Summer 1988

Explorations, Vol. 4, No. 3

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See next page for additional authors

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EXPLORATIONS

A JOURNAL OF RESEARCH AND PUBLIC SERVICE
AT THE UNIVERSITY OF MAINE

Cover: Trophy: MooseHorn, from the Trophy Series, by Caellaigh B. Desrosiers.

EXPLORATIONS, A JOURNAL OF RESEARCH AND PUBLIC SERVICE at the University of Maine, is published by the Office of the Vice President for Research and Public Service at the University of Maine. The magazine's editorial office is located at 28D Coburn Hall, University of Maine, Orono, Maine, 04469. Telephone (207) 581-1506. Third class postage paid at Orono, Maine, 04473. Requests for copies, further information, and letters to the editor may be sent to 28D Coburn Hall, University of Maine, Orono, Maine, 04469. Circulation is 7,000 per issue.

EXPLORATIONS

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Printed by Knowlton & McLeary Co.
Farmington, Maine 04938

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Editorial Reflections

In this issue of EXPLORATIONS, we have included a number of our students in various capacities. Male, female, scientist, artist, writer, physician-alumnus, their interests and experiences are different, and the ways in which they have chosen to lead their lives and pursue their careers are different as well.

Climate, water sources, and the current drought are parts of graduate student Mauri Pelto's work. Working on his Ph.D. in the Institute for Quaternary Studies, he is a glaciologist. He is also Director of the North Cascade Glacier-Climate Project, and as such, measures the mass balance of the North Cascade glaciers. The glacial mass balance which claims his pioneering attention determines the water supply for several states in the Northwestern United States.

We've also included excerpts from award-winning papers of two Ph.D. students working in Botany and Plant Pathology at the University of Maine.

Charles Gregory works with Dr. Bernard McAlice and won Outstanding Student Paper for his symposium presentation, Contribution of the Ciliated Protozoa to the Microplankton Biomass in the Gulf of Maine During 1987, at the April, 1988, spring meeting of the New England Estuarine Research Society meeting in Woods Hole, Massachusetts. Steven R. Dudgeon works with Dr. Robert L. Vadas and Dr. Ian R. Davison. He won Best Student Paper for his presentation, Physiological consequences of freezing to photosynthetic metabolism in the intertidal macroalgae *Chondrus* and *Mastocarpus* in April, 1988, at the Annual Northeast Algal Symposium at Woods Hole, Massachusetts.

Both Gregory and Dudgeon are looking actively at aspects of the Gulf of Maine, a huge but discrete body of water in the North Atlantic Ocean. That body of water is critical to the health of the Northeast and Maritime Canada in terms of fisheries, development, tourism, economics, recreation, aesthetics, and as yet untapped resources. The two small parts of the puzzle researched by the students are widereaching in impact.

In another area of endeavor, our cover was done by a student artist, Caellaigh Bennett Desrosiers, who holds a degree from the University of Maine in Animal and Veterinary Sciences. In her own words, *It seems to startle people that I would, after four years of studying sciences, commit myself to the making of artwork.*

She goes on, *These reactions from others have sparked my realization that I have indeed been straddling two camps, two supposedly different ways of being. Scientific activity is thought to be rational, controlled, and concrete. Artistic activity is thought to be intuitive, spontaneous and subjective. I feel that both these stereotypes are false and limiting, and that serious creative exploration in both art and science would be similar.*

Desrosiers elicits echoes of C.P. Snow's Rede Lecture given at Cambridge in May, 1959. The questions are still relevant. The divisions persist. The need for synthesis and overview becomes increasingly pivotal to civilized survival. Our students are hunting the answers.

We've also included an abstract of a medical research project recently carried out by a young University of Maine graduate. It reflects the discipline and persistence which are marks of University of Maine training.

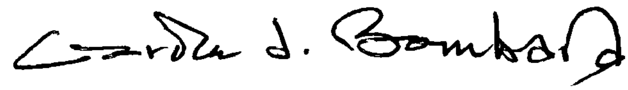
Finally, we have included work by Marcia Gauvin, a graduate student in English who earned her bachelor's degrees in chemistry and biochemistry in 1986 from the University of Maine. With a career goal of combining science and non-fiction writing, Gauvin reflects the recurring student tug toward combining the arts and the sciences. She is serving as student summer assistant to the magazine and bringing a foundation in the sciences to her writing talents. The magazine has benefitted from her work.

These are but a few University of Maine students. They represent different talents, views, values and outlooks. They have assorted goals and worldviews. They enhance the rich mixture of the University intellectually, socially and normatively.

Most importantly, they reflect the pioneer work being conducted at the University of Maine. They are living evidence of an interdisciplinary approach to many efforts, and they retain the best of Maine tradition alongside a respect for change and growth. In many respects, they are being prepared for the global workplace and the global exchange of information which is in many cases critical to the survival of the planet and the species. In some cases they are promising novices; in others they are virtually indistinguishable from the faculty and staff whom we also feature in our magazine.

Our students are tackling some of the eternal questions and mysteries of science and civilization; they are actively addressing major current crises and problems; they are disciplined and focused in their work; they provide a refreshing reminder of the values of mindpower and commitment.

We salute them.



Carole J. Bombard
Editor

Kneeling on Monte Cristo Pass, I am surrounded by snow and cloud. The whiteout prevents my seeing more than a few feet and there is nothing but whiteness. I can feel the strong wind blowing the damp cloud past me, yet there is no sound.

North Cascade Glacier Climate Project

by Mauri Pelto

There are 756 glaciers in the North Cascades of Washington. These glaciers store as much water as all of the state's lakes, reservoirs and rivers, and supply 40 percent of the summer runoff (160 billion gallons) in the region. This runoff is fully utilized for irrigation and hydroelectric power generation.

Since glacier runoff is controlled by climate, climatic fluctuations affect the timing and amount of glacier runoff available. To manage water resources intelligently and avoid depleted reservoirs, changes in glacier runoff must be taken into account. For this reason, I established the North Cascade Glacier-Climate Project in 1983.

Since 1977, the summer temperatures in the Pacific Northwest have been 2 degrees F above normal, and winter precipitation has been 15 percent below normal. To identify the effect of this climatic change on North Cascade glaciers the mass balance and glacier runoff has been monitored on 47 glaciers, and the terminus behavior determined for 107 glaciers.

Mass balance is the amount of ice and snow accumulated on a glacier minus the amount of snow and ice melted from the glacier during a hydrologic year (October-September). Whether a glacier is retreating or advancing is determined by the mass balance. A positive mass balance causes advance, and a negative mass balance due to more melting than accumulation causes retreat. Mass balance fluctuations also control glacier runoff. Cool summers and wet winters cause advances.

After retreating rapidly during the first half of this century, most of the 750 North Cascade glaciers advanced slightly during the 1950s and 1960s. This advance was due to cool summers particularly in 1953-1955 and 1964, and wet winters particularly in 1955 and 1967-69.

North Cascade glaciers maintained an advanced position through the heavy snow year of 1976. Since 1977, in response to the recent warm summers and dry winters, North Cascade glaciers have again begun to retreat rapidly. In the summer of 1987, 91 of 107 glaciers examined had retreated significantly since 1983; only three glaciers had advanced.

The North Cascade Glacier-Climate Project is sponsored by the Foundation for Glacier and Environmental Research headquartered in Moscow, Idaho. As director of this project, each summer I hire geology students from Oregon, Washington and Idaho universities to complete the glacier measurements under my supervision. The goal of this project is to monitor glacier behavior, relate this behavior to climate, and help manage water resources provided by the glaciers.

The primary task above the snowline is to measure the depth and extent of the previous winter's snowpack late in the summer. Winter snowfall averages 500 inches on North Cascade glaciers and by the end of the summer 60 to 100 inches usually remain on a large portion of the glaciers.

Mauri S. Pelto is the Director of the North Cascade Glacier-Climate Project. He is also a student working on a Ph.D. in the Institute for Quaternary Studies at the University of Maine, and cross-country skiing instructor at that institution. He is a glaciologist with research interests in the climatology and hydrology of glaciers, and his work relies considerably on remote sensing.

Pelto seated on the Canada-Alaska boundary on the Juneau Icefield.

The crevassed, advancing front of the Lower Curtis Glacier on Mt. Shuksom, Washington.

The Daniels Glacier, Washington, descending to Pea Soup Lake.

Snow depth is measured by probing and crevasse stratigraphy. Each annual snowlayer in a crevasse is separated by a dirty band marking the previous summer snow surface. A weighted tape measure is lowered into the crevasse to measure the thickness of this layer.

In regions where crevasses are absent, copper probes are driven into the snowpack until meeting the previous summer surface, which the probes cannot penetrate. Crevasses have not been used extensively in any previous studies of glacier mass balance because of the danger they pose. To minimize the risks, only crevasses with vertical walls are used, and all crevasses are approached and measurements completed on skis.

After more than 10,000 measurements, no untoward incidents have occurred. The hardest part of avoiding crevasse accidents is spotting the pencil thin line that is the only surface evidence of many crevasses. Below the surface the crevasses widen from two to 10 feet. Crevasse measurements

A view across the Hubbard Glacier, Alaska.

Crevasses and blue ice near the terminus of the Coleman Glacier, Washington.

are made more rapidly than using other techniques, and because of the large number of crevasses usually present, are an easy source for obtaining high density measurements in a short period of time.

Below the snowline, fiberglass stakes are drilled into the blue glacier ice, and the lowering of the ice surface by ice melting is determined. In this region, crampons are used to prevent slipping on the rugged surface.

In order for a glacier to be healthy, approximately 60 percent of the glacier must still be snow covered at the end of September. In 1985, 1986, and 1987, only 45 percent of the average North Cascade glacier remained snow covered at the end of September. The result has been glacier retreat, greater spring runoff, and less summer runoff.

Accumulated layers of snow on a glacier act as sponges, soaking up and holding meltwater. Not until this sponge is saturated with water does the glacier begin to yield significant runoff. The delay in runoff caused by the ability of a glacier to store water is two to eight weeks. In a normal year, glacier runoff is delayed by four to six weeks, versus peak spring snowmelt in nonglaciated areas of each drainage basin. Thus, spring runoff is spread out enabling water managers to use the runoff more effectively.

In recent years, the thin, less extensive snowpack has made for a small sponge that is filled by spring meltwater in only two weeks. This raises flood danger as peak glacier runoff overlaps normal peak spring snowmelt runoff in nonglaciated areas. The spring runoff season is also shortened by a month reducing the ability of water managers to utilize the runoff, using standard management practices.

"I hope the spring snowfall has given the glaciers a positive mass balance."

In 1983, the National Academy of Sciences stated that monitoring the mass balance of an entire ice clad mountain range was a high priority. Having established a system for answering this priority, the next goal is to develop a model that directly correlates weekly weather data, glacier mass balance and resulting glacier runoff.

Though drought has been prevalent across most of the United States the North Cascades have experienced unusually heavy spring snow. I hope that upon my return to the North Cascades this summer, the spring snowfall gives the glaciers a positive mass balance.

Silhouette of Pelto above Cache Col Glacier, Washington.

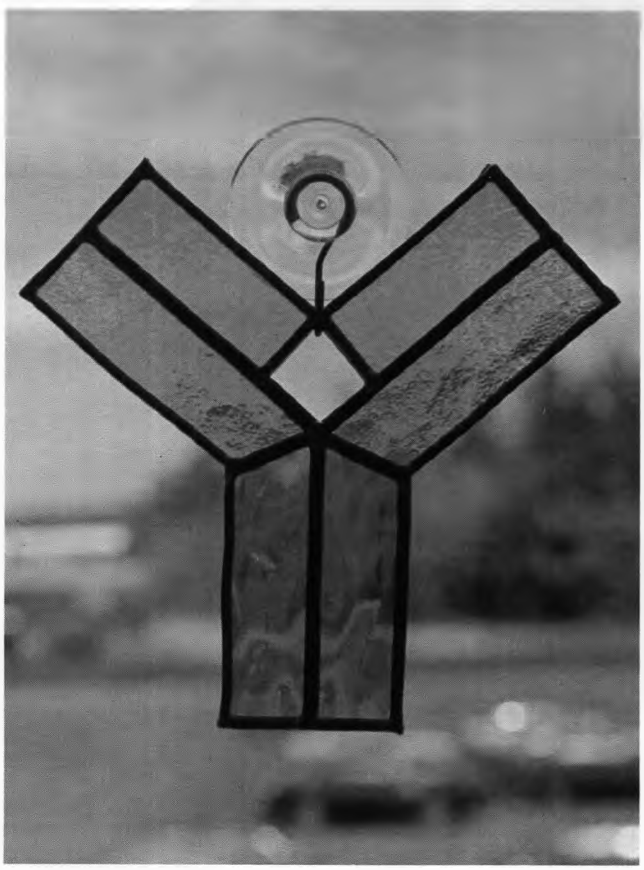
In our Winter, 1988, issue of EXPLORATIONS, we brought you an article authored by Anne P. Sherblom and Charles E. Moody. As indicated then, Dr. Sherblom is Associate Professor of Biochemistry at the University of Maine, and her research interests focus on carbohydrate biochemistry and the role of glycoproteins in immunosuppression. In the current issue, we are pleased to share with you some examples of Dr. Sherblom's avocation, an aesthetic expression of some aspects of her work. Join us as we enjoy THE SUNCATCHERS.

Stained Glass Molecules

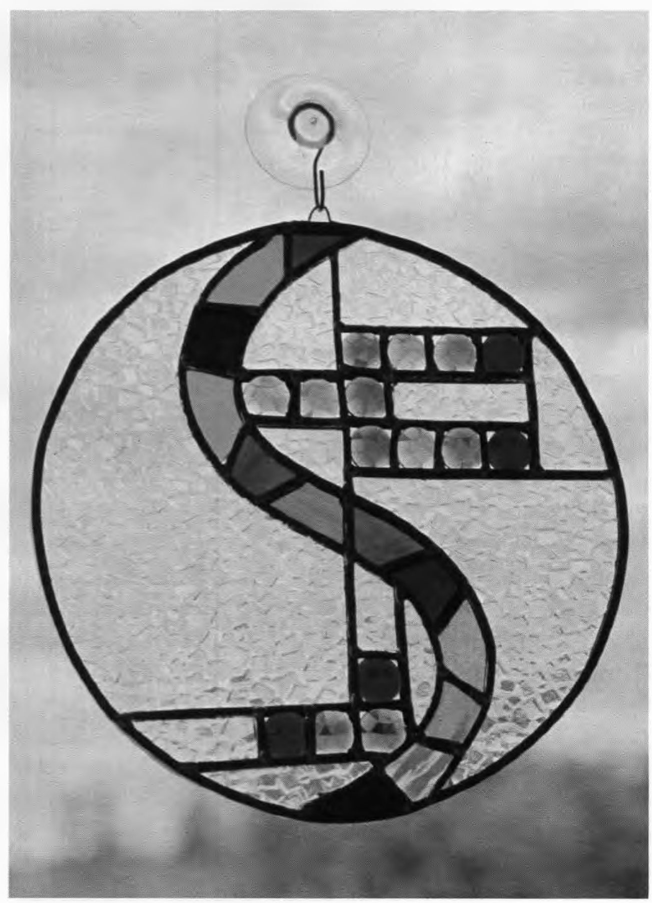
by Anne Sherblom

I began making *suncatchers* as a hobby when I took a stained glass course in the fall of 1986. I enjoyed designing and assembling the projects as gifts and as decorations for my home. The stained glass molecules arose out of a desire to provide a meaningful decoration for the office. As a biochemist, I have long been attracted by the beauty and symmetry of molecules, especially biological molecules. I have also found stained glass to be a uniquely *living medium*, which changes as the angle of the sun changes throughout the day. Assembling these suncatchers for myself and some of my colleagues was a very enjoyable undertaking.

