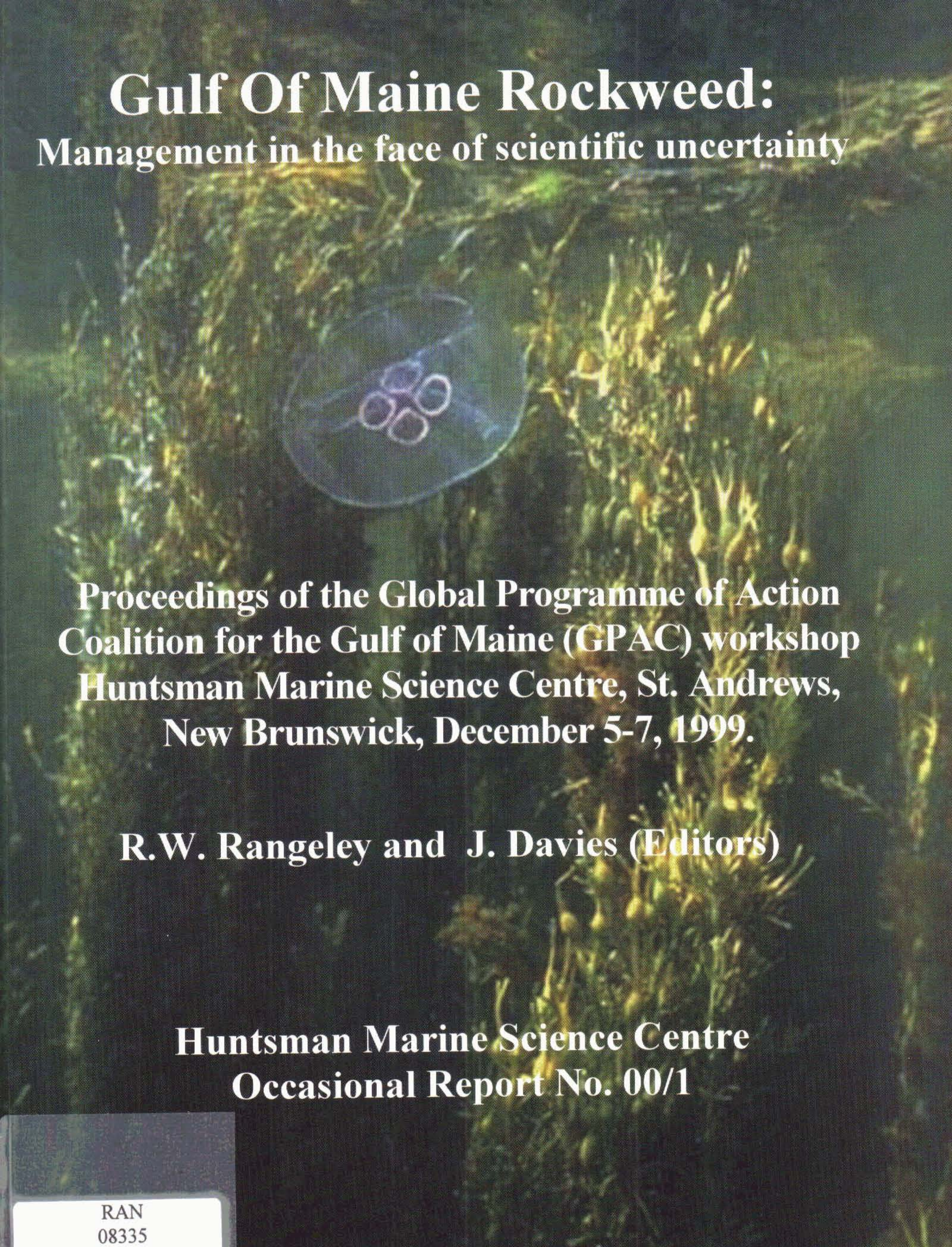

Gulf Of Maine Rockweed:

Management in the face of scientific uncertainty

Proceedings of the Global Programme of Action Coalition for the Gulf of Maine (GPAC) workshop Huntsman Marine Science Centre, St. Andrews, New Brunswick, December 5-7, 1999.

