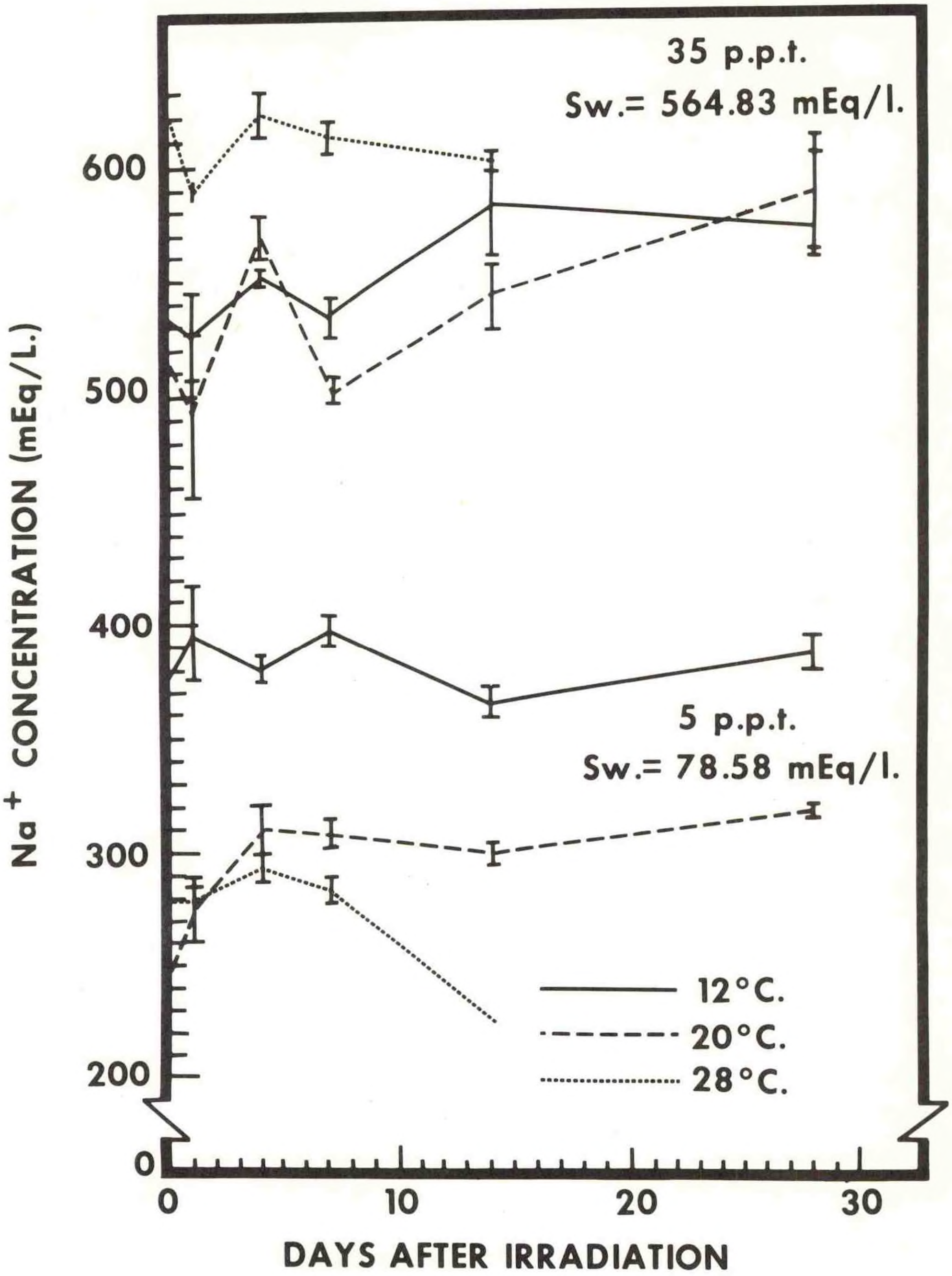

Figure 42.--The effects of salinity and temperature on the concentration of Na$^+$ in the hemolymph of unirradiated and irradiated blue crabs. Control values are plotted at time zero with the vertical bars at each point representing plus or minus one standard error. Sw. means sea water concentration.

at 12° C were different at 5 and 35 p.p.t. At the high salinity there was a slight increase in concentration with time after irradiation despite some fluctuations, while at the low salinity radiation had no effect upon Na^+ concentration throughout the experiment. At 20° C the pattern of response was basically the same at 5 and 35 p.p.t. The Na^+ concentration increased with time after irradiation in both cases despite some wide fluctuations at 35 p.p.t. The large peak on the 7th day was probably due to a passive influx of Na^+ caused by radiation damage to the gills. The crabs at 28° C and 5 p.p.t. had similar patterns of response, but the decrease after the 14th day was more pronounced at 5 p.p.t, where osmotic failure occurred at or around the 14th day after irradiation. The point at 14 days is from a single individual and is presented to demonstrate that the cause of death was probably osmotic failure.

The potassium levels in the hemolymph of blue crabs at the two salinities and the three temperatures change with time after irradiation, but following irradiation there was a reduction in the effect of salinity (fig. 43). At 35 p.p.t. the K^+ concentration in the hemolymph of crabs decreased at all three temperatures during the first day after irradiation increased through the seventh day, and then remained relatively stable in the crabs at 12° and 20° C, but decreased sharply in those at 28° C. At 5 p.p.t. and 12° C the pattern of response was basically the same as at 35 p.p.t. At 20° C there was a steady