The first piece was a stylized **IMMUNOGLOBULIN** (Figure 1), a gift for Dr. Charles Moody, an immunologist in the Department of Microbiology. Immunoglobulin G (IgG) is often represented in this Y-like fashion. Although a simple symbol, this representation conveys that IgG contains four separate pieces or subunits, two small (yellow) and two large (blue/green). Furthermore, the ability of IgG to recognize foreign substances is contained in the tip of each arm (where yellow and blue meet); the ability to signal and trigger other parts of the immune system is at the base (green).

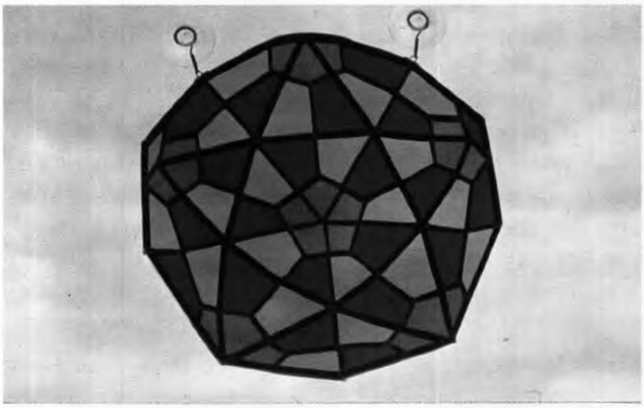


Immunoglobulin



Glycoprotein

The **GLYCOPROTEIN** (Figure 2) was built in the summer of 1987 and hangs in my office. My research has centered around the structure and function of cell surface glycoproteins (sugar-protein), and this model has proved useful in teaching and research discussions. The S-shaped curve at the center represents the protein core, with the variety of colors representing the variety of amino acids which make up proteins. Two different types of sugar chains are shown. The one which stretches horizontally (top right) is similar to sugar chains found in all cells, where each bead represents a single sugar residue. The smaller chain (lower left) is similar to sugar chains found in mucous secretions, and is thought to play a protective role in the stomach and intestinal tract.

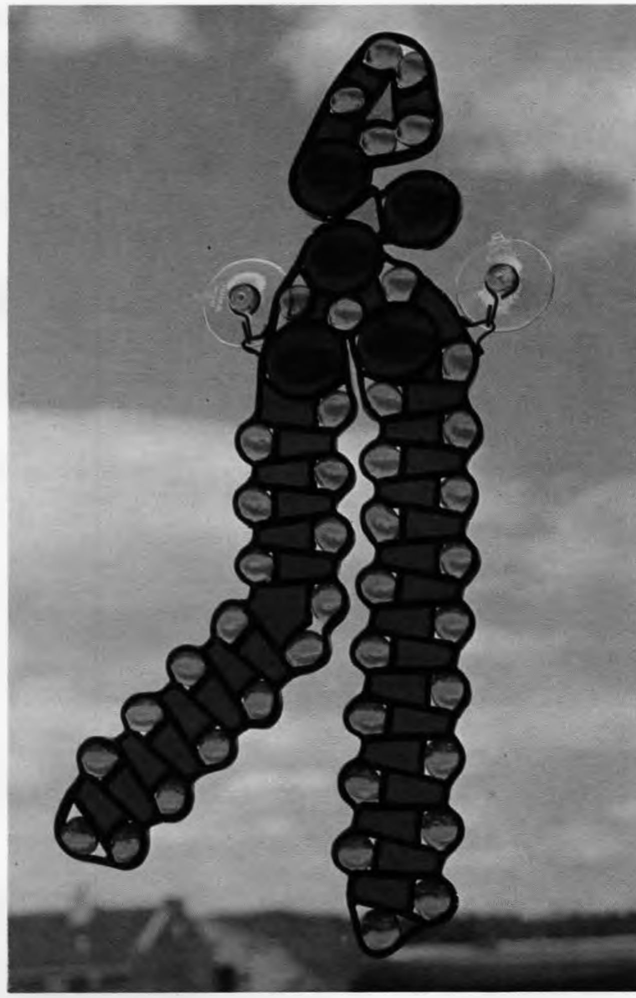


Virus

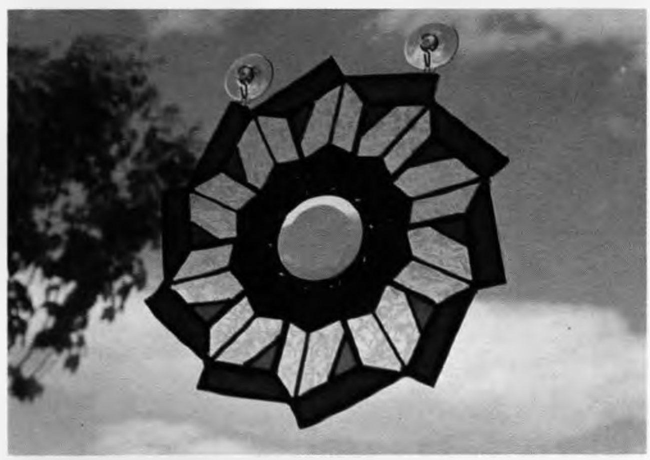
The **VIRUS** (Figure 3) belongs to Dr. Maryann Jerkofsky, a virologist in the Department of Microbiology. The original sketch for this came from a review article on viruses in *Scientific American*, and an enlarging photocopy machine facilitated the design of the pattern. The piece is meant to convey a soccer-ball-like structure, with three different types of molecules (blue, red, and orange) clustered together in a unique five-sided (pentagonal) arrangement.

The **PHOSPHOLIPID** (Figure 4) is owned by Dr. August Desiervo, a lipid specialist in the Department of Microbiology. The pattern was adapted from a space-filling model of phosphatidylcholine (lecithin)in *Biochemistry,* a text by Stryer. Phospholipids are a major component of cell membranes. Here the two long blue-and-yellow legs represent fatty acid chains, and the top which is rich in oxygen atoms (red circles) is the polar head group. In membranes, the fatty acids of many phospholipids cluster together to make a lipid bilayer.

Imagine yourself looking down the center of the DNA double helix, and you will be at the **EYE OF THE HELIX** (Figure 5). This piece resides in the main office of the Department of Biochemistry, as many of the department members work with DNA. The pattern was also adapted from Stryer's *Biochemistry. It is a diagram of one of the strands of a DNA double helix, viewed down the helix axis. The bases (all pyrimidines here) are inside, whereas the sugar-phosphate backbone is outside. The tenfold symmetry is evident.*[1]

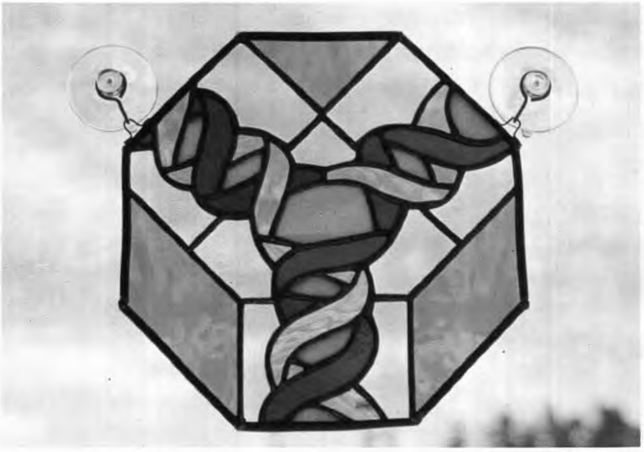


Phospholipid



Eye of the Helix

REPLICATING HELIX (Figure 6) belongs to Dr. Keith Hutchison, a molecular biologist in the Department of Biochemistry. This is a stylized version of how the two strands of DNA (dark and light green ribbons at the base) can unfold and become the pattern for two new DNA molecules (at



Replicating Helix

the top). The green color was chosen to further symbolize Dr. Hutchison's research area of gene expression in conifers.

REPLICATING HELIX, assembled in the spring of 1988, is the most recent of the stained glass molecules and reflects different techniques learned in a stained glass course in the fall of 1987. Each of the other pieces contains leaded glass, whereas a copper foil technique was used in **REPLICATING HELIX**. Will there be more stained glass molecules? Perhaps. Whenever I finish the giant sunflower I'm working on now.

[1]Stryer, L. *Biochemistry*, 2nd edition (1981), W. H. Freeman and Company, San Francisco, p. 565.

A problem of educational need was identified related to community forestry. The following article describes an approach to respond to that need and simultaneously build capability in the client group to assess and address their own needs. As community forestry is a community issue, a community development approach is being employed. The project is in progress.

Community Forestry

University of Maine Cooperative Extension Service

by Nancy E. Coverstone
and William D. Lilley

For many years, Maine woodlands provided the products and recreation required by local forest industries and residents. Now, in the southern part of the state, the woodlands are decreasing because of development pressures. In the northern part of the state there is less apparent impact. This is likely to change over time as development continues moving north. The greatest effect of development at present is in more urban areas.

Awareness of our environment and concern for its fragility are causing more attention to the use of our woodlands. These concerns are related to people's perception of their communities as attractive places to live, to which to recruit new business establishments, and to draw tourists.

The concerns pivot on balancing the sustainability of the quality of life and the viability of economic development. There is also concern about the future of existing forest industries. All of these act together to motivate people to take an active approach to managing their community forest resources.

Interest in community forestry exists in all parts of Maine, from Linneus to Sanford; however, community forestry is not actively pursued in all Maine towns and cities. There are communities which have forestry programs with varying levels of support. Some have paid staff; others use volunteer staff or volunteers from a local group such as a church or a land trust. Other communities have no community forestry programs at all.

Agencies are responding to the interests and needs expressed by citizens. The federal Extension Service (Extension Service-United States Department of Agriculture), in setting educational goals for the next four years, has identified urban forestry as an item of national interest. In Maine, urban forestry is translated to community forestry.

Nancy E. Coverstone is a University of Maine Cooperative Extension Agent in Androscoggin and Sagadahoc Counties. William D. Lilley is a University of Maine Cooperative Extension Service Forestry Specialist.

The University of Maine Cooperative Extension Service is working with people who recognize this need in our state and has incorporated community forestry into its activities. One of the efforts of UMaine Extension in community forestry was cosponsoring a tri-state conference on community forestry in October, 1987. Relevant local efforts include supporting the Thorncrag Bird Sanctuary in Lewiston and the George's River Land Trust in the midcoast area.

THE PROCESS

Maine, New Hampshire and Massachusetts groups cooperated in the development of the Community Trees Workshop which was held in October, 1987, in Portsmouth, New Hampshire.

The workshop was directed toward people involved in community forestry in the tri-state area: public works departments, urban foresters, municipal officials and planners,

FINDING OUR COMMON LANGUAGE

The following will help establish a common understanding of some of the terms used in our article.

Community forestry refers to those policies and technical issues relating to trees in a community: street trees, park trees, green belts, public grounds, and public and private woodlands.

Community development refers to the purposeful activity of people associated by their geographic proximity or by their shared interests. In the context of community forestry, several communities are relevant. They consist of the many geographic communities in Maine and all people in the state who have interest in community forestry.

The terms woodlands and forests are used interchangeably here to mean our undeveloped forestland independent of our goals for its management.

parks and recreation professionals and tree wardens. While the technical presentations were important, the workshops generated a vital series of interactive groups and a written survey of participants which identified the range of interests surrounding community forestry.

A clear mandate came from these sources: develop community programs to ensure a long-term commitment by cities and towns for the establishment, maintenance, protection and preservation of community forests in New England.

The technique of involving representatives of the client group in all stages of problem solving is a sound community development practice. It gives the clients ownership of the problem, which after all, is where the true concern resides.

Clients' careful considerations and attempts to state the problem clearly start them on a healthy problem solving process. They begin to see alternative solutions. A further strength of this approach is that these people recruit others in their communities into the problem solving process. Ultimately, a critical mass of people is involved and solutions begin to be implemented.

The University of Maine Cooperative Extension Service was the Maine group involved in the tri-state conference. To ascertain the level of interest in this issue in Maine, and to identify particular interests, UMaine Extension conducted a survey of Maine participants in the tri-state conference.

The needs they identified serve as a preliminary needs assessment to help develop future programs in Maine and will be updated with each subsequent program either to confirm, expand, or change the array of perceived needs.

The major interests indicated by the survey responses included maintenance of trees, planning for urban trees, street tree inventories, budget justification, and liabilities.

How complex are some of these topics? The number one educational need indicated was maintenance of trees, and it includes species selection, soil relationships, salt resistance, planting, pruning, and treatment for insects and diseases. These concerns become highly significant in the light of limited municipal funding which makes the survival and health of any planting very important. Correcting errors is expensive.

THE COMMUNITY FORESTRY CONFERENCE

Given these expressed needs and its own organizational initiatives, the University of Maine Cooperative Extension Service sought to provide community forestry groups the necessary education and training, and to empower them to act collectively on their own behalf.

The initial step was to create a committee which would be representative of the interests involved. They included the Maine Forest Service, several urban foresters, a private nursery sponsor, an Extension forestry specialist, an Extension horticulture specialist, and a county Extension agent with experience in community development and large conference planning.

The committee was invited to plan a statewide conference on community forestry to focus awareness on issues and provide education and training.

At the first meeting, the members of the planning committee defined community forestry, drafted objectives for an educational program, decided on the audiences to be targeted, and identified the range of educational needs expressed by the audiences.

The final item was a discussion of who else needed to be represented on the committee. It was decided that a small-town perspective should be added, so a town conservation commission member and a municipal tree warden were added. A larger town and a planning perspective were lacking, and that led to the addition of staff persons from a council of governments and a regional planning commission.

A second meeting, complete with new members, yielded a refined definition of community forestry and a decision to narrow the focus of the state conference to policy and technical issues relating to all aspects of community forestry except woodlands. The decision to exclude town woodlands from the subject matter of the conference was based on the

idea that a focused conference would be better and more productive than a superficial survey of topics. The conference date was then set for February, 1989.

Throughout this process, the committee is learning to plan an educational program, to identify resources to help them reach their goals, and to work together as a committee. All these skills will be helpful to the individual members in future activities.

Many agency people are not comfortable with the group process. They feel it easier, safer, and more manageable to use client groups to advise or rubber stamp decisions. Working with groups on problem solving and decision-making leads professionals finally to trust the group. While it may take longer than unilateral action, group process provides for the integration of all interests and allows consensus to produce intelligent decisions. By extension, decisions and plans are more likely to receive full support from the groups involved.

The wisdom of the decision to limit the focus of the February, 1989, conference was illustrated by a subsequent action. Another group is being convened by University of Maine Extension and the Maine Municipal Association to consider developing a conference on municipally owned woodlands and forest management within municipalities. The representation on the second committee is substantially different from the one currently planning the February conference. The interests of the two committees differ but will be complementary.

IN CONCLUSION

We have been looking at a community development process beginning in Maine and focusing on the issue of community forestry. Education is at the center of the process, and the education has two objectives, the first of which is general; the second of which is particular. The first is the involvement of representatives of the forestry community in defining the issues and developing solutions to implement and evaluate those solutions. The people involved will gain skills in problem solving and group process which they will be able to apply to many situations. The second objective of the education is to provide information and training in skills to all members of the forestry community for planning and implementing sound community forestry practices.