R.W. Rangeley and J. Davies (Editors)

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ACKNOWLEDGEMENTS

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- Commission for Environmental Cooperation (CEC)
- New Brunswick Department of Fisheries & Aquaculture
- Maine Department of Marine Resources
- Canadian Department of Fisheries & Oceans
- Environment & Sustainable Development Research, UNB
- St. Croix Estuary Project (SCEP)

The workshop steering committee consisted of Mark Bader, Mick Burt, David Coon, Jessie Davies, Phil Holmes, Tom McEacheron, Linda Mercer, Gerhard Pohle, Robert Rangeley and Glyn Sharp. Additional help was provided by Heidi Leighton, of the Cobscook Bay Resource Center and Haseeb Randhawa, HMSC, who assisted with summarizing the presentations and discussions.

Cover photo credit: Sue Scott. Email: **ssstrome@aol.com**
These proceedings may be downloaded from the SCEP web site: http://personal.nbnet.nb.ca/scepnet/titlepage.html

FOREWORD

The Global Programme of Action Coalition for the Gulf of Maine (GPAC), was brought together by the Commission for Environmental Cooperation (CEC), a North American organization which fosters environmental cooperation on transboundary issues between the United States, Canada and Mexico. This bi-national project is in response to the United Nations Environment Programme's global action plan to reduce degradation of marine and coastal environments. It is internationally recognized that about eighty per cent of marine pollution is caused by human activities on land. GPAC has been working to facilitate the implementation of the United Nations' global plan through the various communities, organizations, industries and governments of the Gulf of Maine. The Global Programme of Action for the Protection of the Marine Environment from Land-based Activities, usually abbreviated to the Global Programme of Action or simply the GPA, was developed and adopted by the United Nations Environment Programme on November 3, 1995. The GPA calls for actions by each signatory nation to preserve and protect the marine environment on a national, regional and international basis in order to reach the goal of "sustainable seas". The GPA goes into detail on recommended approaches for nine different source categories such as sewage, heavy metals, and physical alterations.

In North America, the Commission for Environmental Cooperation (CEC) was created as a result of the North American Free Trade Agreement (NAFTA) negotiations to facilitate cooperation and public participation to foster conservation, protection and enhancement of the North American environment. In pursuing its mandate, the CEC decided to promote a series of pilot projects in North America to implement the GPA, and selected the Gulf of Maine (GOM) as a candidate site for one of the projects. CEC brought together a diverse group of individuals with an interest in the GOM and the GPA to develop and implement a project of their own design, with some support from the CEC. The group, which has named itself the GPA Coalition for the Gulf of Maine, has formulated an action plan to (1) focus on regional problems and issues and (2) engage a broad, multi-sectoral support base to implement actions at the local and regional levels.

On November 15-17, 1998 under the sponsorship of the Global Programme of Action Coalition for the Gulf of Maine (GPAC), over 140 stakeholders from the region reviewed existing activities, identified gaps in current environmental protection and land-use programs, and developed an action package to reduce pollutants and protect and manage habitats. The Portland workshop was a follow-up to the GPAC workshop held earlier in April of 1998.

Sixteen top strategies were proposed at the Portland workshop to reduce priority regional pollutants and other human impacts on critical marine habitat. After careful review, the GPAC recommended that the Commission for Environmental Cooperation provide seed funding for five activities. The 'Gulf of Maine Rockweed' workshop is one of the products of the CEC and GPAC initiative.

EXECUTIVE SUMMARY

Over 60 people attended and enjoyed lively discussions in formal and informal sessions. Workshop participants included scientists from federal, provincial and state governments, universities and industry. Non-scientist representation included those from the seaweed harvesting industry, various NGO's, universities, and government resource managers; there was also interested individuals from various coastal communities and good media coverage.

The workshop was considered a great success judging from all the positive feedback we've received. The scientific talks stimulated a considerable amount of discussion and highlighted additional problems and some solutions to a growing list of conservation concerns facing our coastal environment. The Working Group tackled their assigned questions with enthusiasm and delivered large volumes of questions and recommendations. Subsequent plenary discussions helped to focus the deliberations which then lead to a list of specific research recommendations and mechanisms or tools for getting things done.

The objective of the Workshop was to identify knowledge gaps in our understanding of the role of rockweed as an essential habitat and the consequences of ecosystem-level changes to rockweed populations in the Gulf of Maine. It became clear throughout the workshop that determining ecologically sustainable harvest levels and management recommendations for a species at a low trophic level is a complex and difficult problem.