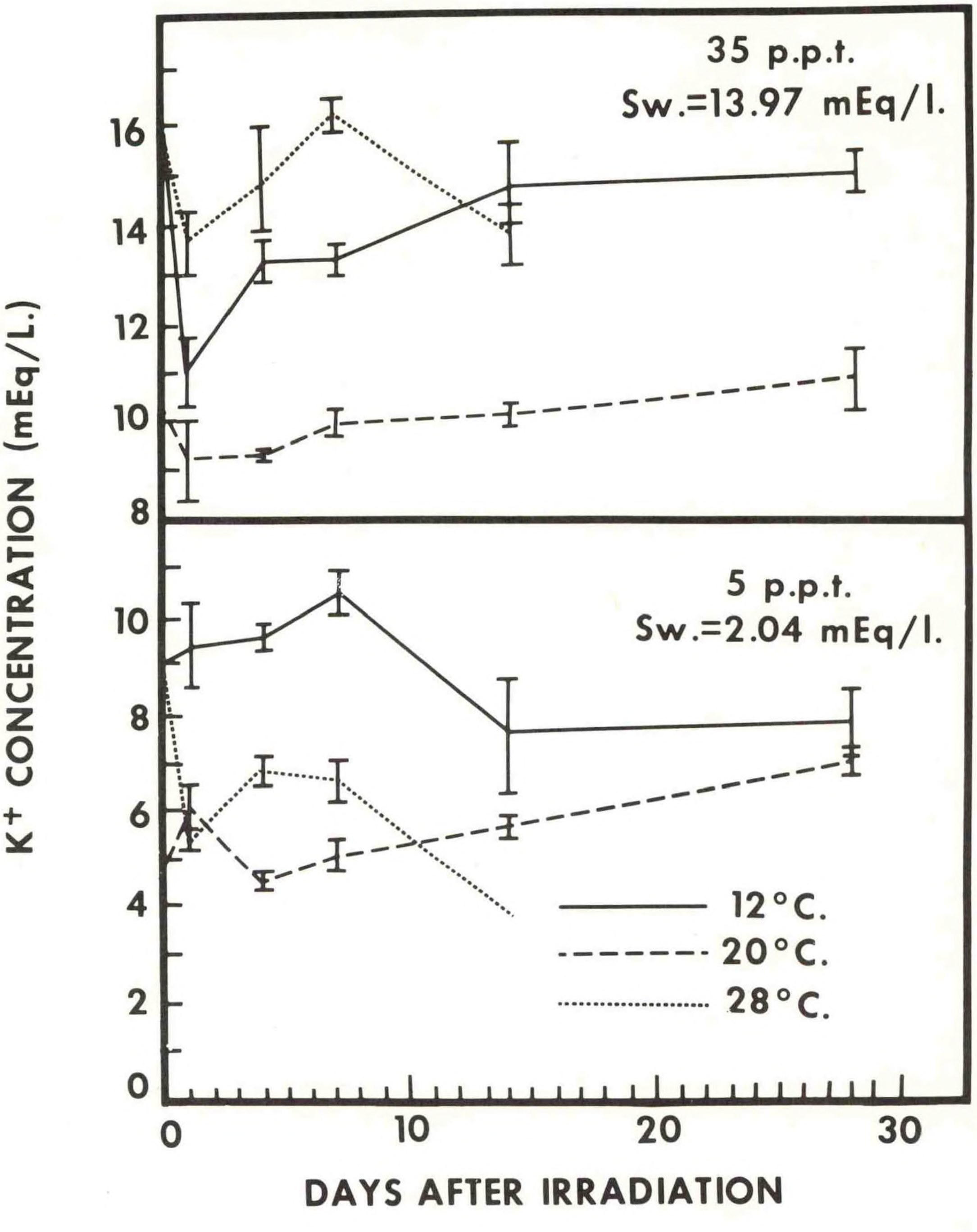

Figure 43.--The effect of salinity and temperature on the concentration of K^+ in the hemolymph of unirradiated and irradiated blue crabs. Control values are plotted at time zero and the vertical bars represent plus or minus one standard error. Sw. means sea water concentration.

increase in K^+ level from the 4th through the 28th day following some initial fluctuation. The animals maintained at 28° C had an almost 50 percent decrease in K^+ concentration in the hemolymph during the 1st day after irradiation, followed by an increase through the 7th day, and a great decrease on the 14th day. The patterns of response for Na^+ and K^+ are similar, and particularly those at 12° C and 5 p.p.t.

The effects of radiation, temperature, and salinity on the regulation of chloride ion in the hemolymph of the blue crab were different for each of the temperatures used, but the differences in patterns between the two salinities were not great (fig. 44). At 35 p.p.t. and 28° C, there were large changes in the Cl^- concentration in the hemolymph of the crabs, with a decrease on the 1st day followed by a large increase on the 4th day, and then a decrease to the control level on the 7th day where it remained. The cause of the large increase was probably the passive influx of Cl^-. At 5 p.p.t. and 28° C the level of Cl^- increased through the 4th day after irradiation and then decreased sharply. The pattern of response for the crabs at 20° C was the same at 5 and 35 p.p.t. with increasing levels of Cl^- through the 14th day followed by a decrease on the 28th day after irradiation. The Cl^- concentrations in the hemolymph of irradiated crabs at 12° C and 5 and 35 p.p.t. did not have similar response patterns to irradiation. At 35 p.p.t. radiation significantly affected Cl^- concentration,

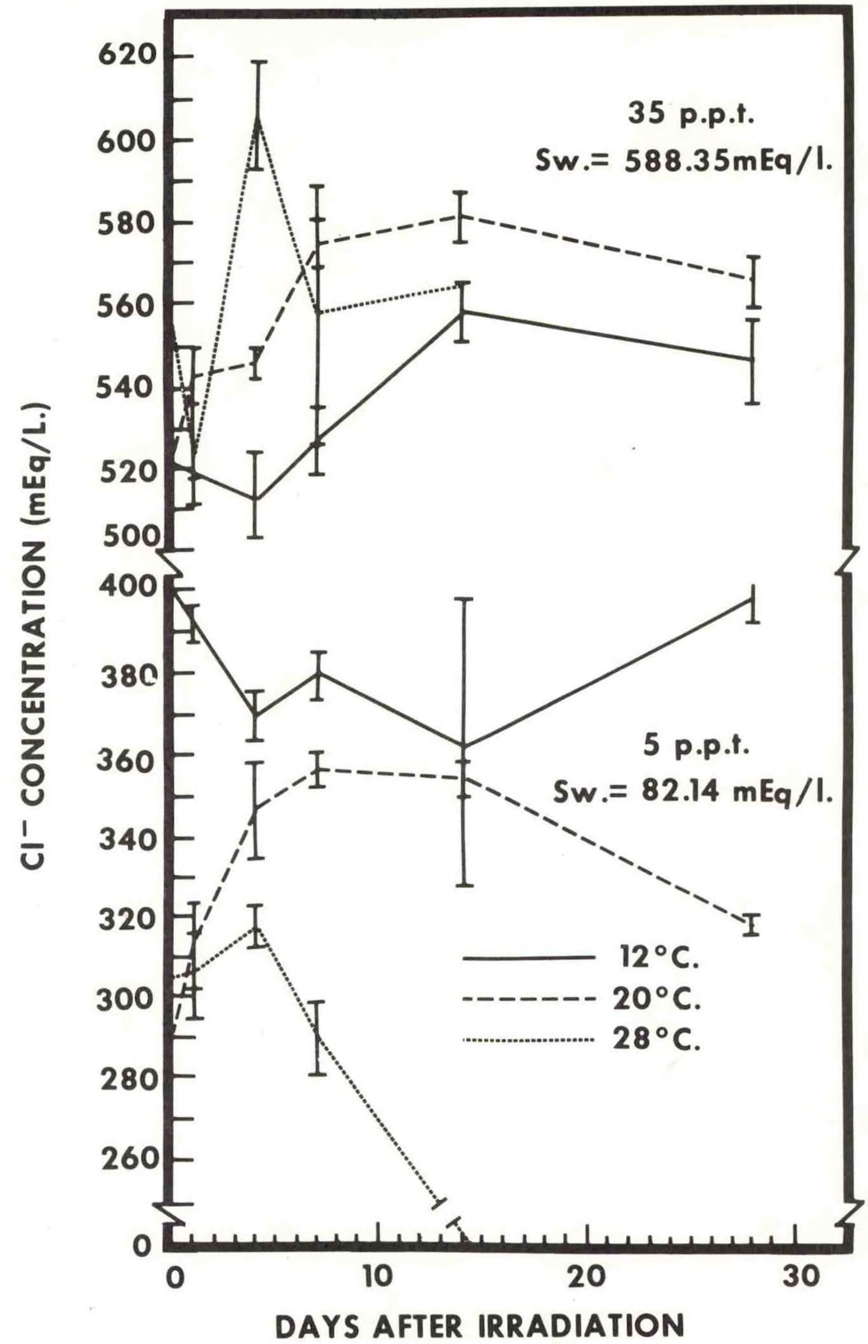

Figure 44.--The effect of salinity and temperature on the concentration of Cl⁻ in the hemolymph of unirradiated and irradiated blue crabs. Control values are plotted at time zero and the vertical bars represent plus or minus one standard error. Sw. means sea water concentration.

while at 5 p.p.t. the effects of radiation on Cl^- concentration were slight. However, the high initial level of Cl^- at 5 p.p.t. and 12° C indicates that this salinity-temperature combination caused an active uptake of Cl^- from the medium, but the mechanism of uptake was not as sensitive to radiation as the one of elimination which operates at high salinity.