Where Are They Now? -- Robert F. LaPrade, M.D. '81

Where do the graduates from the University of Maine go? In the case of Robert F. LaPrade, M.D., who earned a baccalaureate degree in Forestry Engineering in 1981, it's medical school. Now LaPrade is an orthopedic surgeon in Kalamazoo, Michigan, undergoing the rigors of medical residency. And, as the following abstract of a research project indicates, he took with him the disciplined focus and attention to detail which produces Maine excellence. The full paper was delivered to the Michigan Orthopedic Society in June.

Advances in Scoliosis treatment in Duchenne Muscular Dystrophy: A Historical Perspective and Results of Segmental Spinal Stabilization and Fusion in a Case Series

Until the past two decades, scoliosis in Duchenne Muscular Dystrophy (DMD) patients was a virtually undiscussed, poorly treated physical deformity. The course of development of treatment for this disease and results of segmental spinal stabilization and fusion for eight DMD patients treated over the period 1981-1987 are presented.

The current recommendations in the orthopaedic literature for DMD patients are as follows:

1. Segmental spinal stabilization and fusion from the upper thoracic spine to L5 or the sacrum should be undertaken in all patients with a Cobb angle of greater than 30 degrees and a vital capacity of at least 30 percent;
2. Spinal orthoses fail to prevent the eventual development of scoliosis and should be reserved only for those patients who refuse or could not tolerate surgery.

Curve progression and seating difficulties were the most common indications for surgery in this series. These problems were successfully treated and all patients maintained or improved seating balance postoperatively. Based upon our experience, we make the following recommendations:

1. All patients should be routinely followed for scoliosis with serial x-rays because Cobb angles of greater than 30 degrees may not be clinically evident;
2. In selected cases, due to improved respiratory care technology, patients with a vital capacity less than 30 percent should be considered for surgery;
3. Segmental wiring should be performed through the spinous processes rather than sublaminarly, and
4. Allogenic banked bone should be used to supplement autogenous bone for spinal fusion in all patients.

The following is written from excerpts of a research presentation by Charles Gregory at the Annual Spring New England Estuarine Research Society (NEERS) Meeting April 20-22, 1988, in Woods Hole, Massachusetts. The presentation is the result of his participation in six oceanographic cruises in the Gulf of Maine and extensive microscopic analysis of the plankton community and its biomass distribution. Gregory, a Ph.D. candidate in the University of Maine Department of Botany and Plant Pathology, was awarded Outstanding Student Paper for his research and symposium presentation.

Little Critters with a Big Job:
Ciliated Protozoa and the Gulf of Maine Food Chain

by Marcia Gauvin
from a paper by Charles Gregory

The name *plankton* denotes any organism that lives in the water column and is unable to maintain its distribution against the movement of the water masses. Although plankton are commonly viewed as microscopic organisms, such as *Gonyaulax tamarensis*, the toxin producing, red-tide dinoflagellate, this definition of plankton can also be applied to relatively large organisms. The major sizes and biological groups of plankton range from 0.02 um for the virio-plankton to 20 cm for metazoo-plankton like jellyfish.

All five biological kingdoms are present in the ocean as plankton: bacteria, fungi (as yeast), plants, protozoa, and the animal. Protozoans are generally single celled organisms that live by photosynthesis, absorption or ingestion of food particles, or a combination of the two processes.

From the 1970s to the present, many advances in oceanographic technology have occurred. These improvements are providing researchers with a better understanding of the smaller size classes of the previously unknown planktonic organisms such as bacterio-plankton. Before the 1970s, biological oceanographers generally accepted the concept of the food chain whereby the big fish ate the smaller krill or zooplankton, that ate the microscopic plants or phytoplankton. However, it was soon realized that this was an oversimplified view of a very complicated ocean.

Charles Gregory, a University of Maine Plant Science Ph.D. student working with Dr. Bernard McAlice won the Outstanding Student paper award for his symposium presentation, Contribution of the Ciliated Protozoa to the Microplankton Biomass in the Gulf of Maine during 1987, *at the April, 1988, Annual Spring New England Estuarine Research Society (NEERS) Meeting in Woods Hole, Massachusetts.*

From the 1970s to early 1980s, the food chain concept was replaced by the food web. Ecologists felt that the food web provided a better picture of the complex way food was cycled through the water. Today, the generally accepted food web view of microscopic plankton is called the *microbial loop* and is simplified by the process depicted in figure 1.

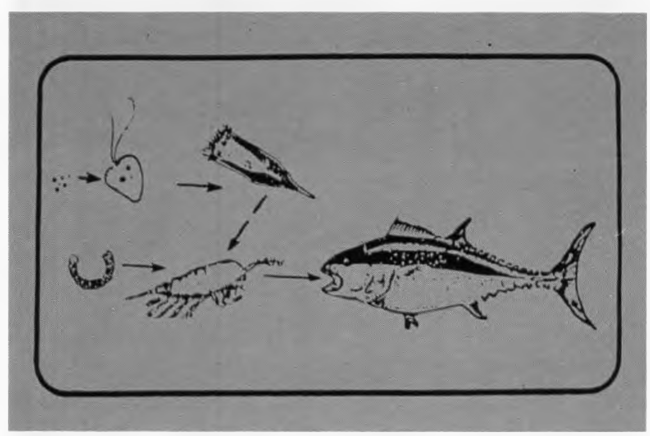


Figure 1

The smallest and most highly productive plankton, the picoplankton, are eaten by slightly larger nanoplanktonic flagellates. The flagellates are in turn grazed upon by even larger microplanktonic ciliates, which, together with the larger phytoplankters, are consumed by larger members of the zooplankton. The zooplankton are then eaten by smaller members of the nekton, such as small fish or squid. At all stages of this cycle, carbon and other nutrients are released into the water and are recycled back to support some of the lower trophic levels like bacteria.

Several scientists across the world are studying the minute pico- and nano-plankters, and are confident that they represent a major food source for the ocean grazers. Ecological evidence is still lacking, however, to support the role of the ciliated protozoa in this microbial loop. The problem can be represented by the following question: *Is there a sufficient abundance of ciliated protozoa in oceanic waters to feed off these highly productive pico- and nano-plankters, and to transfer this food energy to higher trophic levels?*

All planktonic ciliates have a similar form, consisting of a body and an apical or mouth region. The apical region is surrounded by cilia which function in two ways: to propel the organism, and to cycle food particles from the water to the mouth region. There are two types of ciliates, those referred to as *naked* or aloricate ciliates that have no protective outer covering, and tintinnids, ciliates with a protective gelatinous or chitinous outer covering or lorica. (The two types of ciliates are represented by figures 2 and 3.)

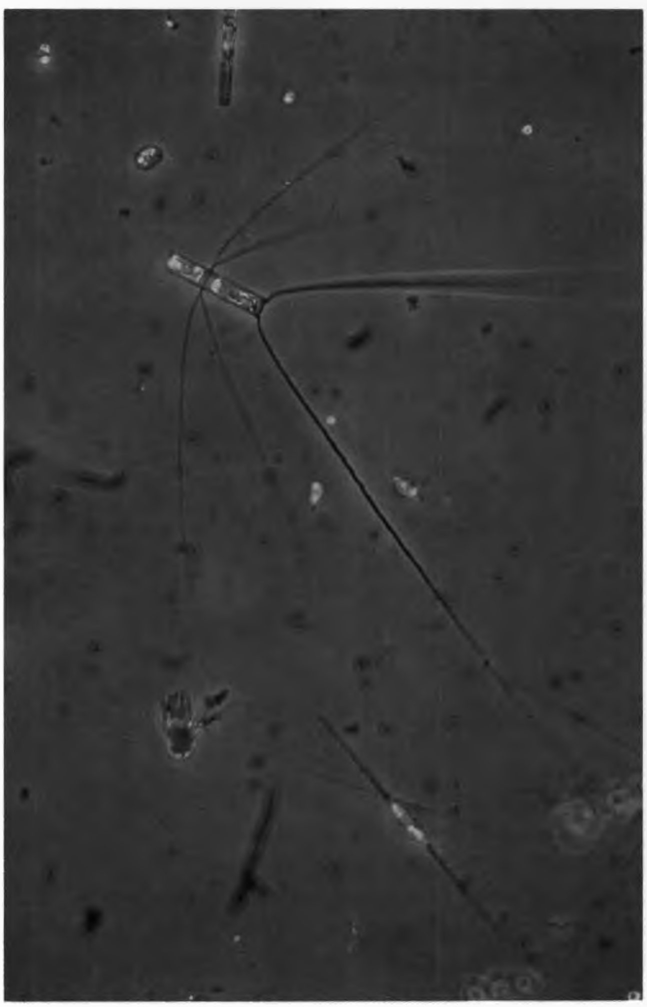


Figure 2

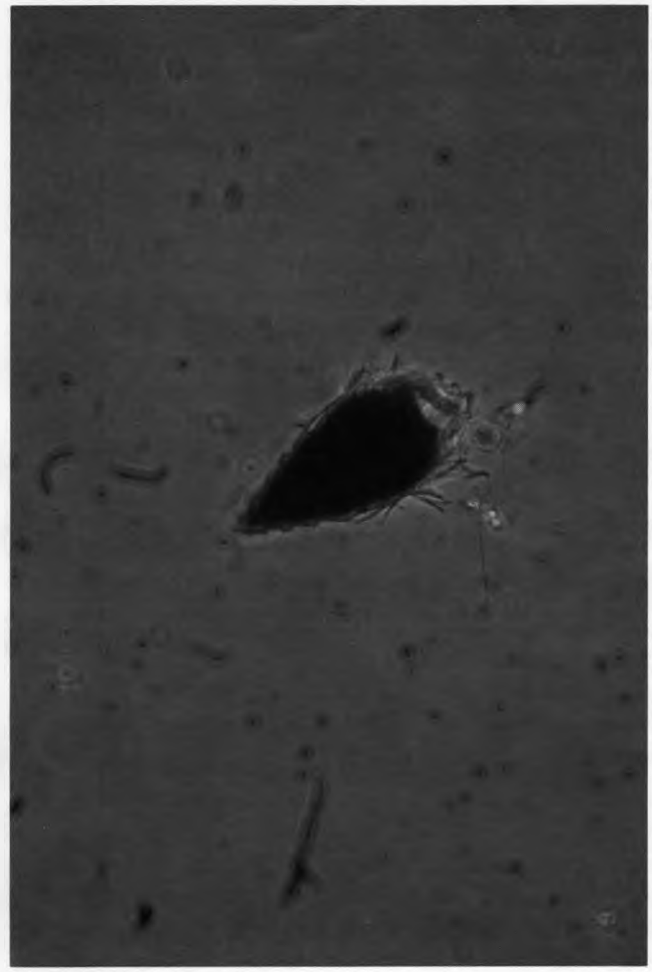


Figure 3

Research has been done in the central Pacific, the southern United States, and in Australia's Great Barrier Reef to assess the role of the planktonic ciliates in the microbial loop. The results of these efforts strongly indicate that the major group of organisms capable of grazing these smaller food particles, and, in turn being grazed upon by the commonly known zooplankton, are the ciliated protozoa.

Almost all of these studies were conducted in warm, tropical, or temperate waters, however, and cannot automatically be applied to the colder, boreal waters of the Gulf of Maine. Thus, the two objectives of Gregory's research were to determine the abundance, biomass, and population characteristics of the ciliated protozoa in Gulf of Maine waters, and to estimate the contribution of the ciliated protozoa to the Gulf of Maine's microplankton community. Gregory's research focused on the phyto- and protozoo-plankton biological groups which exist in the micrometer to millimeter size range.

The method typically used to obtain the water samples for these studies is called hydrocast. Water bottles are attached to a weighted line, lowered to a certain depth, and later retrieved. (See Figure 4.) Also attached to the hydrocast line is a device that tests the conductivity, temperature and depth

Figure 4

of the water sample, referred to as the CTD. In addition to these tests, the CTD probe analyzes the water column for salinity and density. Upon retrieval to the ship, the CTD is plugged into a computer and the data are immediately printed on hard copy.

The method of sample analysis to determine microorganism identification and quantification, as well as biomass and biovolume determination, was carried out by inverted microscope examination.

RESULTS

Samples were taken at sites in the Gulf of Maine ranging from the Canadian-Maine border to just off the coast of Portsmouth, New Hampshire. The six cruises took place in February, March, May, June, July, and August. (See Figure 5.) The results of the sampling were categorized for February-March, May-June, and July-August.

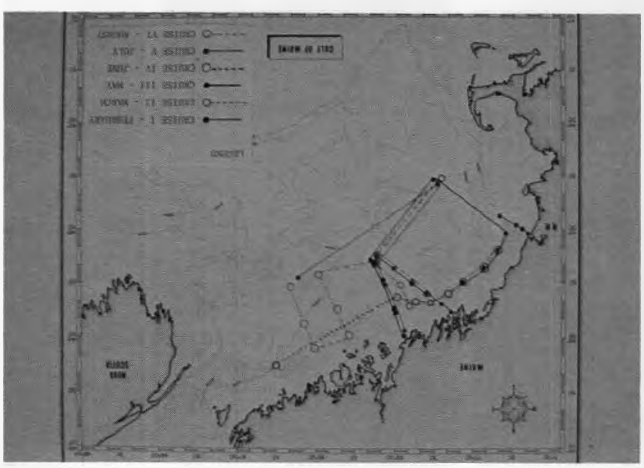


Figure 5

Nearshore (within a depth limit of 100 meters) and offshore (greater than 100 meters in depth) sites were tested and compared. Gregory determined the seasonal mean biomass, in ug carbon per liter, and biovolume distribution, in cubic microns per liter, for the ciliated protozoa. Pigment abundance, which is representative of phytoplanktonic levels, was also determined by shipboard technology.

Gregory charted a biomass budget (Figure 6) for the Gulf of Maine for the months of July through August, using his own data in combination with previously published results. From this budget, several trends can be noted. Bacterial numbers and biomass increased from nearshore to offshore sites. Cryptomonad and diatom biomass, representing other planktonic groups, also increased from nearshore to offshore. For diatoms, this biomass increase occurred in spite of an observed numerical decrease from nearshore to offshore. Ciliate and dinoflagellate biomass values decreased from nearshore to offshore by a factor greater than three.

GULF OF MAINE MICROPLANKTON BUDGET

JULY - AUGUST, 1987

	NEARSHORE ABUNDANCE		OFFSHORE ABUNDANCE	
	NUMERICAL (X 10^6/l)	BIOMASS (µg C/l)	NUMERICAL (X 10^6/l)	BIOMASS (µg C/l)
BACTERIA	650	20.8	1100	34.7
CYANOBACTERIA*	150	46.8	140	43.9
MICROFLAGELLATES	0.333	9.3	4.126	5.0
CHOANOFLAGELLATES	0.113	0.8	[illegible]	0.6
CRYPTOMONADS	0.294	3.3	0.529	10.6
CHRYSOPHYTES	0.053	1.5	0.020	[illegible]
EUGLENIDS	0.009	0.7	0.008	0.6
DIATOMS	4.914	11.2	2.107	15.1
DINOFLAGELLATES	0.116	110.0	0.069	32.1
SILICOFLAGELLATES	0.001	0.5	0	0
CILIATES	0.021	46.6	0.018	12.3
TOTAL	805.854	251.5	1246.995	155.8

* From Murphy and Haugen, 1985 assuming mean diameter of 1.0µm

Figure 6

In general, Gregory's biomass table supports the current hypothesis that offshore regions of the Gulf of Maine are numerically dominated by small, highly productive pico- and nanoplankters, and the biomass of the nearshore waters by larger, less productive microplankters. The pico- and nanoplankton size fraction constituted a third of the nearshore biomass and two-thirds of the offshore biomass, while microplankton size fraction constituted two-thirds of the nearshore and a third of the offshore biomass.