At present, very limited knowledge exists with which we can assess the impacts of harvesting macroalgae. There was a considerable amount of success in defining knowledge gaps and to some extent prioritising them. Nevertheless, **the final list of studies requiring immediate attention remains daunting**. Recurrent themes included grappling with scientific uncertainty with respect to harvest impacts to rockweed populations as well as the consequences for everything else, from single species to the whole Gulf of Maine system.

The main recommendations resulting from the workshop are the following.

- Government agencies responsible for the marine waters in the Gulf of Maine should develop a generic policy for managing low trophic level species. Harvesting these species may present a disproportionately higher risk to ecosystem health.

- Current management of the pilot rockweed harvest in New Brunswick could serve as a model for other regions. While a number of important questions remain unanswered, there are positive attributes that should be adopted; for example, use of a cutting rake for harvesting, resource and by-catch monitoring and participation of industry, other stakeholders and two levels of government in the assessment process. In all regions there is a critical need to address research questions and closely monitor harvesting practices and population responses.

- Properly designed impact assessments and rigorous monitoring should be implemented and integrated into management plans. Public reporting of impact studies, monitoring, harvest and bycatch statistics should be required.

- Marine Protected Areas (MPAs) should be established as they can provide, "impact insurance", consistent with the precautionary approach, but a number of important questions first need to be resolved.

- A recruitment and recolonization model for rockweed in each area should be developed.

Four general areas of research that require immediate attention are:

1. **Nutrient cycling and nutrient budget**. What are the relative contributions of rockweed and other sources to nutrient cycling? A monitoring program capable of detecting excessive eutrophication is required.

2. **Invertebrate community**. A clearer understanding of how structural changes to rockweed beds impact the invertebrate community is needed. An initial focus should be on the littorinids, gammarids, harpacticoid copepods, blue mussel and shore crab.

3. **Pollock habitat use**. Pollock is one commercially important species that occupies rockweed beds in high densities yet it is not known if growth and survival of juveniles are affected by rockweed harvesting or if there are impacts to the pollock fishery.

4. **Eider habitat use**. Eider duckling survival is low due to predation, additional impacts are unacceptable. A clearer understanding of how harvesting affects their foraging behaviour in rockweed beds and the location and timing of eider use of intertidal zone habitats is required.

SESSION ONE: INTRODUCTION

Chair: ***Robert Rangeley, Fisheries & Oceans Canada***

Opening Comments

Tom Sephton, Director of the Fisheries & Oceans Biological Station

Welcome & Introduction to the Workshop

Linda Mercer, Maine Department of Marine Resources
Jessie Davies, University of New Brunswick
David Coon, Conservation Council of New Brunswick
Robert Rangeley, Fisheries & Oceans

Keynote Address

The Challenge: Why Should We Care About Rockweed?
Mick Burt, Huntsman Marine Science Centre

Opening comments

Tom Sephton, Director, Fisheries and Oceans Biological Station

I would like to welcome everyone to the St. Andrews Biological Station here in Southwestern New Brunswick, on behalf of myself and the Department of Fisheries and Oceans. It is timely that a debate on scientific uncertainty is taking place here. This year we celebrated our 100^{th} anniversary at the Biological Station. One of the reasons the station was established was that very little was known about the inshore fisheries or of the interactions among the animals, plants and marine environment. Thus began a very long history of research here in the Bay of Fundy. Many milestones occurred along the way including the founding and opening of the Huntsman Marine Laboratory, now the Huntsman Marine Science Centre, in the early '70s.

The "face of scientific uncertainty" is a timely topic as we head into the year 2000. With a new emphasis on the ecosystem approach, the precautionary approach and uncertainty in stock assessments we are revamping how things are done and we will be talking about some of these changes here in the next couple of days. But more important is that those directly and indirectly involved in fisheries get together in workshops and, through co-operation and discussion, develop management plans in ways that people can understand.

Looking back in history, St. Andrews has played a very prominent role in these discussions and working together with professional groups and non-government organisations. So with that in mind, I wish you the very best in the next few days.