The magnesium concentration of the hemolymph of the blue crabs at all three temperatures and both salinities varied greatly after irradiation (fig. 45). At 35 p.p.t. and 12° and 28° C there was no generalized pattern to the radiation response. At 20° C there was an overall increase in the level of Mg^{++} in the hemolymph throughout the experiment, reaching the maximum level by the 28th day. The levels of Mg^{++} in the hemolymph of crabs at 5 p.p.t. and 12° and 20° C were basically the same following irradiation from the 1st through the 28th day. At 28° C the response pattern was the same as described for the other ions.

Changes in the pool of free amino acids or ninhydrin positive substance (NPS) in the hemolymph of blue crabs after irradiation were followed at the two salinities and three temperatures (fig. 46). There was a lack of correlation between levels of NPS in the hemolymph and salinity for all three temperatures. At 12° C the response patterns of NPS were basically the same at two salinities, but there were large differences in the magnitude of the effects.

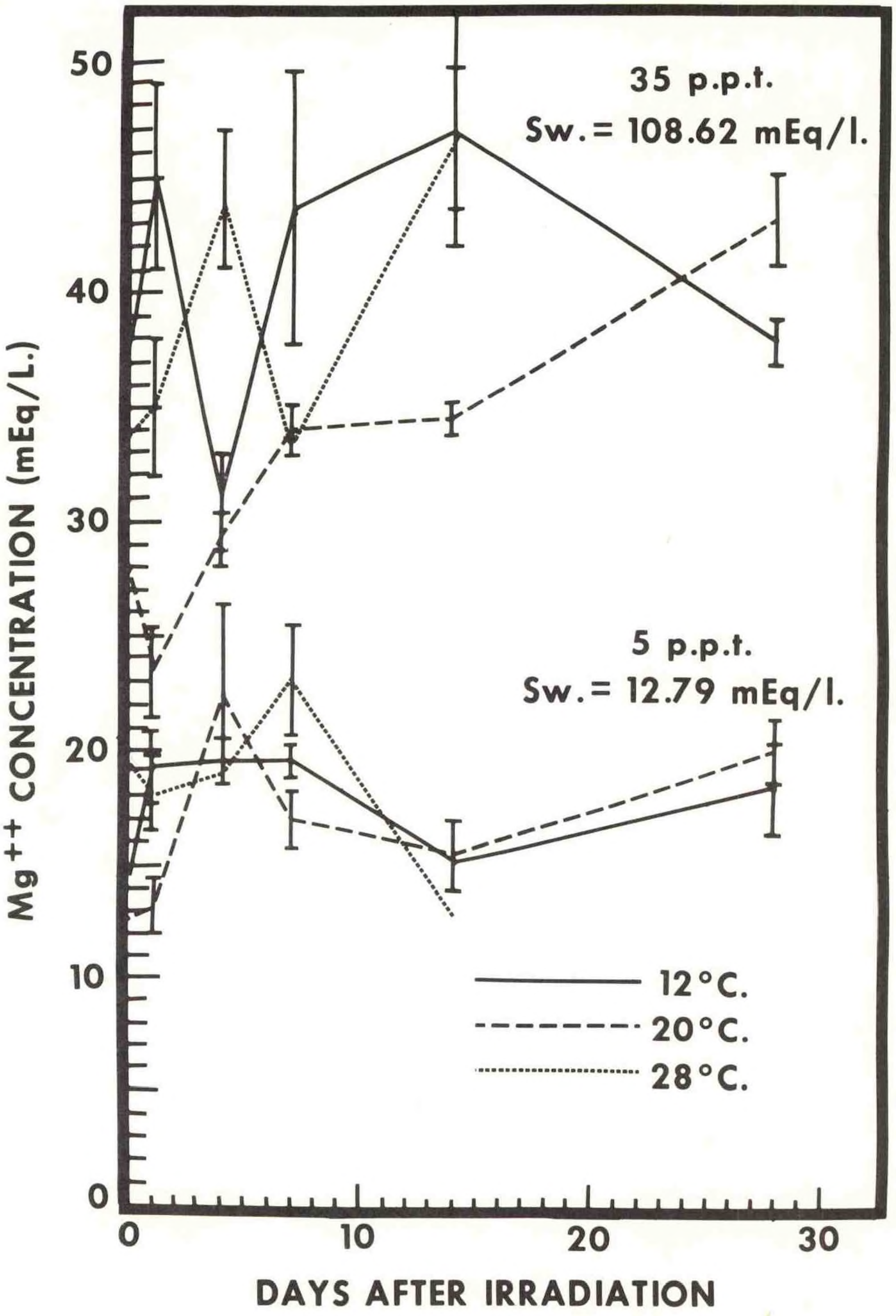

Figure 45.--The effect of salinity and temperature on the concentration of Mg^{++} in the hemolymph of unirradiated and irradiated blue crabs. Control values are plotted at time zero and the vertical bars represent plus or minus one standard error. Sw. means sea water concentration.