In Gregory's research, 32 species of tintinnids, and 22 spe-

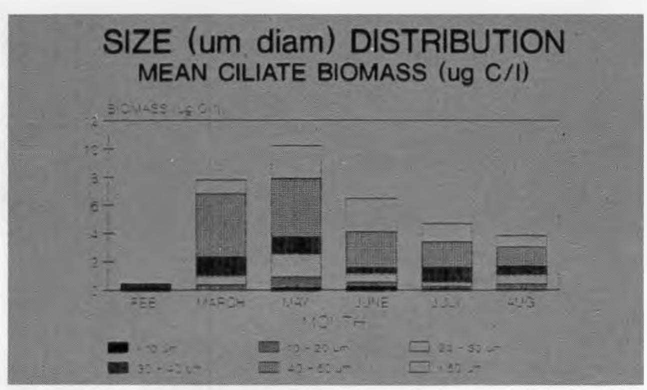


Figure 7

cies of non-tintinnid ciliates were enumerated. Non-tintinnids were consistently found to be more dominant than tintinnids.

The ciliates' seasonal distribution was also determined according to apical diameter sizes (Figure 7). From these determinations it was found that more than 50 percent of the March bloom was composed of nontintinnid ciliates in the 40-50 um size range. This size class was at its maximum mean biomass at this time, and gradually declined from May to August. The 20-30 um and the 30-40 size classes fluctuated over the course of the study, reaching maximum biomass abundances in May and March respectively.

The 1987 maximum mean biomass abundance of ciliates (Figure 8), generally 20-50 um in apical diameter, occurred in May and reached approximately 10 micrograms of carbon per liter. This is a result of a ciliate bloom that occurred between February and March, and into May. After the May maximum, the mean ciliate biomass gradually declined.

Pigment abundance also increased from February to March, indicating a phytoplankton bloom that declined from March to May. Whether the February to May ciliate bloom is a direct result of the February phytoplankton bloom has yet to be determined.

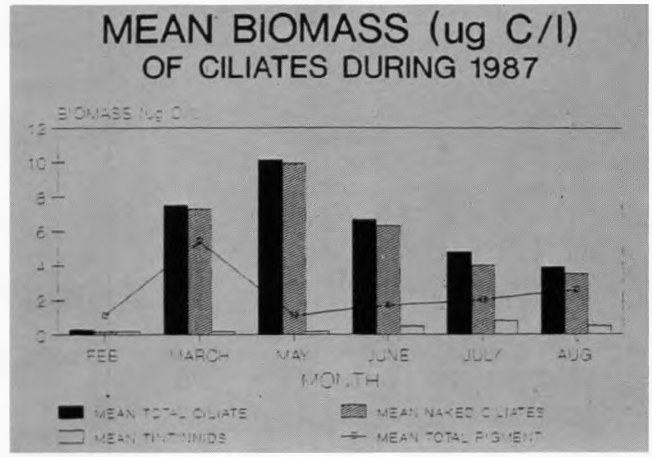


Figure 8

Figure 9

The simplest and perhaps the most complex problems facing marine researchers today pivot around understanding how nutrients are transferred and cycled in the intricate network of the ocean's food web. Because a major fraction of the state's economy depends upon participants in this network, the query is a particularly important one for Maine. As is this study examining the contributions of the protozoan ciliates, because even the microscopic elements of this cycle contribute significantly to the ocean's nutrient distribution (Figure 9).

The Innovation of Tradition
Low-Cost, Low-Input Alternatives for Maine Farmers

by Marcia Gauvin

In America we trade soil for oil. The basis of this expression is the proportional relationship between a farm's soil erosion and its petrochemical energy input: as more soil is washed away from a piece of land, more energy is needed for compensation. A major component in this energy-erosion relationship is nitrogen.

Carbon, oxygen, hydrogen, and nitrogen are the four most important chemical elements for plant growth. Nitrogen, however, is the limiting factor. In spite of comprising 78 percent of the air, nitrogen in its elemental form, N_2, cannot be utilized by green plants. It must be *fixed*, converted to a useable form.

Two sources of fixed nitrogen are legumes (peas, vetch, clover, and lupines) and synthetic chemical fertilizers. Although legumes have been used as a nitrogen source in agriculture since the beginning of civilization, in the past several decades cost comparisons of the two sources of nitrogen have greatly favored the use of chemical fertilizers. Maine farmers rely largely upon synthetic chemical sources of nitrogen, applying more than 25 million pounds of nitrogen fertilizer per year.

Thirty to fifty percent of this synthetic fertilizer, however, never reaches the target crop because it is lost to rainwater leachate, runoff or volatilization. Thus, chemical fertilizers can be inefficient and a source of contamination of ground water. In addition, the production and application of synthetic nitrogen fertilizer involves a large amount of petrochemical energy input in the form of oil, natural gas, and gasoline, natural reserves which are slowly being depleted. High utilization of national natural resources influences the amount of material that must be imported from international sources. The use of synthetic nitrogen can have an impact on the international oil market.

A type of bacterium which lives in the root nodules of legumes, *Rhizobium*, is able to convert free gaseous nitrogen to a form available to green plants. In one single season, the *Rhizobium*/legume root nodules may add 100 to 200 pounds of nitrogen per acre of soil. In addition, the use of legume systems can greatly inhibit soil erosion. Thus, several studies have focused on the use of legumes as a source of nitrogen that will neither jeopardize the environment nor deplete valuable natural resources.

This scheme, outlining the national and international implications of agricultural practices utilized locally, is just one example of an emerging concept of agriculture that connects local agronomics to international economics. **Sustainable agriculture: a realization that environmental preservation is, in fact, economically advantageous.**

SUSTAINABLE AGRICULTURE

Sustainable agriculture can also be referred to as low input agriculture, or a decrease in the use of pesticides, herbicides, fertilizers, and concentrated feeds. The desirable objectives of sustainable agriculture are environmental quality and economic efficiency.

The University of Maine is emerging as a pioneering force in this new wave of agriculture with the arrival of Dr. Matt Liebman, an assistant professor in the Department of Plant and Soil Sciences. Liebman received his undergraduate degree *cum laude* from Harvard, did graduate studies at Cornell, and earned his Ph.D. at the University of California at Berkeley. He and six other University of Maine researchers have recently been awarded a grant to study sustainable crop and livestock production in Maine from the Jessie Smith Noyes Foundation, the sixth largest private foundation giving money to environmental concerns in the country.

The first major driving force about why to go to so-called low input systems is the protection of water quality and human health, Liebman said. *The second is that high crop yield doesn't necessarily mean that you make a lot of money: there is really no longer any way to equate production and profitability. So we have to start talking about efficiency and the difference between production costs and the sales price of the commodity.*

It is important to realize that when you talk about low input agriculture, you aren't talking simply about a cessation of activities and then everything reverts to its so-called natural improved state, Liebman said. *You are talking about the need for substituting management skills and intelligent manipulations of biological interactions for chemicals.*

The three year grant involving four different University of Maine departments, will fund experiments designed to

Marcia Gauvin, a native of Caribou, Maine, is currently a graduate student in English at the University of Maine. She earned bachelor's degrees in chemistry and in biochemistry from the University of Maine in 1986. She is interested in the combination of science and nonfiction writing.

on page 17

Intercropping legumes with a cereal crop is a good source of nitrogen and inhibits soil erosion.

provide farmers with alternatives to their current dependence on synthetic fertilizers, pesticides, and purchased feeds. Although the work is being carried out on sites in Maine, the research will have relevance to other northeastern states and Atlantic Canadian Provinces.

The other principal investigators on the project: Dr. Randy Alford, Department of Entomology; Dr. Barbara Barton, Department of Animal and Veterinary Sciences; Dr. Kevin Boyle, Department of Agricultural and Resource Economics; Dr. Gregory Porter, Dr. Mary Wiedenhoeft, and Dr. Larry Zibilske, Department of Plant and Soil Sciences, are all employees of the Maine Agricultural Experiment Station. The agricultural extension of the Experiment Station provides a forum for presenting to farmers and extension educators the information generated by the experiments.

The research is broken down into four projects: a study of legume intercropping as a source of nitrogen for potato production, a determination of cropping systems that provide management capabilities for the Mexican bean beetle, an evaluation of the agronomic and economic performance of low-herbicide weed management strategies, and a comparison of livestock grazing methods.

LEGUMES AS A SOURCE OF NITROGEN

The use of legumes in agriculture typically involves rotation of crops within a single field: planting legumes one year and planting a cash crop the next. The legumes then serve as feed for livestock. With an increased availability of synthetic forms of nitrogen and a decreased reliance upon draft animals, legumes have become a less efficient form of nitrogen. Farmers are more dependent upon chemical fertilizers as the major source of replacement nitrogen. Although nitrogen derived from legumes production generally costs more than purchasing and applying an equivalent amount of nitrogen fertilizer, other beneficial aspects of legume-generated nitrogen must be considered.

Yields of a grain crop grown in rotation are often 10-20 percent greater than those for continuous grain, regardless of the amount of fertilizer used. Studies have demonstrated that rotation of crops can reduce the population and activity of some pathogenic soil organisms. It has similarly been shown that rotations may break weed and insect cycles that often occur with continuous cropping.

While benefits of crop-legume rotation are obvious, Maine potato farmers generally do not raise a sizable number of livestock and find it difficult to take land out of cash crop production for a full year or more to produce unused legumes. Many Maine farmers do, however, grow cereal cash crops like rye, barley, oats, and wheat, in rotation with their potato crops.

It has been recognized for years that rotations are better for the soil; the question is 'Is it economically effective to use legumes and crop rotations?' Liebman said. *The challenge is to figure out better multiple cropping systems that include legumes so that people can get those biological efficiencies without losing the economic efficiencies.*

One of the methods that Liebman has been employing to incorporate legumes as a source of nitrogen has been to combine legumes and grain in a single field. This practice of planting more than one plant species together in the same field is called intercropping. Liebman's legume/cereal intercropping is accomplished by the broadcasting of legume seed when the cereal is planted to produce a lawn of legume beneath the taller cereal crop. This practice can increase the amount of available nitrogen without significantly inhibiting the cash crop yield. In addition, when allowed to grow after the harvest of the cash crop, the legume provides a winter cover to prevent erosion.

Although a 1980 survey indicated that 30 percent of Maine farmers used cereal/legume intercropping practices, the optimum conditions for nitrogen fixation with cereal/legume intercropping have not been adequately quantified. Liebman is working with Dr. Larry Zibilske and Dr. Gregory Porter, to quantify the nitrogen fixation of five different varieties of legumes when broadcast with barley, and to determine the nitrogen contribution that each intercrop system makes to subsequent crops of potatoes. These experiments will be carried out over three growing seasons in order to account for variations in soil or weather.

250,000 pounds of active herbicide ingredients can have incredible consequences

WEED MANAGEMENT

The effect of weed competition on any crop can be devastating. Weeds compete with the crop for water, nutrients, and light, and make harvesting more difficult. Although weeds between crop rows are usually mechanically cultivated, the two current agricultural methods of in-row weed management are the use of chemical herbicides or the use of hand labor to pull individual weeds. The approximately more than 250,000 pounds (active ingredient) of herbicides used by Maine farmers to kill weeds each year have many environmental implications. They can contaminate ground water and threaten human and plant life. And although not dangerous to ground water, the use of hand labor for weed management jeopardizes a farm's economic viability by tremendously increasing labor costs.

Nodules of *Rhizobium*, living symbiotically in the roots of legumes, are capable of converting free gaseous nitrogen to a fixed, usable form.

Non-pesticide methods of controlling the Mexican bean beetle are being tested.

The Voisin method: allowing livestock access to small sections of a pasture at a time results in a more complete grazing of each section (compare right to left), and improves a pasture's forage potential.

The Voisin method fencing crew: (from left to right) Dr. Tom Settlemire from Bowdoin College, Wyatt Courtemanch, Jeff Cummings, Dr. Mary Weidenhoeft, Rupert Stafford, Dr. Barbara Barton, Will Steele, and Rae Rowell.

As an undergraduate, Liebman explained, *I became very interested in the idea that planting two crop species together might be a better use of environmental resources than planting one. I thought that if you have two plants that are complementary in their patterns of water, nutrient, and light use, that would usurp a lot of the resources that weeds could get hold of.*

Liebman, whose graduate work concentrated on complementary cropping systems, will be studying alternative forms of weed management in Maine using several cropping practices and mechanical technologies recently introduced. Dr. Kevin Boyle will compare the net economic returns from alternative and conventional management systems, based on yield data and costs of production inputs and field operations.

An alternative system of weed control can be based on the fact that many cereal crops, such as barley, wheat, and oats, release selective toxins which suppress the growth and germination of many small seeded weeds, but do not affect large seeded crops like corn, peas, and beans.

Liebman will be studying this effect in a system which involves planting a cereal in the fall, mowing the cereal the following spring to leave a residue, and no-till planting beans into the mulch residue. If the rye mulch suppresses the weed growth moderately but not sufficiently, small quantities of herbicides may be used in subsequent years to enhance the process.

Several growers in the state have expressed an interest in viewing the bean/rye mulch experiments during the summer of 1988 and establishing trials on their own farms in 1989 using cereal mulches for bean, sweet corn, pea, and squash production systems if the system shows promise.

Other weed management techniques to be explored by Liebman and Boyle include the intercropping of clover with cereal crops and the utilization of new machinery specifically designed to suppress weeds within the crop row without damaging the crop.

Legumes have a late season growing pattern, complementary to the early season development of cereal plants, and do not compete strongly for nutrients. The broadcasting of legumes with cereal crops, as described above, has been shown in some cases to provide a significant amount of competition against weeds without interfering with the yield of grain. Legumes, such as clover and vetch, can also be sown after the last mechanical cultivation of corn and vegetable crops to provide late season weed control and winter cover to prevent soil erosion. The use of such late season planting has also been shown to increase nitrogen availability.

Weeds within the crop row often cannot be mechanically torn out without significant crop damage. In-row weed management typically involves the use of herbicides and hand labor. Although most Maine growers are not aware of cultivation implements capable of effective in-row weed control, a California company has begun to market mechanical implements specifically designed for this purpose. Liebman will study the effectiveness of such devices in Maine.

THE BEANS OF MAINE

Dry beans are grown on about 2000 acres of Maine farmland, and the potential yield of this crop in certain areas of the state is quite high. Several companies that purchase, process, and market beans are located within the state, yet current production levels do not meet the demand of these companies. To make up the difference, a large quantity of beans is imported from other states. Maine farmers may very well be able to increase their bean production and realize a profit.

finding ways to bug the bugs and debug the beans

The expansion of Maine's bean production is threatened by one of the most destructive pests in North America: the Mexican bean beetle. Recent years have seen the arrival of this beetle into the state, and its population is spreading. Because the bean beetle is relatively new in Maine, and because a chemically-based program to control the pest has not yet been established for the state, researchers have a good opportunity to initiate a nonchemical system of insect management. Experiments conducted in other states have suggested that the Mexican bean beetle can be controlled in ecologically sound ways involving cultural practices like strip cropping, intercropping, and selective manipulation of weed populations.