Welcome and Introduction

Linda Mercer, Maine Department of Marine Resources

I would like to welcome you to this conference and extend my thanks to the local group that made all of the arrangements. I am glad to be here and looking forward to a productive meeting. This workshop grew out of two workshops sponsored by the Global Programme of Action Coalition for the Gulf of Maine in April and November 1998. Out of those workshops came a list of priority pollutant and habitat issues for the Gulf of Maine and recommended actions for implementation. This is a binational effort being carried out by a diverse group of stakeholders with the goal of increased protection of the marine environment in the Gulf of Maine. One of the habitat issues identified at the first workshop was "harvesting of low trophic-level species". The recommended action was a workshop to formulate an action plan. The committee selected rockweed as an example of a low trophic-level species because of the debate on the impacts of commercial harvesting to the coastal ecosystem.

Maine has an active fishery for rockweed. We are fortunate to have a well-organized industry with whom we have been working for several years to develop regulations for the fishery. The members of this industry have basically been regulating themselves up to this point through the Maine Seaweed Council. The Maine legislature passed legislation which will enable the Department of Marine Resources to establish regulations for the industry. In addition to the regulatory environment, there has been considerable research on rockweed and close interaction between the researchers and harvesters. We don't understand the impacts of harvesting rockweed, or other low trophic level species for that matter, on the ecosystem. It is clear that rockweed is an important habitat for a variety of species. This workshop is a good opportunity to begin to identify the issues of concern and then begin to address them. Again, I welcome you all here and thank you for participating.

Jessie Davies, University of New Brunswick

The Regional Advisory Process of the Department of Fisheries and Oceans met in March of 1999 to discuss the status of the rockweed habitat and the impact of the rockweed harvest. The report issued following that meeting (DFO Martimes Regional Habitat Status Report 99/2E), concluded that the current fishery is being exploited within the guidelines of the southwest New Brunswick Fishery Management Plan, that the total harvestable biomass was 77,000t and that the 1998 harvest of 5,781t was not detrimental to the sustainablity of this resource. This is an average exploitation rate of 10 percent, below the 17 percent target and is a relatively low percentage of annual production. While the conclusion was that there was no evidence to support discontinuing the harvest, it was concluded that there was insufficient knowledge to fully evaluate potential habitat or ecosystem level impacts of the harvest.

A Working Group was set up to review research in this area, identify knowledge gaps and make recommendations on future research. We have good research on seaweed itself, especially on the regeneration of seaweed. There is little information on habitat, ecosystem impact, and impacts on other species. This conference is the first major activity of the working group. Many people here are involved with the working group. We need to know what, if any, knowledge base we have, and what the priorities are in order to know with certainty that harvest can be sustained and that the ecosystem can be sustained. Please keep these deliverables in mind for the duration of this conference.

David Coon, Conservation Council of New Brunswick

In 1988 a Nova Scotia-based rockweed processor, PROTAN, requested exclusive harvesting rights to rockweed on the New Brunswick side of the Bay of Fundy. In response the federal and provincial departments of fisheries formed a working group which raised major concerns about the impact of rockweed harvesting on its habitat services and on coastal fisheries. Today, after four years of a pilot harvest by Acadia Seaplants (who have been granted exclusive harvesting rights to rockweed), the same questions are being asked. There is currently no public process in place to assess how, where, or whether we should harvest rockweed. Unlike fish, rockweed provides numerous ecosystem services.

In 1991, the Conservation Council of New Brunswick requested that a full federal environmental impact assessment of the proposed rockweed harvest be carried out with public hearings. This request was supported by the Grand Manan Municipal Council, a number of Fundy fishermen's associations and a variety of conservation organizations. A survey of fishermen's associations and academic biologists in the region elicited broad support for such a federal environmental impact assessment. A number of respondents argued that there should not be any harvest because of the ecological services provided by rockweed.

In 1992 there was a written commitment from both the federal and provincial governments to carry out an environmental impact assessment. But it never materialized. As the pilot harvest was getting underway the Grand Manan Fishermen's Association, the Chamber of Commerce, the Municipal Council, along with representatives of dulsers and periwinkle harvesters formed the Island Rockweed Committee to protect their coastal ecosystem from rockweed harvesting. They described rockweed as essential to their fisheries as topsoil is to farmers. Conservation organizations, fishermen's associations, and community groups remain concerned about any expansion of rockweed harvesting beyond the current level of landings. Without the active engagement of these sectors of civil society, it is likely we would have a much more aggressive rockweed harvest than exists today.