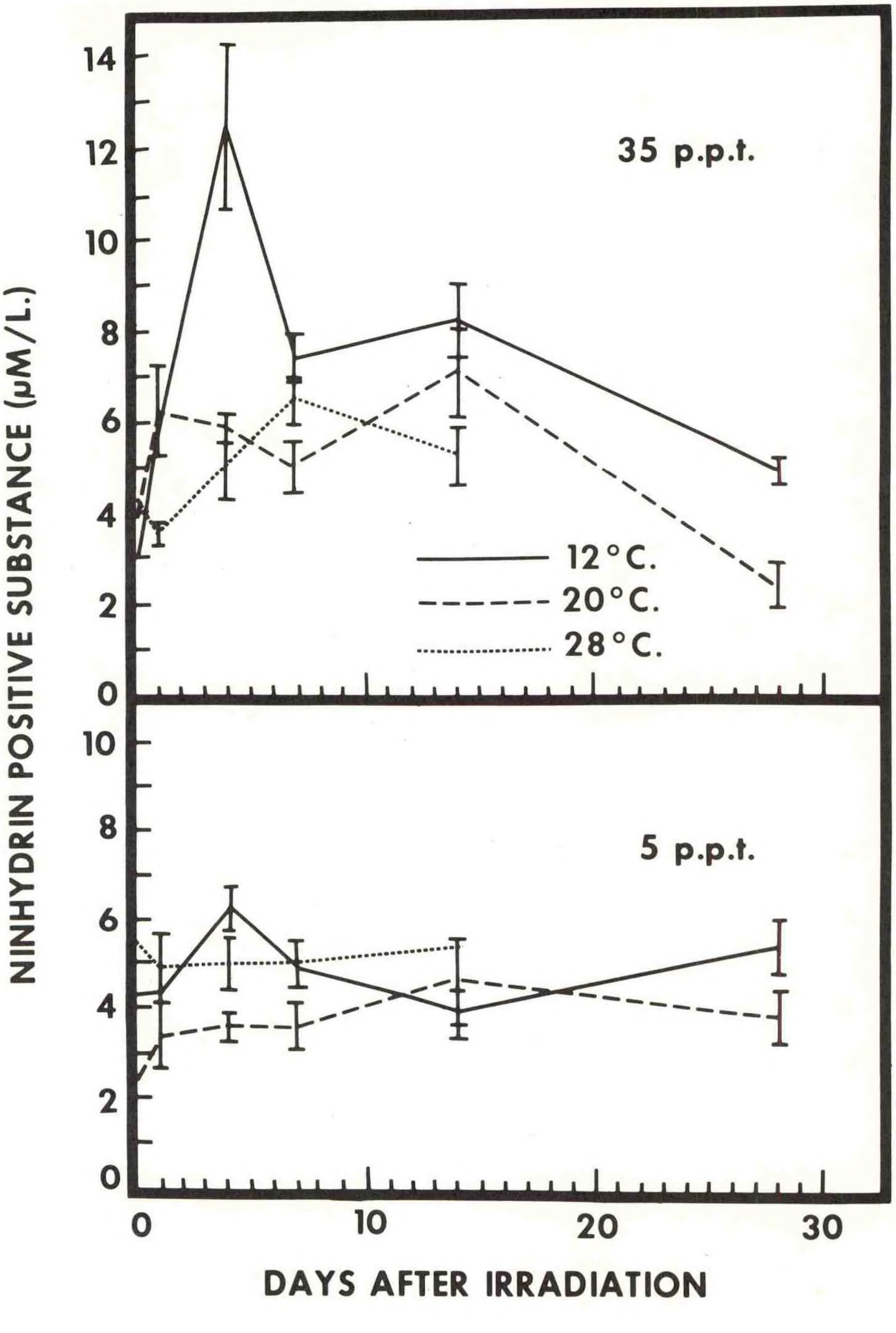

Figure 46.--The effect of salinity and temperature on the concentration of NPS in the hemolymph of unirradiated and irradiated blue crabs. Control values are plotted at time zero and the vertical bars represent plus or minus one standard error.

The large peak at the 7th day at 12° C and 35 p.p.t. was probably caused by leakage of free amino acids from the tissues where the level of NPS is about 40 times that of the hemolymph. At 20° C and 35 p.p.t. there was an initial increase in NPS which remained constant through the 14th day and then decreased on the 28th day, but at 5 p.p.t. time after irradiation had virtually no effect on NPS levels. The NPS levels following irradiation at 28° C fluctuated about the control value at both 35 and 5 p.p.t. An interesting fact is that the decreases in ion concentrations which occurred at 5 p.p.t. and 28° C did not occur with NPS.

The survival of euryhaline, eurythermal aquatic organisms depends upon a complex interrelationship between the organism and its environment, both thermal and ionic. This balance is disrupted by the introduction of the stress of ionizing radiation. Once the ionic and thermal integrity of the organism is destroyed, the animal must compensate physiologically to survive. This compensation typifies the response of the blue crab to ionizing radiation in conjunction with different combinations of temperature and salinity.

The overall response of the blue crab to irradiation was an increase in Na^+, K^+, and Cl^- in the hemolymph with time after irradiation. The trend toward increase in ionic concentration occurs both at high salinity, 35 p.p.t., and at low salinity, 5 p.p.t. At the high salinity the increased level of ions is most probably caused either by radiation damage to the active transport system which eliminates ions from the hemolymph to keep it hypotonic to the medium, or by damage to the cell membranes of the gills which allows an influx of ions. In either case there would be an increase in the levels of ions in the hemolymph. At low salinity where the ion levels in the hemolymph are many times that of the environment, the increases in ion levels must be caused by a radiation induced increase in active transport into the hemolymph. Such a response is not typical, but is the only possibility under these circumstances.

The primary difficulty in trying to explain the interactions of these variables on crustacean ionic regulation is that the effects of each variable on these organisms are not well understood. Therefore further investigations, particularly of thermal and radiation effects on ionic regulation, should be expanded and pursued. Such information would be invaluable in predicting the impact of nuclear power generating facilities on estuarine areas.

References

Angelovic, J. W., and D. W. Engel. 1968. Interaction of gamma irradiation and salinity on respiration of brine shrimp (*Artemia salina*) nauplii. Radiat. Res. 37: 108-117.

Angelovic, J. W., and D. W. Engel. 1970. Effects of radiation on estuarine organisms. Mar. Pollution Bull. 1: 103-105.

Angelovic, J. W., J. C. White, Jr. and E. M. Davis. 1969. Interactions of ionizing radiation, salinity, and temperature on the estuarine fish, *Fundulus heteroclitus*, p. 131-141. *In* D. J. Nelson and F. C. Evans (eds.), *Symposium on Radioecology*. USAEC CONF-670503. Oak Ridge, Tenn.

Ballard, B. S., and W. Abbot. 1969. Osmotic accomodation in *Callinectes sapidus* (Rathbun). Comp. Biochem. Physiol. 29: 671-687.

Engel, D. W. 1967. Effect of single and continuous exposures of gamma irradiation on the survival and growth of the blue crab, *Callinectes sapidus*. Radiat. Res. 32: 685-691.

Gifford, C. A. 1962. Some aspects of osmotic and ionic regualtion in the blue crab, *Callinectes sapidus* and the ghost crab, *Ocypode albicaus*. Publ. Inst. Mar. Sci., Univ. Texas. 8: 97-125.

Lee, V. P., and T. Takahashi. 1966. An improved colorimetric determination of amino acids with the use of ninhydrin. Anal. Biochem. 14: 71-77.

Mantel, L. H. 1967. Asymetry potentials, metabolism and sodium fluxes in gills of the blue crab, Callinectes sapidus. Comp. Biochem. Physiol. 20: 743-753.

Potts, W. T. W., and G. Parry. 1964. Osmotic regulation in brackish waters. Osmotic and ionic regulation in animals, 119-164 p. The Macmillan Co., New York.

Rudy, P. P., Jr. 1966. Sodium balance in Pachygrapsus crassipes. Comp. Biochem. Physiol. 18: 881-907.

Smith, R. I. 1967. Osmotic regulation and adaptive reduction of water-permeability in a brackish-water crab, Rhithropanopeus harrisi (Brachyura, Xanthidae). Biol. Bull. (Woods Hole) 133: 643-658.

Tan, Eng-Chow, and W. A. Van Engel. 1966. Osmoregulation in the adult blue crab, Callinectes sapidus Rathbun. Chesapeake Sci. 7: 30-35.