The beetles fly in from outside the field, trying to locate their host plant, Liebman said. *They don't eat everything, they prefer to eat beans. So anything that inhibits their ability to colonize and reproduce on bean plants can decrease the population of the pests.*

using weeds to scramble the radar

Some methods of inhibiting the bean beetle from recognizing their host plant include strip cropping or intercropping beans and corn. The tall corn plants in between the bean plants may disturb the chemical and visual cues used by the pest as it tries to locate its preferred host. Certain weeds in low numbers, which may have only a minor effect on the crop yield, can also affect the ability of the insect to locate the bean plant. Sometimes the decreased incidence of insect pests more than offsets any loss of yield due to weed competition.

With the objective of developing an ecologically advantageous Mexican bean beetle management program for Maine, Liebman and Dr. Randy Alford will be studying the responses of the beetle to alternative crop management practices. Alford has had considerable experience in studying similar parameters for the Colorado potato beetle, the blueberry maggot, the spruce budworm, and the fall armyworm.

GRAZING SYSTEMS

Dairy farmers in the northeastern United States generally consider permanent pastures to be useful only as holding or exercise areas for their cattle. They rely heavily on commercial feeds and stored forage. For Maine farmers, more than a third of the cost of producing livestock goes toward the purchase of concentrated feeds, and almost all of these feed products are from outside Maine. Farmers using commercial feeds are caught between rising operating costs and falling milk or livestock prices.

One technique of intensive grazing management, developed by Andre Voisin in 1959, has been extensively and successfully used in several European countries and New Zealand. The Voisin method, involving the rotational use of smaller grazing areas, has recently been introduced to the northeastern United States. Although the Voisin method involves year-round grazing management, similar techniques can be applied in this area between May 1 and October 1, with positive results for participating farmers.

In continuous grazing practices, animals decide when to graze and which plants to graze. Usually legumes and grasses are grazed preferentially and regrazed after about seven days of regrowth. Plants need, however, from 12 to 42 days of recovery time between grazings in order to have adequate leaf surface for photosynthesis and the replenishment of their carbohydrate reserves. Given a choice, animals generally will not graze weedy plants, and weeds are consequently given a competitive advantage over the more frequently grazed plants. Because weeds are allowed to reach their reproductive potential at a far greater rate than the more nutritious, higher protein plants, continuous grazing decreases the forage quality of a pasture.

In the Voisin method, however, livestock are confined for a 12 to 48 hour period to smaller pasture areas in paddocks, where they consume virtually all the above-ground plant materials. After this period, the animals are placed in a fresh paddock and the grazed paddock is allowed to recover for several weeks. After each recovery period, the animals are rotated back into the regrown paddock for another period of intensive grazing. This rotational, intensive grazing process has been shown to increase forage quality by allowing legumes and grasses enough recovery time to be competitive. The method has been shown to increase product-to-feed ratios with milk, meat, or other animal products. The result of this decreased use of commercial feeds is an increased profit margin.

Dr. Barbara Barton and Dr. Mary Wiedenhoeft are leading a project that will establish a base of knowledge and a test system by which to promote such practices in Maine and to help establish this method in the northeastern United States. The experiment site will serve to educate visiting farmers, soil conservationists, and University of Maine Cooperative Extension workers about the opportunities and requirements of intensive grazing systems. Many Maine farmers have already been requesting information concerning the Voisin method's applications within the State.

CONCLUSION

Agriculture, Liebman maintained, *is inherently unnatural. To get highly productive crop yield year after year in the same place requires some perturbation of the environment. To go from conventional agricultural systems and practices to something that is less chemically oriented requires a pretty well-developed knowledge and experience base. Hence, we need research and education for practical alternatives.*

In these days of farm crisis, methods of more efficient production and of decreased ecological impact are crucial for the independent farmer and the process of farming in general. Many of the methods suggested for study by Dr. Liebman and his colleagues are not new and involve timeless methods of agriculture management: the use of legumes as a source of nitrogen, the practice of intercropping for weed and insect management, and the use of pastures as a primary feed source. *The combination of tradition and innovation,* however, has resulted in new agricultural advances that *may be the only hope for the farmers in the State of Maine.* And perhaps such practices in Maine will have regional, national, and worldwide effects.

LIEBMAN ON SUSTAINABLE, ALTERNATIVE, AND ORGANIC AGRICULTURE

The difference? It's not that easy you know. It's kind of an open discussion as to what the words actually mean.

When we talk about sustainable systems, we're talking about ways to protect the soil from eroding, ways to decrease dependence on purchased synthetic pesticides, and ways to begin to build into the system ecological dynamics that decrease the farmers' dependency on purchased inputs. What those actual practices are will change from farm to farm. Before I'm willing to see what things aren't, I'd like to see what they are.

I don't want to define boxes that people do or do not fit into; I want to talk about trends. So to say that sustainable agriculture is this, alternative agriculture is that, and organic agriculture is something else gets really difficult. In some ways I think it's better that it doesn't get too closely defined.

Ultimately what I'd like to see is a large coalition of people working towards a similar end of the spectrum, but that doesn't dictate what people have to do.

Test Plots: No-till planted beans in rye mulch in foreground, conventionally planted beans in background. Planting in a grain mulch is being tested as a method of natural weed control.

Just What IS An Animal?
Preschoolers Investigate

When you're only three or four years old, chances are good you've not yet had a chance to see an octopus up close, much less touch one. And even when you're older, you may well entertain vague notions that the creatures are tens of feet long and serve to threaten ships and divers with their long sucker-covered tentacles and faces only a mother could love.

Youngsters from the schools surrounding the University of Maine, however, get an opportunity during Animal Survey Week to see and touch an octopus (and to hear that they are huge vicious creatures only in science fiction and old horror movies).

The youngsters commonly range in age from two-and-a-half to five, and they are welcome to come on field trip visits to the animal laboratory which is maintained for the use of students in Biology 100 classes, the academic introduction to that discipline at the University of Maine.

Last April, the Lewis Libby School kindergarten class from Milford arrived 12 strong to investigate the laboratory, and later that week the University of Maine's preschool Child Study Center brought a dozen children to discuss and explore what an animal is.

Kevin Tracewski is the Laboratory Coordinator for the Biology 100 Animal Survey Lab, and he organized the first such visits about four years ago.

Everyone—youngsters, parents, teachers, and even University students—enjoy it so much that I plan to keep it going for the indefinite future.

Kids have some funny ideas about what animals are: they are usually convinced that the animal kingdom is confined to pet dogs, cats and ponies, with perhaps a few fictional creatures thrown in.

It's wonderful to see their faces when I begin to explain to them that animals are as diverse as worms and corals; leeches and shellfish. I'll admit we have trouble with the leeches however. They tend to escape through the aerating tube holes at night; crawl away under furniture or equipment, and not be found until they are desiccated remains, Tracewski mused.

We're fortunate to have cooperative colleagues at the Ira C. Darling Center in Walpole, Tracewski continued. *As the University's marine laboratory, they have all sorts of samples of marine life: clams, oysters, scallops, sea cucumbers, and so on.*

They provide living samples to us, and we can then use them with the youngsters as examples of native marine lifeforms. It also helps prepare the kids to notice and really see animals when they take trips to the coast.

During last April's visit, youngsters were amazed with a very large starfish (where its stomach was located and how it ate); they cheerfully accepted being squirted by a scallop; one youngster was repeatedly removed from the vicinity of the tarantula's glass case; baby rats were living examples of being born hairless; a delightful young fellow with a big grin let a couple of white mice loose, announced they were having a race, and was not particularly pleased when the adults managed to recapture them.

40,000 LEAGUES UNDER THE SEA—The real octopus that the children learned about and touched, on ice and in hand, came from the Gulf of Maine where it is fairly commonly found amid fishermen's catches. It was also of a typical size and not frightening at all compared to those of film and legend.

Tracewski said that very young children are one of his favorite age groups to teach about animals: *They aren't worried about grades and they aren't self-conscious about what they say. The little ones are surprised and open with the animals; their delight renews the wonder of biological sciences for all of us.*

NOT A RAT RACE — Nice mice were on hand to be observed in an especially playful fashion when released on the floor for impromptu speed competitions.

WHEN YOU GAZE UPON A STAR — Mysteries of where a starfish's stomach is, what and how it eats, and its ability to regenerate missing arms, elicited responses which ranged from touching the creature to the security of a finger quickly popped in mouth.

SOMETHING ABOUT AN OYSTER — Bivalves including oysters, clams and scallops were pulled out of cold water tanks and handed around for the young children to observe. This oyster behaved itself, but one large scallop copiously sprayed a number of squealing preschoolers with seawater.

TIME TO VISIT FAVORITES — After the formal part of the program when youngsters heard about animal diversity and touched specimens, they were free to return to their favorites and handle them in more detail. When you're very young, however, you need be inventive to get the creatures out of tanks and cages.

Merging Two Cultures
Our Cover Artist

In May of 1986, I graduated from the University of Maine with a degree in Animal and Veterinary Sciences. It seems to startle people that I would, after four years of studying sciences, commit myself to the making of artwork.

These reactions from others have sparked my realization that I have indeed been straddling two camps, two supposedly different ways of being. Scientific activity is thought to be rational, controlled, and concrete. Artistic activity is thought to be intuitive, spontaneous, and subjective. I feel that both of these stereotypes are false and limiting, and that serious creative exploration in both art and science would be similar.

My own motivation to make artwork stems from a need to relate scientific ideas and intuitive ideas. When I combine the two in a visual artistic form, a conflict or an ambiguity results. It is an exhilarating experience for me to search out this relationship and to resolve it pictorially. In the process I hope to transcend divisions, and create a picture which allows fact and fantasy to coexist with equal validity.

As an animal and veterinary science student I learned to appreciate the focused scientific study of specific animal functions. In my art, however, I couldn't limit my view of the animal to a mechanistic one described merely by feed-conversion-ratios and blood-glucose-levels.

I had to consider the animal which existed in the cultural imagination of different peoples, at different times, in different places. What does the animal mean to us? The animal has always been used as imagery in art: symbolically, literally, and ritualistically. The animal is a rich concept, still virtually unexplored.

In 1986, I wrote in my notebook,
What is the appropriate way for me to use my interest in animals, physiology, anatomy, ecology in art? The problem has always been the restrictiveness that I feel the Western conception of the animal places on Western traditional art. The emphasis is often on illusion: getting it to look objectively real, three-dimensional form, and some undefined sense of animal character. Yet in Alaska, I saw that Indian people had real knowledge of animals that came from deep experiences rather than control oriented manipulation of the lesser beasts. For them, animal imagery did not constitute genre art of a lower status, just as the animals themselves did not have less status in the scheme of things. In contrast, in the Western tradition the human figure and illusion have dominated. Drawings are successful if they look real in a superficial sense, if the skin appears to be modeled over invisible skeleton and muscle. Even if the artist truly knows the anatomy underneath, he shows it through subtle surface appearance. An Indian artist, on the other hand, might show the importance of internal organ systems in diagramming them boldly on the surface of the animal. Indeed what we as artists choose to show reflects what we think is important, whether that is optical reality or a mental concept.

I aspire to express the totality of my thinking, feeling, seeing, and sensing in my art. My latest work has been a series of intalgio prints entitled Moosehorn, Black Rhino, Man-Eater of Tsavo, Big Horn, Caribou, Grizzly Skin, and Bison.

I started by reading outdated accounts of big game hunts which gave me a feeling for the quest for the exotic trophy. A trophy requires an extensive and difficult quest toward

ACADEMICS

1983-1986	Travelli Scholarship Student
1984-85	Canada Year Student, University of British Columbia, Vancouver, Canada
1986	B.S. Animal and Veterinary Sciences, with High Distinction, University of Maine
1987	Studio Art Award, University of Maine
1988	Roger B. Hill Scholarship, University of Maine
1988	Honors Art Award, University of Maine
1988	Binney and Smith Art Achievement Award

Currently enrolled as senior in a B.A. Studio Art program, University of Maine

EXPERIENCE

Woodswork, Biological Aide work in Southeast Alaska, for U.S.F.S.
Parks Service Volunteer doing soils work in Southeast Alaska, for S.C.S.
Work-study with The Eagle Project, University of Maine
Work-study at Witter Animal Research Center, University of Maine
Goat husbandry on a ranch in Washington State

some control over powerful forces. The result is a material symbol: the trophy. In my making of the prints I tried to hunt the big game of my own fascination with exotic animals, not of the flesh so much as of the mind.

I used the medium of intaglio, a technical and nonspontaneous process whereby I was forced to plan strategies for my exploration of the images. Each image involves an overall acid-bitten pattern, a major symbol for an animal, and a submerged field of marks meant to resemble archaic written language, eroded by time.

On some, I took ghost prints that appear faded, and over these I wove stories written in a florid script with a fountain pen and old brown ink. I mixed stories of the moment of triumph over the man-eating tiger with those of the hunter becoming the hunted as the tiger turned to stalk him in the dense brush. A shopping list for a civilized British Safari (including Bromo-powder and lime juice cordial!) contrasts with goblin stories told by cowboys of sasquatch beasts.

The prints represent different forms of knowledge. They are both visual and verbal. They contain all kinds of communication through marks: imagery, pattern, pictographic marks, alphabetical language, all of which are symbols for other things. They have undefined areas that will remain so. For me, they are trophies of a successful hunt.

My artwork comes from a personal need to sort out ideas in a visual format. Although I do not presume that viewers will have the same response as myself, I can hope that through the elements of art (color, line, form . . .) the prints will convey a sense of the process I have attempted to describe.

MOI LASCAUX

Meditation on an orange orb
in a pillar of primitive, immoveable deep red,
pressed in upon,
blue waves crashed against it,
green herds trammelled it,
they couldn't move it either!
The problem for me became one of control
over the primitive red.
I tried to use magic
and yet maintain the monumental presence
of the pillar of red.
When the mushroom-shaman was submerged,
she reappeared in small scratchings,
that I mistakenly believed
originated from my own imagination.

—Caellaigh Bennett Desrosiers
1986

TURTLE TEMPLE

Reverence for the ancient creature
self-enclosed, meditative, centered thing
no muck-dweller is this!
no rough character
in its own environment
it is a radiant emblem
embodiment of knowledge
not digging down in shame
but rather bouyant in the glory of the order of things
not slow and waddling
but rather infinitely patient
not repulsive in its texture
but rather each horny nob consisting of compressed wisdom
dense, concentrated
the temple is necessary
to protect the internal eternity
from the limited vision of prying eyes
and poking sticks.

—Caellaigh Bennett Desrosiers
1987

Freezing and Photosynthesis

Physiological consequences of freezing to photosynthetic metabolism in the intertidal macroalgae *Chondrus* and *Mastocarpus*

by Steven R. Dudgeon,
Ian R. Davison and Robert L. Vadas

The full text of the following paper has been accepted for publication in *MARINE BIOLOGY.*

The lower intertidal of moderately exposed rocky shores in New England is dominated by two species of red algae, *Chondrus crispus* and *Mastocarpus stellatus* (Mathieson and Burns, 1971). A pure *Chondrus* stand occupies the lowest part of this zone, above which is a mixed assemblage of *Chondrus* and *Mastocarpus*, followed by a *Mastocarpus* zone (Mathieson and Burns, 1971; Green, 1983). Increased desiccation tolerance has been suggested as the factor that allows *Mastocarpus* to occur higher on the shore than *Chondrus* (Mathieson and Burns, 1971; Green, 1983). Desiccation is generally thought to control the upper limits of most intertidal algae (Zaneveld, 1969; Connell, 1972; Schonbeck and Norton, 1978; Hodgson, 1980; Lubchenco, 1980; Beer and Eshel, 1983).