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THE EFFECTS OF CONTINUOUS LOW LEVEL GAMMA RADIATION ON ESTUARINE MICROCOSMS

Richard B. Williams and Marianne B. Murdoch

Although information on the effects of chronic irradiation on marine organisms is needed to evaluate possible adverse environmental effects of coastal atomic power plants, there has been little research on this problem. The effects of radiation on aquatic organisms have received far less attention than that given terrestrial organisms, and most of these studies on aquatic organisms have examined acute rather than chronic irradiation and have utilized fresh water species rather than marine. Studies on the effects of chronic irradiation on marine organisms appear limited to one species of algae (Rice, et al., 1970), one species of copepod (Williams and Murdoch, 1965), brine shrimp (Grosch, 1962), blue crab (Engel, 1967) and a few fishes (Donaldson, 1969; Donaldson and Bonham, 1964; Polikarpov and Ivanov, 1962; Templeton, 1966; White, 1969). These studies and others on fresh water species have revealed that low levels of chronic radiation, although in general either neutral or damaging to organisms, may in some cases produce enhancement of particular parameters such as growth rate or survival.

It is difficult to extrapolate results obtained with single species into a general evaluation of the effects of low level chronic radiation on marine or other ecosystems. Organisms have fecundity far in excess of that needed to replace the adult population. In all but the most severe environments the number of progeny which survive to maturity reflects primarily stresses placed upon populations by the abundance of their food organisms, competitors, predators and parasites -- rather than direct environmental stresses like temperature or radiation. Small differences between species in sensitivity to radiation might be almost undetectable in single species experiments, but may permit one species to out-compete and eliminate another from mixed populations exposed to radiation (Blaylock, 1969). Chronic irradiation leads to a simplification of terrestrial ecosystems by elimination of the most sensitive species (Garrett, 1969; Woodwell, 1962). This simplification may permit less sensitive species to increase in abundance. Low level chronic irradiation of soil invertebrate populations for example caused some species to multiply apparently because the predators were more susceptible than prey organisms (Edwards, 1969). It is therefore likely that low levels of radiation in general will not modify aquatic ecosystems directly by obvious damaging of organisms but rather will act indirectly by altering to various degrees the relative ability of species to survive and thus change the abundance of species within an ecosystem. There appears to be no previous research on this aspect of chronic irradiation of marine ecosystems.

This paper summarizes the results of several preliminary experiments in which small marine communities were exposed to low level gamma radiation for periods of 10 to 14 months. The rates of irradiation, 0.040 to 3.30 rad/hr, although very high when viewed from the standpoint of human safety, are lower than those generally used in radiation experiments on fish and invertebrates and possibly are low enough to have relevance to environmental problems. Our general approach consisted of setting up a number of similar communities and maintaining these at several levels of radiation under otherwise similar environmental conditions. At the end of an experiment we analyzed the communities and sought correlations between the parameters measured and the radiation dose received. Throughout these experiments we were aided by the advice and assistance of many individuals at the Center for Estuarine and Menhaden Research. Special thanks are due Dr. Austin B. Williams, University of North Carolina Institute of Marine Sciences, who identified an amphipod for us and Dr. I. E. Grey, Duke University Marine Laboratory, who identified many of the other invertebrates.

Methods

Our experiments were run in a fully enclosed radiation room at the Center for Estuarine and Menhaden Research. Gamma irradiation was obtained from a ^{60}Co source with an intensity at the start of our experiments, January 1970, of 4.0 ± 10 percent rad/hr at a distance of 1.0 m. Radiation was measured with a 250 rad Victoreen ionization chamber. We exposed marine communities to various levels of radiation by placing them at different distances from the source. Control communities were maintained in the same room largely shielded from radiation behind a concrete wall 40 cm thick. In calculating the radiation reaching the communities relative to that measured at 1.0 m, we treated the cobalt source as a point source. We also made corrections for attenuation of radiation by passage through air, water, and concrete. Radiation reaching motile organisms in an aquarium was considered equal to the average radiation passing through a plane at the midpoint of the aquarium.

During our experiments the communities were irradiated continuously except when the radiation room was entered to maintain equipment and examine the communities. On a weekly basis the percentage of time that communities were exposed to radiation ranged from 55.5 to 99.9 percent. For the entire duration of the experiments, communities were exposed to radiation at least 96.7 percent of the time. We calculated total radiation reaching our communities during the experiments and the average rates of irradiation from the initial rates of irradiation, the decay rate of ^{60}Co and percentages of time that the source was exposed. Data on radiation are summarized in table 50.

Table 50.--Chronology of experiments and levels of radiation. Levels of radiation for the fouling experiments are for block faces nearest the source. Controls received 10^{-3} to 10^{-6} rad/hr.

Experiment	Start	End	Duration	Average time exposure	Distance from source	Radiation intensity (rad/hr) initial	Radiation intensity (rad/hr) average	Total radiation received
			Days	Percent	M	Rad/hr		Rad x 10^2
Microcosms	13 Jan. 1970	3 March 1971	415	96.7	1	2.14	1.92	191
					2	.46	.41	41
					3	.19	.17	17
					4	.10	.090	9.0
					5	.060	.054	5.4
					6	.040	.036	3.6
First fouling	29 Jan. 1970	6 Apr. 1971	433	96.9	1	3.30	2.96	308
					2	.67	.60	62
					4	.14	.13	13
					6	.055	.049	5.1
Second fouling	11 June 1970	6 Apr. 1971	300	98.5	1	3.14	2.94	212
					2	.63	.59	42
					4	.13	.12	8.9
					6	.052	.049	3.5

Microcosms

We set up two types of marine communities, microcosms with estuarine water, sediment and included organisms, and fouling communities of preeminently sessile organisms maintained in running water. Our 29 microcosms consisted of plastic pails (35 cm high x ca. 27 cm diameter) each containing 11 liters of unfiltered water and 1/3 liter of sediment from the Beaufort Channel. This unfiltered water contained phytoplankton, copepods and a few chaetognaths. The salinity of this water, 34 o/oo, was maintained by adding distilled water to replace that lost by evaporation. The sediment, muddy sand from the lower intertidal zone of a beach near the Center, contained a variety of small molluscs, polychaetes and other invertebrates. The microcosms were aerated and were covered with translucent plastic to reduce evaporation. Water temperature followed air temperature in the radiation room and ranged from 13 C in midwinter to 25 C in late spring. The average was 19 C. Light for photosynthesis was supplied by banks of fluorescent lights hung from the ceiling. Measurements with a Weston exposure meter showed a four-fold range in light reaching the microcosms. Presumably there were also slight differences in spectral composition of this light because the pails were translucent and either white or aqua in color. Three pails (one white and two aqua) were placed at one meter intervals from 1.0 to 6.0 m from the source; there were 11 controls (four white and seven aqua).