Less attention has been given to the effects of freezing on intertidal algae (Kanwisher, 1957; Parker, 1960; Biebl, 1970; Bird and McLachlan, 1974; Green, 1983). Intertidal macroalgae in temperate or boreal regions may be exposed to freezing temperatures between November and March, with plants in the mid-to-upper intertidal potentially experiencing up to 8 hours exposure to temperatures as low as -20°C. Freezing reduces cell viability and adult and zygote survival in several seaweeds (Parker, 1960; Bird and McLachlan, 1974; Green, 1983). These studies suggest that freezing may be a factor controlling growth and survival of intertidal seaweeds.

Steven R. Dudgeon, a University of Maine Biological Sciences Ph.D. student working with Drs. Robert L. Vadas and Ian R. Davison, won the Best Student Paper award for his presentation Physiological consequences of freezing to photosynthetic metabolism in the intertidal macroalgae Chrondus and Mastocarpus *at the April, 1988, Annual Northeast Algal Symposium (NEAS) at Woods Hole, Massachusetts.*

In Maine, *Chondrus* exhibits considerable damage during the winter months (unpublished observations). This is most severe at the upper part of the *Chondrus* zone and in the mixed *Chondrus/Mastocarpus* assemblage where partial or complete loss of pigments and loss of biomass occur. In contrast, *Mastocarpus* appears unaffected. It is unlikely that the damage is due to desiccation, since this stress is probably more severe in summer than winter (Schonbeck and Norton, 1978). Green (1983) has shown that *Chondrus* is less tolerant of freezing than *Mastocarpus*, and that freezing can kill *Chondrus*. However, we have observed regeneration of erect thalli from crusts of *Chondrus* following freezing damage suggesting that freezing may not always be lethal.

Little is known about the effects of sub-lethal freezing stress on the physiology of marine macroalgae. Kanwisher (1957) concluded that the major effect of freezing, like desiccation, was dehydration, and that respiration was reduced under these conditions. Freezing stress has profound effects on photosynthesis in higher plants (Oquist, 1983; Strand and Oquist, 1985; Delucia, 1987; Bauer and Kofler, 1987). In contrast, the effect of freezing on photosynthetic metabolism in seaweeds is unknown. If photosynthesis in *Chondrus* is inhibited by freezing it may affect metabolic activity and reduce growth rates. Thus, prolonged exposure to freezing air temperatures on the upper shore may provide a mechanism excluding *Chondrus* from the *Mastocarpus* zone.

In this paper we describe the effect of freezing on photosynthesis in *Chondrus* and *Mastocarpus*. *Specifically we tested the hypothesis that photosynthesis in* Chondrus *is more susceptible to freezing than in* Mastocarpus. *We also investigated what aspects of photosynthetic metabolism are adversely affected by freezing.*

MATERIALS AND METHODS

Plant material

Chondrus crispus and *Mastocarpus stellatus* were collected from February to March 1987 from Chamberlain (43°56'N, 69°54'W) or Kresge Pt. (same coordinates as Chamberlain) Maine, USA. Plants were collected by hand at low water, transported to the laboratory in sea water, cleaned of visible epibionts and placed in plexiglass aquaria containing 6 dm^3 of aerated GF/C (Whatman), filtered, enriched sea water (Provasoli, 1968). Cultures were maintained at 2.5°C at 60 ± 5 umoles photons $m^{-2}s^{-1}$ on a 16:8 L:D cycle. Plants were used in experiments within 10 days of collection from the shore.

The zonation of *Chondrus* and *Mastocarpus* was determined at Kresge Pt. and Chamberlain by measuring percentage cover of the two species at two randomly selected plots at 1 meter intervals along a surveyed vertical transect. Percentage cover was estimated using two superimposed (to reduce parallax) 20 x 20 cm square plexiglass quadrats, each containing 100 randomly distributed dots (Lewis, 1986).

Effect of freezing on photosynthesis

Three groups of apices (ca. 0.5 cm) of *Chondrus* and *Mastocarpus* were placed in the following conditions: in seawater at 2.5°C, in air at 2.5°C and in air at -20°C for 1,3,6,12 and 24 hours. All treatments were in darkness. Following the above treatments photosynthesis was measured by incubating apices for 30 minutes at 15°C at a saturating photon flux density of 450 umole photons $m^{-2}s^{-1}$ (Mathieson and Burns, 1971) in 200 ml of pH 8.0 seawater containing 10 uCi $H^{14}CO_3$ in a total HCO^-_3 concentration of 2 mM. Carbon-14 incorporation by the plants was measured as described by Davison and Davison (1987).

Rates of evaporation in air at 2.5 and -20°C were determined by the following changes in fresh weight over 24 hours. Total water content was measured by drying at 60°C for 24 hours. Evaporative water loss was determined by calculating the percent of water lost over each time period. The percentage of cellular water present as ice was measured using the calorimetric method of Kanwisher (1957). This method does not distinguish between intracellular and extracellular frozen water. We assume that, given these species close taxonomic affinity, the extracellular volume of the two species is similar. Total cellular dehydration of frozen thalli was defined as the sum of evaporative water loss plus the percent of frozen cellular water. Dehydration in nonfrozen plants was due solely to evaporation.

Recovery of photosynthesis after freezing at -20°C was measured by freezing apices (0.5 cm) of both species for 1,3,6,12 and 24 hours. Photosynthetic rates were measured in a subsample of the apices immediately after freezing and following 24 and 48 hour recovery periods in 2.5°C seawater and 60 umole photons $m^{-2}s^{-1}$ irradiance.

Effect of freezing on membrane permeability

To determine the effect of freezing on the plasmalemma membrane, apices of both species were placed in one of 3 treatments: seawater at 2.5°C, air at 2.5°C and frozen in air at -20°C for 1,3,6,9 and 12 hours. After these treatments apices were placed in vials containing 5.0 ml of millipore filtered seawater and set in a shaker bath at 15°C at a photon flux density of 100 umoles $m^{-2}s^{-1}$. Samples (0.5 ml) were taken from each vial prior to introducing an apex and following incubation for 5,10,15,20 and 30 minutes. Samples were assayed for total amino acids as described by Rosen (1957).

Total cellular amino acids content of untreated apices of *Chondrus* and *Mastocarpus* was measured by extracting 0.5 g fresh weight samples twice in boiling 80 percent ethanol. Amino acids in the pooled extracts were measured as described above.

Effect of freezing on in vivo *phycoerythrin fluorescence*

The effect of freezing on light harvesting reactions of photosynthesis was determined by following changes in *in vivo* phycoerythrin fluorescence at 20°C (phycoerythrin is the dominant accessory pigment in both species; Buggeln and Craigie, 1973) at an excitation wavelength of 380 ± 10 nm in a Perkin-Elmer model 650-10S spectrofluorometer. Phycoerythrin fluorescence peaked at 580 ± 10 nm, corresponding to the fluorescence characteristics of purified phycoerythrin (Porter et al., 1978; Sibbald and Vidaver, 1987). The phycoerythrin excitation peak at 380 nm was chosen rather than the (major) peaks at 490 and 540 nm to avoid the possibility that emitted light detected at 580 nm was due to scattering of the excitation beam by cell walls rather than fluorescence. Preliminary experiments indicated that negligible leakage of phycoerythrin occurred from either *Chondrus* or *Gigrtina* following freezing at -20°C. Thus, increased phycoerythrin fluorescence under these conditions reflected changes in *in vivo* fluorescence of phycoerythrin rather than *in vitro* fluorescence of extracellular phytopigment. Attempts to measure *in vivo* chlorophyll fluorescence at 20°C were unsuccessful.

Three (1.4 cm) sections were cut from 10 plants of each species. Each section was placed in a 1 cm fluorescence cuvette in 3 ml of millipore filtered seawater. Cuvettes were placed in darkness for 1 hour at 2.5°C after which initial phycoerythrin fluorescence was measured. Fluorescence increased rapidly following exposure to the excitation beam and remained stable over the 15-30 seconds required for each measurement. Following initial measurements each cuvette was assigned to one of three treatments: seawater at 2.5°C, air at 2.5°C or frozen in air at -20°C. All samples were kept in darkness throughout the experiment. Fluorescence was measured at 3,6,12 and 24 hours after the start of the experiment and after adding 3 ml of 20°C seawater to the cuvettes. After each fluorescence measurement water was removed from cuvettes (except in water controls) and plants were returned to experimental conditions.

Recovery of fluorescence following freezing was determined by freezing sections of thalli of both species for 6 hours at -20°C and placing them in 2.5°C seawater in darkness. Fluorescence was measured prior to and after freezing, and following 3,6,12 and 31 hour recovery periods.

Effect of freezing on RUBISCO activity

Thallus samples (0.5 g fresh wt) of both species were assayed for enzyme activity of RUBISCO after freezing 3,6, and 12 hours at -20°C. RUBISCO carboxylase activities were assayed as described previously (Davison and Davison, 1987). (RUBISCO: ribulose-1, 5-bisphosphate carboxylase oxygenase).

Statistical Analyses

Data from experiments measuring phycoerythrin fluorescence were analyzed using a non-parametric multiway ANOVA on the ranks and calculating the Kruskal-Wallis statistic to test the level of significance (Zar, 1984). All other experimental data were subjected to multiway ANOVA. Raw data values were used for statistical analyses where percentages are expressed graphically because experimental values occasionally exceeded control values prohibiting use of angular transformation. All statistical analyses used the Statistical Analysis System (SAS - version 5.16).

RESULTS

Zonation of Chondrus *and* Mastocarpus

The vertical distribution of *Chondrus* and *Mastocarpus* at 2 sites on the Pemaquid peninsula is shown in Table 1. Three zones are recognized; a low zone (< 0.5 m above MLW) a mid-low zone (0.5 - 0.75 above MLW) and a mid-high zone (> 0.75 m above MLW). *Chondrus* dominates the lowest zone at Kresge Pt. and Chamberlain covering approximately 74 percent and 63 percent of space, respectively. *Mastocarpus* is rare in this region. *Chondrus* is much less abundant in the mid-low zone and is virtually absent above + 0.75 m MLW. *Mastocarpus* occupies more space than *Chondrus* in the mid-low zone at both sites and is the dominant understory plant in the mid-high zone. The canopy above + 0.75 m at these sites is composed primarily of *Fucus* spp. Similar zonation patterns occur on other moderately exposed rocky shores along the Maine coast.

Effect of freezing on photosynthetic rates

Initial photosynthetic rates of *Chondrus* and *Mastocarpus* were 14 and 10 umoles C-fixed g^{-1} fwt hr^{-1}, respectively. Freezing at -20°C adversely affected photosynthetic rates in *C. crispus* (Figure 1a). After 3 hours at -20°C photosynthesis was reduced to 30 percent of control values and to less than 15 percent after 6 hours. Photosynthesis in *M. stellatus* was unaffected after 6 hours at -20°C and reduced to 50 percent after 12 hours (Figure 1b). A significant difference in photosynthetic tolerance to freezing existed between the two species (F = 28.53, p < .0001). Photosynthetic rates of both species maintained in air at 2.5°C were similar to water controls.

Rates of cellular dehydration of frozen and nonfrozen thalli of both species were similar (Figure 2). However, frozen thalli of both species initially dehydrated slightly more rapidly than nonfrozen thalli. Although evaporative losses from frozen plants were less than those of air-exposed plants, dehydration rates were greater in the frozen group because most of the tissue water was present as ice. Following 3 hours at -20°C *Chondrus* experienced 65 percent dehydration, in contrast to 49 percent dehydration experienced by thalli at 2.5°C (Figure 2a). The difference in the initial rate of dehydration between frozen and nonfrozen *Mastocarpus* thalli was less. In both species the degree of evaporation in nonfrozen thalli was slightly greater than the degree of dehydration in frozen thalli following exposures of 5 hours or more. Six hours at 2.5°C resulted in approximately 85 percent dehydration in both species, with *Chondrus* exhibiting a similar rate of dehydration following 6 hours at -20°C. In contrast, *Mastocarpus* only experienced 65 percent dehydration following 6 hours at -20°C (Figure 2b). Although both species lost water by evaporation at similar linear rates, the rate of freeze-induced dehydration in *Chondrus* was greater than in *Mastocarpus* because a greater proportion of cellular water was frozen.

In addition to differences in freezing tolerance of photosynthesis there were significant differences in the ability of the two species to recover from freezing stress (F = 20.73, p < .0001; Figure 3). A 48 hour recovery period was necessary to reestablish control level photosynthetic rates of *C. crispus* fronds frozen 3 hours or less (Figure 3a). Although photosynthetic rates of *C. crispus* frozen 6 hours approached control levels after 24 hours, they declined again to 32 percent of control levels after 48 hours (Figure 3b). Fronds of *C. crispus* frozen longer than 6 hours recovered less than 50 percent of their normal photosynthetic rate in 48 hours (Figure 3c,d).

Membrane permeability

The permeability of plasma membranes to amino acids in *C. crispus* increased under freezing stress (Figure 4a). Freezing 3 hours resulted in a 40 percent loss of total amino acids within 30 minutes of reimmersion in seawater. The damage to the membrane increased with the duration of freezing. Freezing 6 hours resulted in a 50 percent loss and freezing 12 hours caused an 86 percent loss of total cellular amino acids. Control and air exposed apices typically lost 10 percent of their amino acid content into seawater. In all cases the majority of amino acid release occurred within 5 minutes of reimmersion in seawater (unpublished data).

Freezing had little effect on membrane permeability of *M. stellatus* (Figure 4b). Only 18 percent of total amino acids were released after 12 hours at 20°C. Similarly, water control and air exposed apices lost approximately 10 percent of their amino acids upon reintroduction to seawater, primarily within the first 5 minutes.

The difference in plasma membrane permeability under freezing stress between the two species was highly significant ($F=44.94$, $p < .0001$).

Phycoerythrin fluorescence

Freezing at -20°C resulted in increased *in vivo* phycoerythrin fluorescence in both species (Figure 5). However, there was a significant difference between the species (Kruskal-Wallis $H = 9.46$, $p < .005$). Phycoerythrin fluorescence in *C. crispus* tripled after 6 hours at -20°C, whereas in *M. stellatus* it doubled relative to controls. Fluorescence values of controls of the two species were similar.

The rate of recovery to normal fluorescence levels after 6 hours at -20°C was identical in both species (Figure 6; $H = 0.18$, $p > .99$). However, because the initial damage in *Chondrus* was greater, the actual recovery time was longer.

Carbon Fixation

Twelve hours exposure to -20°C had little effect on the activity of RUBISCO in either species (Table 2). There was no significant difference in RUBISCO activity between the two species in response to freezing ($F = 0.03$, $p = .855$).

DISCUSSION

The results of this study indicate that photosynthetic metabolism of *M. stellatus* is more tolerant of freezing than that of *C. crispus*. Photosynthesis in *C. crispus* rapidly declined following 3 hours at -20°C, declining further with longer freezing exposures. Recovery of normal photosynthetic rates in frozen *Chondrus* plants was slow. Full recovery from 3 hours at -20°C required about 48 hours. Plants exposed to -20°C for 6 or more hours did not regain full capacity within 48 hours. In contrast, photosynthesis in *M. stellatus* was not significantly affected by exposures of < 12 h at -20°C. Full photosynthetic recovery in *M. stellatus* was achieved within 24 hours. Thus, in nature *Chondrus* thalli may not fully recover from freezing before being frozen again during the next low tide, whereas *Mastocarpus* probably regains full photosynthetic capacity. The reduced metabolic rates observed in macroalgae are similar to reductions observed in higher plants (Oquist, 1983; Delucia, 1987).