We set up the microcosms on January 11, 1970 and started irradiation two days later. To stimulate the growth of phytoplankton we added nitrate (0.88 mg at N/liter) and phosphate (0.036 mg at P/liter) on February 3. After copepods originally present had died out, we established an exotic copepod, Tigriopus californicus, in most of the microcosms by introducing small inocula on March 12 and April 9. Except for superficial examination every two weeks the microcosms were left undisturbed until the experiment was terminated February 10, 1971. Over the following 4 weeks, observations were made on the rate of gross photosynthesis and chlorophyll content of phytoplankton, abundance, taxonomic composition and chorophyll content of the attached algae, abundance of zooplankton, and abundance and taxonomic composition of benthos. Gross photosynthesis was measured by the light and dark bottle method (Strickland and Parsons, 1960). Chlorophyll was extracted from algae with 90 percent acetone and estimated with a Beckman model DU spectrophotometer following the methods of Strickland and Parsons (1960). Phytoplankton for chlorophyll extraction were concentrated by filtering water samples through Millipore fiberglass filters. In each microcosm attached algae were scraped from the sides of the pails in three strips (each 2.2 x 23 cm) extending from the water surface nearly to the sediment. Small portions of the sample from each microcosm were used to determine chlorophyll content and taxonomic composition and the remainder the standing crop. We estimated the abundance of zooplankton by filtering about 10 liters of water from each microcosm through netting with openings 153 μ square and counting the plankters retained. We separated benthic organisms from sediment by sieving it through a screen with openings 2 mm square.

Fouling Communities

Our first group of fouling communities were prepared on January 29, 1970 by merely immersing concrete blocks (58 x 93 x 194 mm) in opaque plastic pails of aerated running sea water exposed to various levels of radiation. There were two pails at 1.0, 2.0, 4.0 and 6.0 m from the source and two controls. The concrete blocks were wrapped in pairs with opaque sheet polethylene which covered only the sides and left two large faces exposed. The blocks were oriented with the exposed faces at right angles to the radiation. This eliminated growth of organisms on the sides of the blocks where radiation dose would be hard to estimate and yielded two levels of radiation for each pail because the back face of each pair of blocks received 18.7 percent of the radiation reaching the front. The pails were covered to exclude light and thus minimize growth of algae. The communities which developed on the blocks were left undisturbed save for a superficial examination every 2 weeks.

The temperature of our running sea water was approximately that of the Beaufort Channel from whence the water was pumped and ranged from 5 C to 25 C. The average was 16 C. The flow of water differed markedly from pail to pail and from time to time due to variable clogging of the lines. Since the flow of water was a factor which might affect community development, rates were measured during our biweekly inspections before and after unclogging the lines. Flow rates ranged from 0 to 5.0 liters/min and averaged 1.7 liter/min. Average values for the individual pails ranged from 2.1 to 1.2 liter/min. Salinities in the Beaufort Channel range from ca. 20 o/oo to 35 o/oo and average ca. 29 o/oo.

When it became obvious after 4 months that settlement of organisms on all the blocks was very slow and that the developing communities remained sparsely populated we prepared a second group of communities in generally the same manner as the first. This second group, however, was given a dense coating of organisms before exposure to radiation by soaking the wrapped pairs of blocks for 10 days in an open basket suspended in the Beaufort Channel. The blocks were moved to the radiation room on June 11, 1970 and one pair placed in each of the 10 pails already in use with the first group.

Over the three weeks following termination of these experiments on April 6, 1971 we measured the respiration associated with each block, identified, counted and in some cases measured the attached organisms, and determined the dry weight of organisms which could be scraped from the exposed surface. Blocks were held in running sea water between these measurements. Respiration was estimated by placing individual blocks in large sealed containers of sea water, saturated with oxygen, measuring the loss in dissolved oxygen over 24 hr and subtracting the average respiration of controls of sea water alone. Water temperature was maintained at about 15 C by placing the containers in running sea water. Oxygen concentrations were measured by Winkler titration.

Results

None of our experiments showed any striking and immediately obvious differences between communities correlated with level of radiation either during the superficial inspections or in the final detailed analyses. Instead the communities displayed a large measure of apparently random variation. Statistical analyses of our observations were required to identify apparent effects of radiation on the communities.

Microcosms

Initially the microcosms showed similar behavior. There was no visible growth of phytoplankton or attached algae. Copepods and chaetognaths were not observed in most of the microcosms after the first 2 weeks and entirely disappeared within the next 2 weeks.

Our manipulations of the microcosms, however, created more dynamic communities. Within a week after the addition of nutrients, 18 microcosms had phytoplankton blooms and all had growths of attached algae. Blooms persisted for up to 6 months and often reappeared one or more times. All but two microcosms eventually had a phytoplankton bloom. Growths of attached algae consisting largely of pennate diatoms and coccoid and filamentous bluegreen algae persisted throughout the remainder of the experiment in all microcosms. In a few microcosms *Ectocarpus* was abundant during the latter half of the experiment. Grazing by nudibranchs temporarily slowed the development of attached algae in some microcosms, but these grazers disappeared in a few months. The exotic copepod, *Tigriopus*, which became abundant in 18 microcosms within 4 weeks after the first inoculation, was established for some period in all microcosms and persisted to the end of our experiment in all but four.

Slight disturbances in the sediment indicated the presence of benthos throughout most of the experiment in all microcosms. At the end of the experiment benthos were present in all but three microcosms. These benthos were preeminently bivalve molluscs and polychaetes. There were also a snail, an echiurid and an isopod. Taxa of benthos are listed in table 51.

Table 51.--Benthic organisms persent at termination of the microcosm experiment.

Polychaeta
- *Clymenella torquata*
- *Glycera* sp.
- unidentified sp.

Echiurida
- *Thallesema* sp.

Bivalva
- *Abra aequalis*
- *Chione cancellata*
- *Corbula* sp.
- *Macoma tenta*
- *Mercenaria mercenaria*
- *Nucula proxima*
- *Tellina alternata*
- *T. versicolor*

Gastropoda
- *Retusa canaliculata*

Isopoda
- *Cyathura* sp.

We calculated correlations between 23 parameters relating to the microcosms (Table 52) and found radiation significantly correlated with five of our dependent variables. The other two independent variables, illumination and pail color, had negligible correlations with radiation and few significant correlations with the 20 dependent variables. Wet weight of attached algae, not surprisingly, had a significant correlation with illumination. The abundance of molluscs and of benthos were significantly correlated with pail color for no obvious reason.

Since many of the dependent variables were highly correlated with each other and effectively measured the same thing, we reduced their number to eight (Table 52) and calculated partial correlations with radiation as well as correlations between all variables. Our eight dependent variables covered the four main groups, phytoplankton, attached algae, zooplankton and benthos, and were relatively uncorrelated with each other. Radiation had significant partial correlations with phytoplankton gross photosynthesis and with one measure of zooplankton abundance. The significant partial correlations of radiation with gross photosynthesis and zooplankton abundance at the end of the experiment did not represent consistent trends but rather were both the result of single very large values at the highest radiation level. We concluded that no effects clearly related with radiation were detected by our measurements.

Table 52.--Parameters used in statistical analysis of the microcosm experiment. Asterisk indicates parameters used in calculating partial correlations.

Independent variables

*Radiation (rad/hr)
*Illumination (relative values)
*Pail color (0 = aqua, 1 = white)

Dependent variables

Phytoplankton

*Daily gross photosynthesis (mg O_2/liter)
Chlorophyll *a* (mg/liter)

Attached algae

Dry weight (mg/cm^2)
*Wet weight (mg/cm^2)
Dry weight/wet weight
Chlorophyll *a* (μg/cm^2)
*Chlorophyll *b* (μg/cm^2)
Chlorophyll *c* (μg/cm^2)
**Ecotcarpus* abundance[1]

Zooplankton

*Number at end exp. (/10 liter)
*Average abundance[2]

Benthos

Mollusc wet weight (g/microcosm)
Worm[3] wet weight (g/microcosm)
Total wet weight (g/microcosm)
Molluscs (number/microcosm)
Worms (number/microcosm)
Total benthos (number microcosm)
*Mollusc species (number/microcosm)
*Worm species (number/microcosm)
Total species (number/microcosm)

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[1] Subjective estimates of abundance: 0 = absent, 1 = rare, 2 = common

[2] Average of subjective estimates of abundance made during biweekly inspections: 0 = none visible, 1 = few found only by careful searching, 2 = few immediately visible, 3 = many immediately visible.

[3] Annelids plus echiurids.

First fouling experiment

For unclear reasons the first group of 20 concrete blocks never developed the dense growth of sessile invertebrates which largely covered the exposed faces of the second group. A few tube-forming amphipods appeared after the blocks had been in running sea water 6 weeks and were not joined by other organisms for another 10 weeks. At this time tunicates started growth on most of the blocks and erect bryozoans on a few. Blocks lacking such growths were all at lower levels of radiation. These growths increased briefly and then began to disappear at about the time the second group of blocks were added to the pails. By late August, 7 months after the start of the experiment, the blocks were largely bare of conspicuous organisms save for scattered amphipod tubes and a few tunicates. This condition persisted for the remainder of the experiment. Our detailed examination at the end of the experiment revealed a moderate number of inconspicuous organisms, very small tunicates, sponges and the like. Taxa are listed table 53. Growth, however, was so sparse overall that measurable weights of organisms could be scraped from only seven of the 20 blocks.

Our observations on the fouling communities present at the end of the experiment were pooled into 13 categories (Table 54). None of these parameters was significantly correlated with radiation and only one, respiration, was significantly correlated with the other independent variable, average rate of water flow. There were also no significant

Table 53.--Organisms present at termination of the fouling experiments.

Description	Taxonomic group	Experiment
	Sessile	
Brown sponge	Unidentified	2
Orange sponge	*Halichondrina* sp.	2
White sponge	*Leucosolenia* sp.?	1,2
Green sponge	*Aplysilla* sp.	2
Colonial hydroid	Unidentified	1,2
Sea anemone	*Aiptasia* sp.	1,2
Coral	*Estraeiformis* sp.	2
Tube worm	Serpulidae	1,2
Calcareous tube worm	*Eupomatus* sp.	1,2
Small bivalve molluscs	*Chione grus*, *C. cancellata*	2
Yingle shell	*Anomia simplex*	2
Tube-dwelling amphipod	*Corophium lacustre*	1,2
Barnacle	Unidentified	1
Erect bryozoan	Unidentified	2
Encrusting bryozoan	Unidentified	2
Small tunicate	*Perophora viridis*	1,2
Large tunicates	*Ascidia* sp. *Styela plicata*	1,2
Large tunicate	*Molgula manhattenis*	1
Encrusting tunicate	*Didemnum* sp.	1,2
	Motile	
Limpet	*Diadora fissurella*	1,2
Brittlestar	*Ophiopholis aculeata*	1,2
Sea urchin	*Arbacia punctulata*	1,2
Scale worm	*Pholoë* sp.	1,2

Table 54.--Parameters used in statistical analysis of the first fouling experiment. Taxa organisms are listed in table 53.

Independent variables

Radiation (rad/hr)

Water flow (liter/min)

Dependent variables (/ block)

Slime[1] area (cm^2)

White sponge (colonies)

Small tunicate (number)

Large tunicates (number)

Encrusting tunicate (colonies)

Amphipod tubes (number)

Worm tubes (number)

Other invertebrates (number)

Total species (number)

Total individuals[2] (number)

Daily respiration (mg O_2)

Daily respiration (mg O_2/ total individuals)

Dry weight of organisms

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[1] Many of the blocks had patches of tan slime not clearly a part of any invertebrate.

[2] Colonies plus noncolonial organisms.

partial correlations between radiation and the other 14 parameters. If, however, only three parameters, radiation, respiration associated with entire blocks and number of invertebrates (organisms and colonies) on blocks, were considered, there then existed highly significant partial correlations between radiation and the two dependent variables. The partial correlation was 0.56 for respiration and -0.55 for number of individuals.

Second fouling experiment

In contrast to the first group, most of the second group of 20 blocks maintained heavy growths of organisms throughout the experiment and all had substantial growths at the end. The initial coatings largely of pink hearted hydroid, Tubularia crocea, acquired in the Beaufort Channel were replaced by tube-forming amphipods and erect bryozoans within a few weeks following transfer to the radiation room. Seven weeks after the transfer tunicates were obvious, and within 3 months the blocks had diverse faunas. Besides the above organisms there were encrusting bryozoans, scale worms, tube-forming worms, sponges, gastropods and barnacles. By December, 7 months after the start of the experiment, coral, sea anemones and brittle stars were obvious. Organisms found on the blocks at the end of the experiment are listed in table 53. Values for motile organisms such as scale worms and echinoderms were not included in our statistical analysis because their radiation doses were unknown.

Correlations between the 29 parameters evaluated for this experiment (Table 55) revealed that there were no significant relationships between either radiation or water flow and any of the dependent variables. Many of the dependent variables were significantly intercorrelated. Some, e.g., those between the abundances of the dominant species and total dry weight, respiration and number of individuals, were to be expected. Others, e.g., those between two species of sponge, two species of tunicates and a polychaete and a tunicate, were unexpected and may have reflected mutualistic relationships. To calculate partial correlations with radiation we reduced the dependent variables to 13 which represented all the major groups and were largely uncorrelated with each other (Table 55). There were no significant partial correlations with radiation. Both respiration associated with the blocks and total number of individuals per block had trivial negative correlations with radiation. Restricting the analysis to seven parameters, radiation, water flow, respiration associated with blocks, total area of sponge, number of coral heads, number of large tunicates and number of jingle shells, produced a significant partial correlation of -0.53 between the latter and radiation.

In view of the scarcity of significant statistical relationships between radiation and our various parameters for the fouling communities and the weakness of the few such relationships detected, we concluded that none of the factors we measured were clearly correlated with radiation.