Freezing caused considerable damage to the plasma membrane of *C. crispus* making it more permeable to amino acids. As the duration of freezing increased, so did the loss of amino acids. Freezing had relatively little effect on plasma membrane permeability in *M. stellatus*. Significantly fewer amino acids were released after freezing in *M. stellatus* than in *C. crispus*.

Temporary loss of membrane integrity could have two effects. First, it could result in a loss of fixed carbon and nitrogen, potentially reducing growth rate and stimulating growth of deleterious bacterial epiphytes, and second, it could adversely affect metabolic processes, such as the active uptake of bicarbonate across the plasmalemma (Kerby and Raven, 1985), and, hence, reduce photosynthesis. We suggest the greater damage to the plasma membranes sustained by *C. crispus* may result in greater reductions in metabolic activity and in growth rate compared to *M. stellatus*. The maintenance of high photosynthetic rates in *M. stellatus* after freezing may be due, in part, to the resistance of the membranes to alteration during freezing. Thus, the greater stability of cellular membranes in *Mastocarpus* may be an adaption enabling survival higher on the shore.

Studies of terrestrial species also suggest that plasma membranes are a focal point of freezing-induced damage in non-acclimated plants (Gordon-Kamm and Steponkus, 1984; Singh and Johnston-Flanagan, 1987). Like *Chondrus* and *Mastocarpus*, damage to the membrane increases with the duration of freezing culminating in cell death (Singh and Johnston-Flanagan, 1987).

Decreased efficiency of energy transfer from phycoerythrin to the photosystem II reaction center of chlorophyll following freezing may also adversely affect photosynthetic rates (Porter *et al.*, 1978; Ohki *et al.*, 1987; Sibbald and Vidaver, 1987). Phycoerythrin fluorescence increased more in frozen *Chondrus* plants than in frozen *Mastocarpus*, presumably because the degree of disruption to energy transfer was greater. Since phycobiliproteins are directly attached to the thylakoid membrane (Gantt, 1981) it is possible that disruption of energy flow between pigment molecules results from freeze-induced alterations to the membranes that physically displace the phycobiliproteins. However, recovery rates of photosynthesis and phycoerythrin fluorescence were not closely coupled (compare Figures 3 and 6) suggesting that other factors may be more important in regulating photosynthesis. For example, freezing may cause a physical or functional loss of phycobilisome integrity (resulting in reduced light absorption and fluorescence emission), adversely affect photosynthetic electron transport or other photosynthetic processes. Nonetheless, our data do indicate that the photosynthetic light reactions of *Mastocarpus* are more tolerant of freezing than that of *Chondrus*. *Mastocarpus* may possess a mechanism protecting it from desiccation induced membrane photodamage as has been reported in high intertidal species of the red alga, *Porphyra* (Satoh and Fork, 1983; Sibbald and Vidaver, 1987).

Overall, the results on amino acids release and phycoerythrin fluorescence suggest that a major consequence of freezing in macroalgae is damage to the cellular membranes. This adversely affects photosynthesis because of the loss of metabolites and disruption of transmembrane ion transport and energy transfer. Twelve hours of -20°C had little effect on the activities of RUBISCO in either species (Table 2). Although activities declined slightly, and may have declined further under lower temperatures and/or longer exposures, they could account for very little of the observed reduction in photosynthetic rate.

Freezing, like desiccation, causes cellular dehydration which results from ice crystal formation as well as evaporation (Kanwisher, 1957; Green, 1983). Dehydration in air exposed thalli results from evaporation only. The results of this study suggest that freezing dehydrates plants more rapidly than would occur during non-freezing winter exposures (Figure 2). It is possible that dehydration through ice formation, or the ice crystals themselves, may be the means of damaging the plasma and thylakoid membranes and reducing photosynthetic rates. Therefore, the slightly lower percentage of water frozen in *Mastocarpus* compared to *Chondrus* and the greater tolerance of *Mastocarpus* to evaporative water loss (Mathieson and Burns, 1971; Green, 1983) may confer greater freezing and desiccation tolerances as suggested by Kanwisher (1957). The lower percentage of water frozen in *Mastocarpus* than *Chondrus* may be due to increased concentrations of cell solutes; a mechanism of frost hardiness reported in higher plants (von Swaaij *et al.*, 1985). However, this requires confirmation by further research.

The *Mastocarpus* plants used in this experiment grew slightly higher on the shore than *Chondrus* and, therefore, had been exposed to more severe and frequent freezing prior to collection and use in experiments. It is possible that the differences reported here are due, at least in part, to phenotypic acclimation rather than to species-specific genetic differences. Exposure to chilling temperatures induces greater freezing tolerance in crop species (Guy and Haskell, 1987); Singh and Johnson-Flanagan, 1987). The relative importance of phenotypic acclimation and genetic adaptation in determining the freezing tolerances of *Chondrus* and *Mastocarpus* is currently being investigated.

Freezing damage to photosynthetic metabolism suggests that frequent freezing may be an important factor influencing intertidal zonation of macroalgae inhabiting temperate and sub-arctic shores. It may influence zonation in two ways; as disturbance or stress. Extreme exposures could be lethal to macroalgae (Green, 1983) and, thus, act as a disturbance (*sensu* Grime, 1979). Sub-lethal freeze-induced reductions in photosynthesis, and other aspects of metabolism, may reduce growth rates and, hence, competitive ability of dominant macroalgae such as *Chondrus*, (Lubchenco, 1980) allowing coexistence. Such limitation of productivity results from stress (*sensu* Grime, 1979). An accumulation of stressful exposures may result in physiologically inactive tissue that slows plant growth and prevents monopolization of space by a species.

ACKNOWLEDGEMENTS

The authors would like to thank Dr. Larry Mayer, Linda Schick and the staff of the Ira C. Darling Center for use of the fluorescence spectrophotometer, hospitality, and for providing other facilities. Thanks are also due to E.J. Podolak for laboratory assistance. This research was supported by a University of Maine Center for Marine Studies research assistantship to Steve Dudgeon, in part by a National Science Foundation Grant (OCE- 8700763) to I.R. Davison, and by Maine Agriculture Experiment Station funds to R.L. Vadas.

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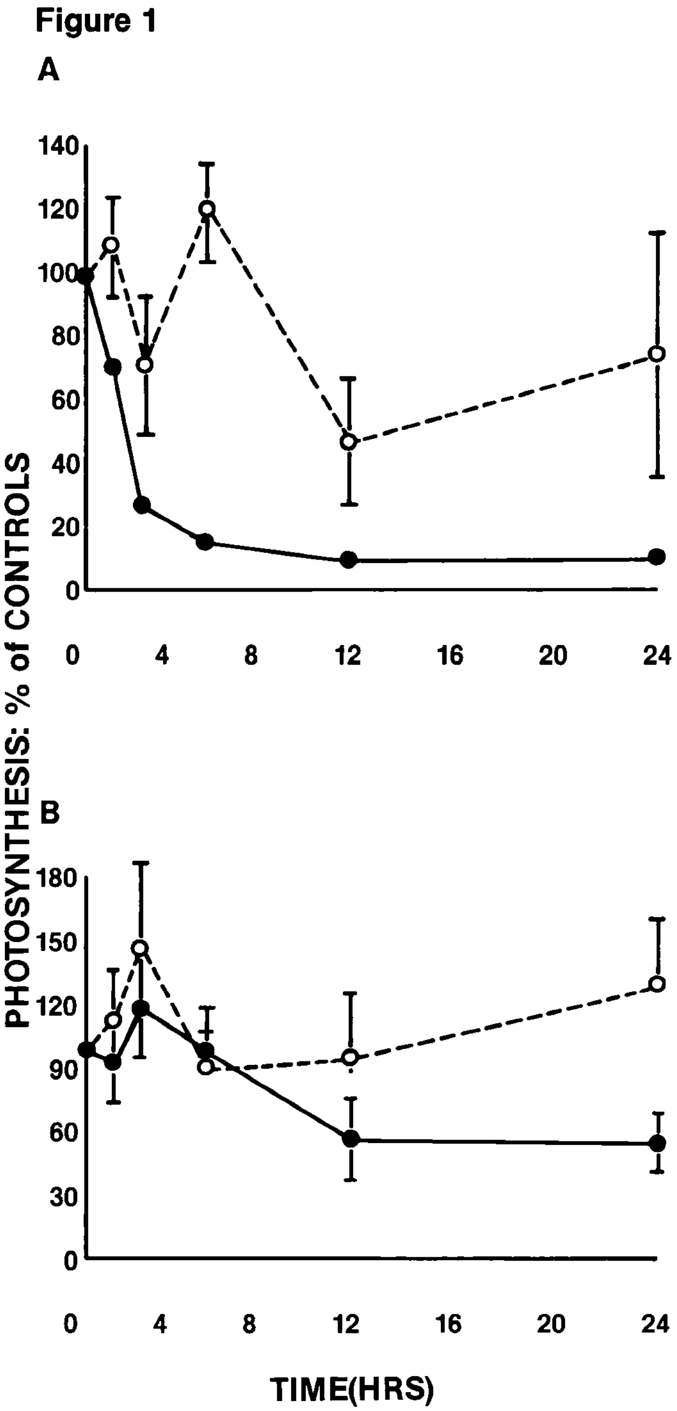
Table 1. *Chondrus* and *Mastocarpus*. Percent cover at 3 tidal levels at two moderately exposed rocky shores. n = number of 20 x 20 cm quadrats. Values are mean percentages +/– standard error (in parentheses).

Tidal Elevation	Kresge Pt. canopy	Kresge Pt. understory	Chamberlain canopy	Chamberlain understory
Low (+ .50 m MLW)				
	n = 20		n = 4	
Chondrus	73.4 (6.4)	71.9 (6.3)	62.8(13.7)	64.5(14.0)
Mastocarpus	4.0 (1.4)	5.3 (2.1)	0.0	0.0
Mid-low (.50 - .75 m above MLW)				
	n = 8		n = 4	
Chondrus	20.9 (9.8)	41.5(10.9)	28.5(20.8)	32.5(15.6)
Mastocarpus	35.8(11.3)	50.1(10.0)	38.3(23.4)	58.0(16.8)
Mid-high (.75 m above MLW)				
	n = 6		n = 4	
Chondrus	0.0	1.6 (1.6)	0.0	0.0
Mastocarpus	31.8(18.8)	65.6(15.8)	0.0	59.3(20.6)

Table 2. *Chondrus* and *Mastocarpus*. Effect of freezing for 12 h at – 20°C on carboxylase activity of RUBISCO. Activities expressed as umoles C fixed g^{-1} fwt/h^{-1}. Value refer to means with 95% CI given in parentheses (n = 3).

Species	Controls	12 hrs. @ – 20°C
Chondrus	0.0523(.028)	0.0444(.039)
Mastocarpus	0.1354(.048)	0.1251(.045)



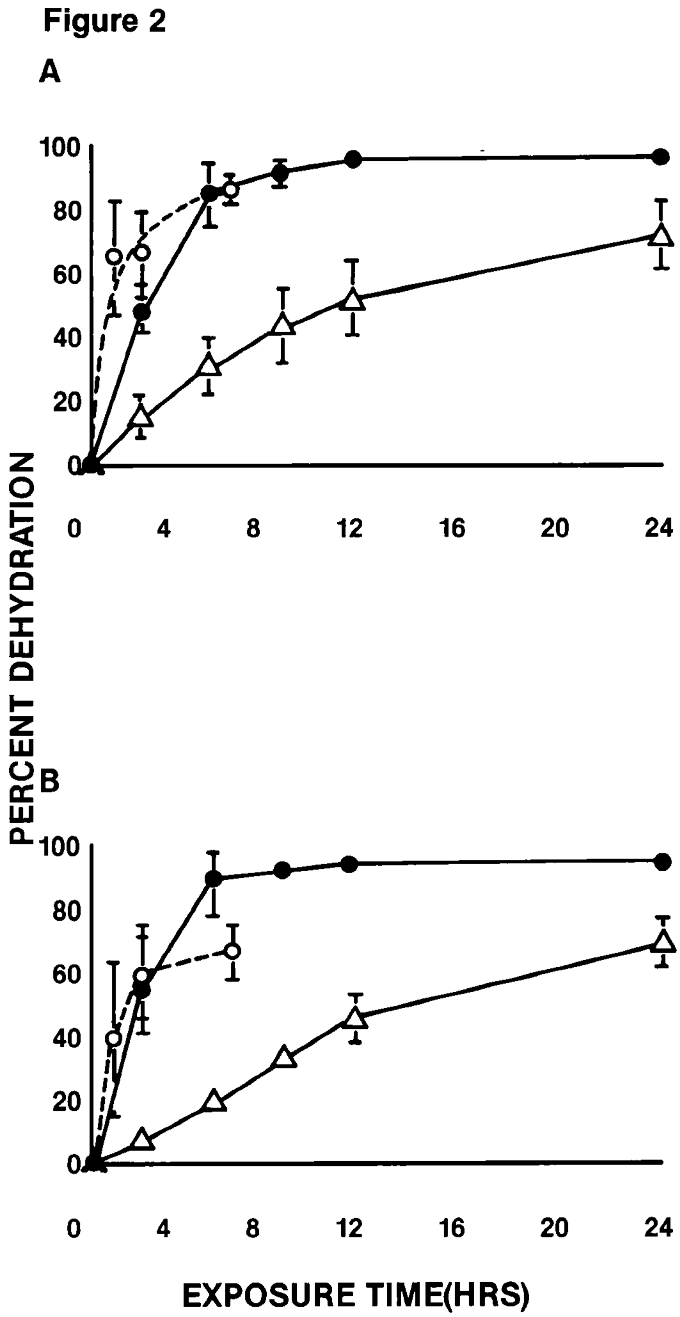


Figure 1: *Chondrus crispus* and *Mastocarpus stellatus* Effect of varying periods of exposure at 2.5 (open circles) or -20°C (closed circles) on photosynthetic rates as % controls mean ± 95%. CI (n=5).

Figure 2: *Chondrus crispus* and *Mastocarpus stellatus* Rates of dehydration and evaporation in frozen and non-frozen macroalgae: evaporation at 2.5°C (closed circles), evaporation at -20°C (triangles) and total dehydration (total evaporative loss plus frozen water) at -20°C (open circles). Percent dehydration means ± 95% CI (N=5).