Table 55.--Parameters used in statistical analysis of second fouling experiment. Taxa of organisms are listed in table 53. Asterisk indicates parameters used in calculating partial correlations

Independent variables

Radiation (rad/hr)
Water flow (liter/min)

Dependent variables (/block)

*Slime area (cm^2)
Brown sponge (cm^2)
Orange sponge (cm^2)
White sponge (cm^2)
Green sponge (cm^2)
*Total sponge (cm^2)
Sponge species (number)
*Sea anemone (number)
Hydroids (colonies)
*Coral heads (number)
*Calcareous tube worms (number)
Tube worms, other (number)
*Amphipod tubes (number)
*Jingle shells (number)
Molluscs, other (number)
Encrusting bryozoans (cm^2)
*Erect bryozoans (colonies)
*Small tunicate (number)
*Large tunicates (number)
Large tunicates (cm^3)
*Encrusting tunicate (cm^2)
Tunicate species (number)
Total species (number)
*Total individuals (number)
Dry weight of organisms (g)
*Daily respiration (mg O$_2$)

Daily respiration (mg O$_2$/g dry wt organisms)

Discussion

The effects of chronic radiation on ecosystems have been approached through laboratory experiments either by measuring changes in growth and survival of individual organisms in response to radiation doses or by examining the effects of irradiation on fecundity and fertility and thus identifying maximum radiation levels which permit survival of populations. Our failure to find any significant effect of chronic radiation at levels up to 3.3 rad/hr appeared consistent with most previous results on growth and survival of individuals. Doses over the range 10^{-1} to 10^{1} rad/hr appeared in general to have little or no harmful effect and sometimes a slight stimulatory effect on marine organisms. Survival of blue crabs was uneffected and growth slightly stimulated by 3.2 rad/hr (5,400 rad total); 7.3 rad/hr also had no effect on survival but slightly retarded growth (Engel, 1967). Growth of pinfish larvae was slightly stimulated by 0.83 and 1.28 rad/hr (865 and 1,335 rad total) at 15 C and slightly retarded by these doses at 25 C (White, 1969). Exposure of the developing eggs of plaice (Templeton, 1966) and salmon (Donaldson, 1969) to radiation doses of 1.1 rad/hr (ca. 485 rad total) and 0.42 rad/hr (820 rad total) respectively did not significantly increase the percentage of abnormal fry. The salmon, which were irradiated from fertilization to yolk sac absorption, had only slightly retarded growth. These results are generally similar to those for freshwater organisms. Cooley and Nelson (1970), for example, reported that a freshwater snail not only survived 25 rad/hr but also showed increased growth at this dose rate. Life span, however, was shortened.

The only claim in the literature of serious damage to individual marine organisms at these or lower levels (Polikarpov and Ivanov, 1961) appeared to contain some experimental error. These authors reported damage, an increased percentage of abnormal fish fry, at ^{90}Sr concentrations as low as 10^{-4} µCi/liter. Calculations by Woodhead (1970) suggested that this concentration exposed their eggs to roughly 10^{-7} rad/hr, a dose slightly less than that received from ^{40}K naturally present in the water.

Although our fouling experiments required no reproduction _in situ_ because populations could have been maintained by larvae carried in the running sea water, the microcosms clearly demonstrated reproduction and population growth of algae and zooplankton exposed to 2.1 rad/hr.

Information in the literature on the maintenance of fecundity and fertility and the survival of populations of marine organisms is less clear cut. Prolonged culturing of the alga, _Nitzschia closterium_, in media containing successively 14.3 and 143 µCi/liter ^{137}Ce had no effect on division rate (Rice, et al., 1970). A culture of the copepod, _Tigriopus californicus_, in 45 µCi/liter ^{137}Ce survived 3 years longer than control cultures (Williams and Murdoch, 1965). Calculations by Woodhead (1970) on the dose rate of fish eggs from ^{137}Ce in sea water suggested that the _Nitzschia_ may have received 0.02 and 0.2 rad/hr (1,700 rad total) and the _Tigriopus_ 0.06 rad/hr. Cultures of brine shrimp, Artemia salina, however, failed to persist in media initially containing 30 μCi/liter ^{32}P or 10 μCi/liter ^{65}Zn (Grosch, 1962). Dose rates to Artemia were not measured but maximum values probably lay in the range 10^{-2} to 10^{1} rad/hr. Populations of the fresh water snail studied by Cooley and Nelson (1970) persisted at 5 rad/hr despite reduced fecundity and fertility, but were exterminated by 10 rad/hr. Thus the persistence of algae and Tigriopus at the maximum levels of chronic radiation used in our experiments is consistent with previous studies. Nothing in the literature precludes the possibility that some of the fouling organisms and some of the benthos in the microcosms were reproducing throughout our experiments, but these experiments neither prove nor disprove the possibility.

References

Blaylock, B. G. 1969. Effects of ionizing radiation on interspecific competition, p. 61-67. In D. J. Nelson and F. C. Evans [eds.], Symposium on Radioecology. USAEC CONF-670503. Oak Ridge, Tenn.

Cooley, J. L., and D. J. Nelson. 1970. Effects of chronic irradiation and temperature on populations of the aquatic snail *Physa heterostropha*. ORNL-4612. (Oak Ridge National Laboratory). 71 p.

Donaldson, L. R. 1969. Low-level chronic irradiation of salmon. Progress report, RL-2056-5. (Univ. Washington, College of Fisheries, Seattle). 9 p.

Donaldson, L. R., and K. Bonham. 1964. Effects of low-level chronic irridiation of chinook and who salman eggs and alevins. Trans. Amer. FIsh. Soc. 93: 333-341.

Edwards, C. A. 1969. Effects of gamma radiation on populations of soil invertebrates, p. 68-77. In D. J. Nelson and F. C. Evans [eds.], Symposium on Radioecology USAEC CONF-670503. Oak Ridge, Tenn.

Engel, D. W. 1967. Effect of single and continuous exposures of gamma radiation on the survival and growth of the blue crab, *Callinectes sapidus*. Radiat. Res. 32: 685-691.

Garrett, A. 1969. Compositional changes of ecosystems during chronic gamma irradiation, p. 99-109. In D. J. Nelson and F. C. Evans [eds.], Symposium on Radioecology. USAEC-CONF-670503. Oak Ridge, Tenn.

Grosch, D. S. 1962. The survival of Artemia populations in radioactive sea water. Biol. Bull. (Woods Hole) 123: 302-316.

Polikarpov, G. G., and V. N. Ivanov. 1962. Injurious effect of strontium-90-yttrium-90 on early development of mullet, wrasse, horse mackerel, and anchovy. A translation of Doklady Akad. Nauk SSSR 144: 491-494.

Rice, T. R., J. P. Baptist, F. A. Cross, and T. W. Duke. 1970. Potential hazards from radioactive pollution of the estuary. Preprint from FAO Technical Conference on Marine Pollution and Its Effects on Living Resources and Fishing. Rome, Italy. FIR: MP/70/E-34. 9 p.

Strickland, J. D. H., and T. R. Parsons. 1960. A manual of sea water analysis. Bull. Fish. Res. Bd. Canada 125: 1-185.

Templeton, W. L. 1966. Resistance of fish eggs to acute and chronic irradiation, p. 847-859. In Disposal of radioactive wastes into seas, oceans and surface waters. International Atomic Energy Agency, Vienna.

White, J. C., Jr. 1969. Interactions of chronic gamma radiation, salinity, and temperature on the morphology of postlarval pinfish, Lagodon rhomboides. M.S. Thesis, North Carolina State Univ., Raleigh, N.C. 37 p.

Williams, R. B., and M. B. Murdoch. 1965. Long-term effects of cesium-137 on a copepod, p. 28-29. In Annual report of the Bureau of Commercial Fisheries Radiobiological Laboratory, Beaufort, N.C., for the fiscal year ending June 30, 1963. U.S. Fish and Wildl. Serv., Circ. 204.

Woodhead, D. S. 1970. The assessment of the radiation dose to developing fish embryos due to the accumulation of radioactivity by the egg. Radiat. Res. 43: 582-597.

Woodwell, G. M. 1962. Effects of ionizing radiation on terrestrial ecosystems. Science 138: 3-8.