Figure 3

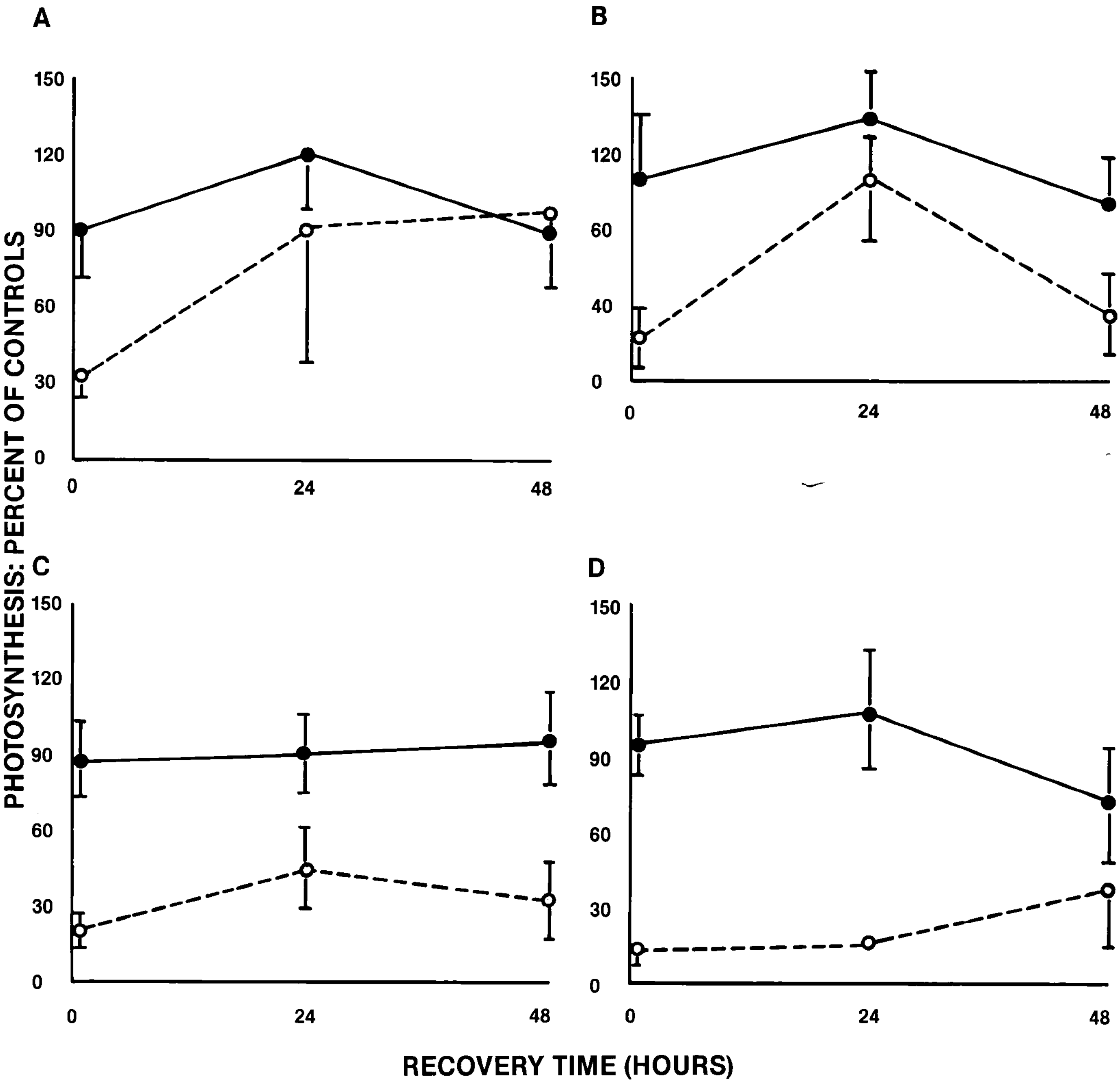


Figure 3: *Mastocarpus stellatus* and *Chondrus crispus* Recovery of photosynthesis in *C. crispus* (open circles) and *M. stellatus* (closed circles) following (A) 3 hours, (B) 6 hours, (C) 12 hours and (D) 24 hours at -20°C. Vertical bars denote 95% CI (n=5).

Figure 4

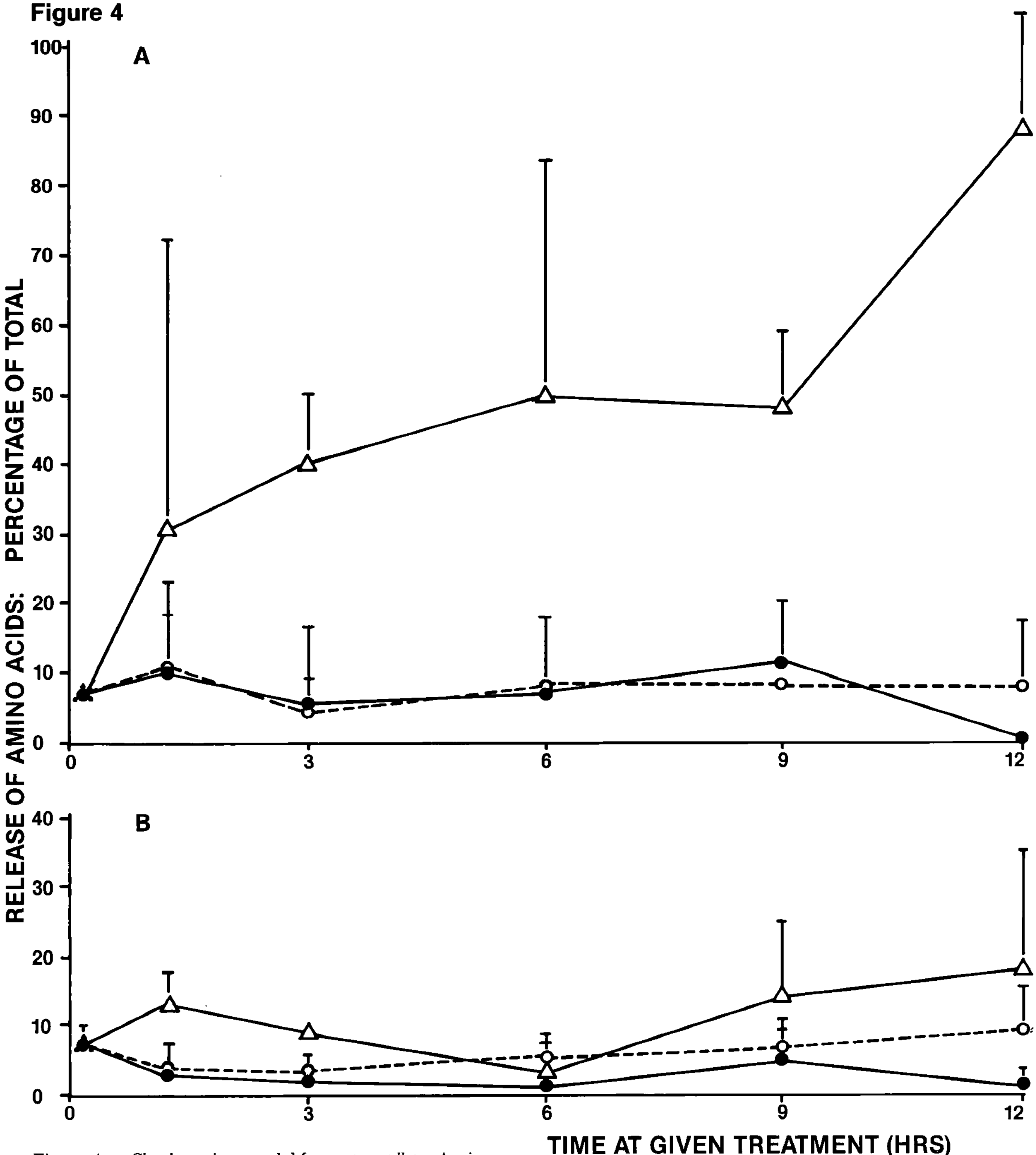


Figure 4: *Chondrus crispus* and *Mastocarpus stellatus* Amino acid release in (A) *C. crispus* and (B) *M. stellatus* following exposure in: water at 2.5°C (open circles), air at 2.5°C (closed circles), or air at -20°C (triangles). Vertical bars denote 95% CI (n=3).

Figure 5

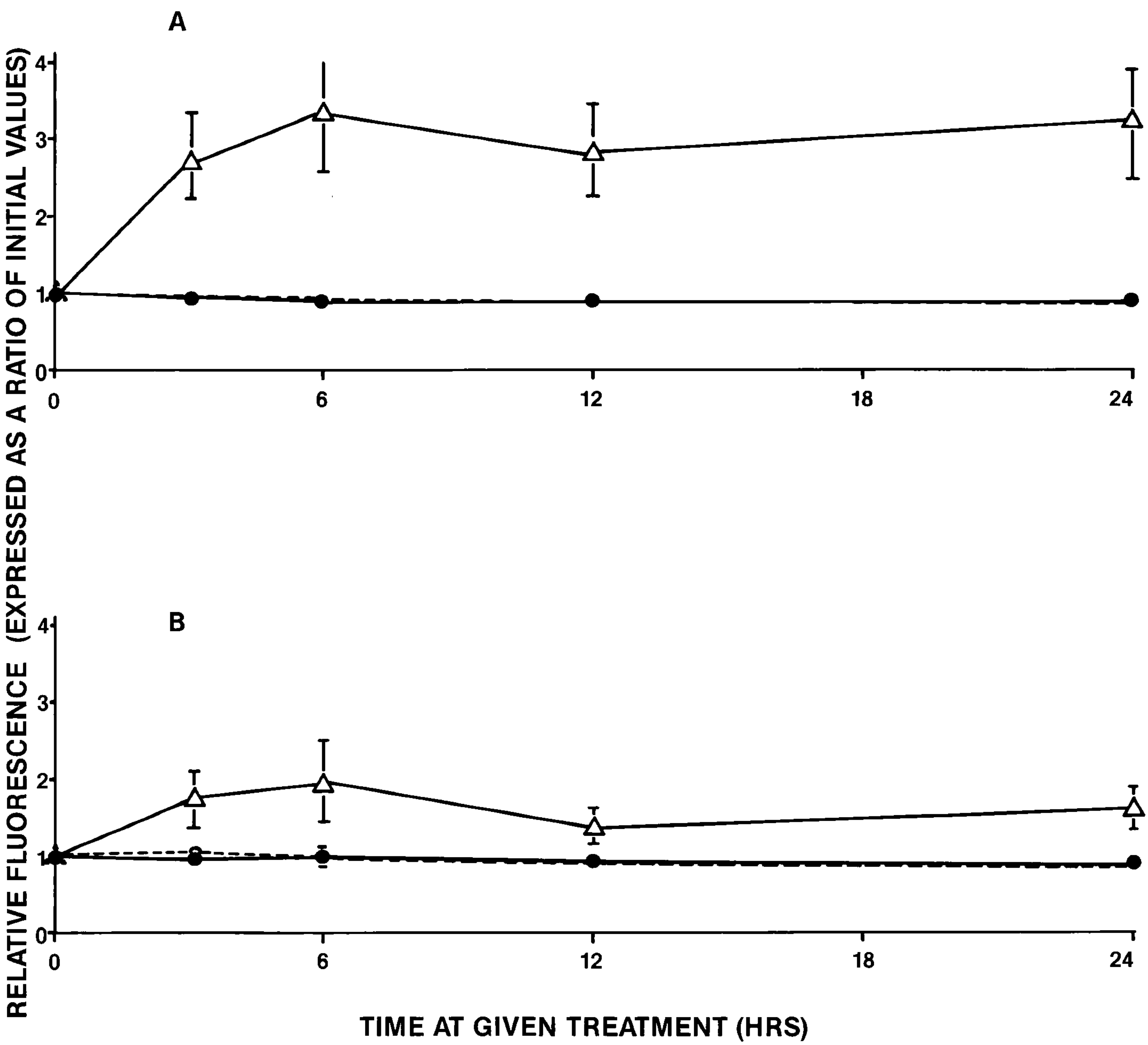


Figure 5: *Chondrus crispus* and *Mastocarpus stellatus* Phycoerythrin fluorescence in (A) *C. crispus* and (B) *M. stellatus* following exposure to -20°C for varying time periods. Graphs present data for plants in water at 2.5°C (open circles), in air at 2.5°C (closed circles) and at -20°C (triangles). Vertical bars denote 95% CI (n=10).

Figure 6

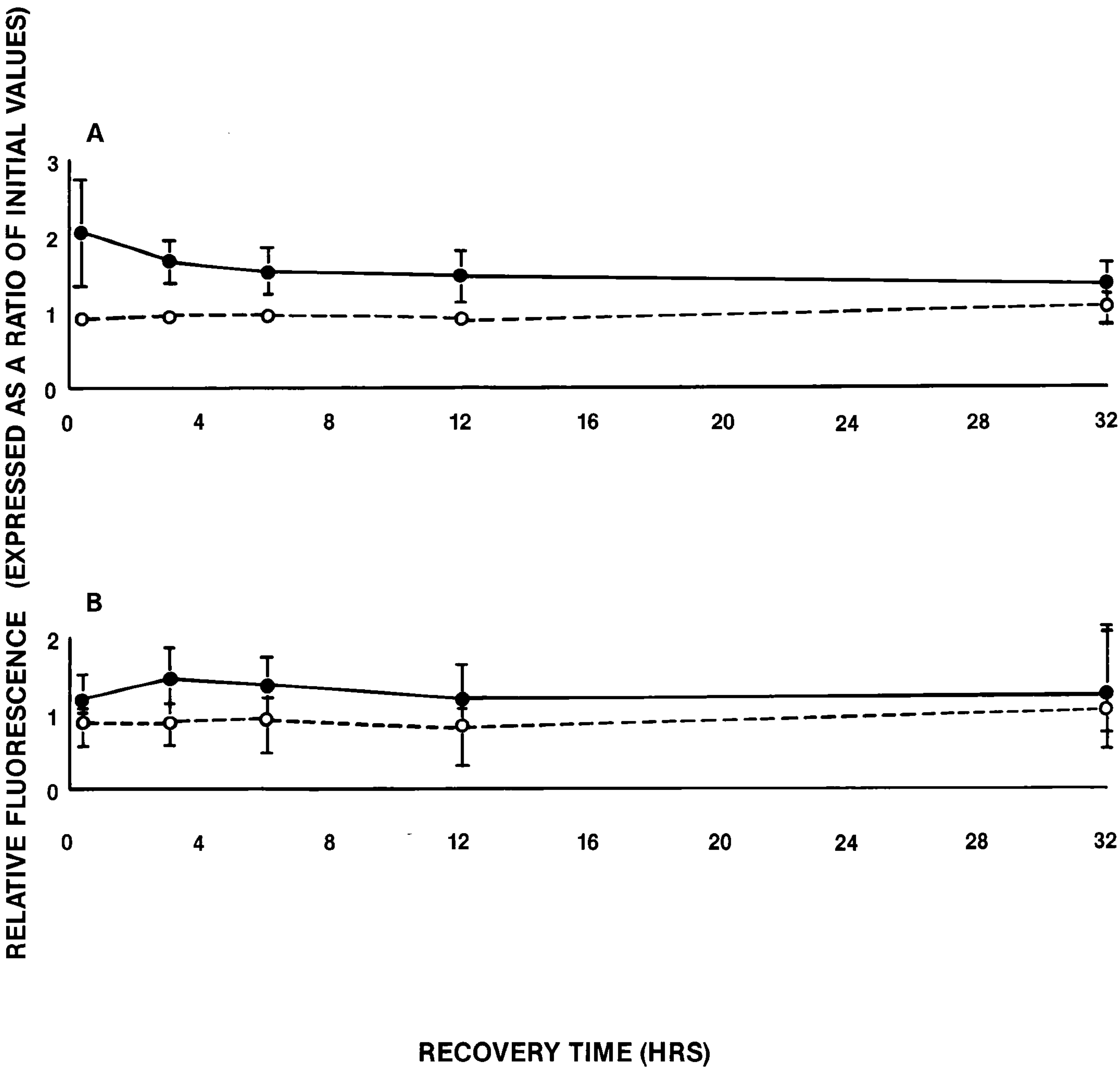


Figure 6: *Chondrus crispus* and *Mastocarpus stellatus* Phycoerythrin fluorescence in (A) *C. crispus* and *M. stellatus* as a function of recovery time following 6 hours at -20°C. Graphs present data for plants at 2.5°C (open circles), and -20°C (closed circles). Vertical bars denote 95% CI (n=10).

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