Robert Rangeley, Fisheries & Oceans Canada

Commercial harvesting of rockweed algae (*Ascophyllum nodosum*) has generated intense debate in recent years over potential impacts to the coastal ecosystem. Attempts to resolve the issue have revealed fundamental knowledge gaps. It is clear that scientific research and monitoring must attempt to fill these gaps while at the same time new approaches are required for management decision-making in the face of scientific uncertainty.

Determining ecologically sustainable harvest levels for species at a low trophic level is a complex and difficult problem because of their role as food or habitat, directly or indirectly, for most organisms in the marine ecosystem. These dependencies form complex webs of interactions and create unique challenges for harvest impact assessments.

The workshop will address these challenges by initiating discussions between those making fisheries policy and regulations and those with knowledge of the ecological consequences of disturbance to marine plant populations. The final goal is for the workshop participants to contribute to the Rockweed Action Plan for science and resource management decision-making.

The main objectives during the workshop will be to identify and prioritise essential knowledge gaps in:

1. the role of rockweed as an essential habitat;
2. the consequences of ecosystem-level changes to rockweed populations in the Gulf of Maine.

And, 3. to provide management decision-making tools for ecologically sustainable low trophic level harvesting.

We will meet these objectives by first synthesising the scientific knowledge on marine plant – animal interactions and the role of marine plants in ecosystem-level processes. The goal is to provide precise summaries of the relevant science and to prioritise major knowledge gaps. Research summaries were be provided in the form of briefing notes circulated prior to the meeting, oral presentations by experts in their respective fields, panel discussions and poster sessions. The next challenge we will deal with is how to develop a decision-making framework for the ecological sustainability of low-trophic level harvesting. We will draw on examples and experience globally in an attempt to conserve Gulf of Maine resources with a specific focus on rockweed.

Keynote address: ***The challenge: Why should we care about rockweed?***

Mick Burt, Huntsman Marine Science Centre

The question is easy to ask; the answer is much more difficult.

As everyone knows by now, the specific "rockweed" we are focusing our attention on is the brown alga, *Ascophyllum nodosum.* It might be worth noting, in the interests of correct pronunciation, that the genus name has a double "l" which makes the "y" sound like a short "i" as in "fill" and not like the "y" sound as in "why". According to Klugh (1917), the only pre-existing paper dealing with the algae in and around Passamaquoddy Bay was a paper by Prof. D.C.Eaton who developed a **"List of Marine Algae collected near Eastport, Maine, in August and September, 1873, in connection with the work of the United States Fish Commission".** Klugh (1917) provides a compendium of algal species including 12 blue-green algae (Cyanophyceae), 25 green algae (Chlorophyceae), 24 brown algae (Phaeophyceae), which includes *Ascophyllum nodosum,* and 26 red algae (Rhodophyceae). In addition to pointing out differences in algal populations within Passamaquoddy Bay itself as opposed to the islands comprising the Deer Island archepelago and in the Bay of Fundy, based on differences in salinity, Klugh made some other interesting observations. He stated:

> "In many countries the marine algae are of great economic importance, as food, as the source of food products such as isinglass, in the production of "size" for textile fabrics, in the clarifying of beer and wines, as the source of iodine and potassium, in the manufacture of very strong adhesive known as seaweed glue, in the production of a demulcent for use in relieving coughs, and as a fertilizer. Except that some are put to the last-mentioned use along the coast, and some small quantities of dulse *(Rhodymenia palmata)* are gathered and dried for eating, the marine algae are made no use of in Canada , and therefore represent one of our undeveloped resources."

Thomas, in his classic Marine Biology text "Introducing the Sea" (first printed in 1973; now in its 5th edition, 1994) states:

> "On almost all Fundy shores the zone (Midlittoral) is dominated by the knotted wrack *Ascophyllum nodosum*. This fucoid may grow to over 1m in length, normally makes up 90% of the biomass."

In a later publication, Thomas *et al.* (1983) report that the total coastline of the Bay of Fundy is 2,745 km and that the intertidal area is a huge 1,052 square kilometres. About half of this is described as "rocky intertidal" and represents suitable habitat for rockweed. In this same publication, Thomas *et al.* (1983) point out that broken fucoids represent an important food source to sub-littoral species, such as sea urchins, and that the detritus from rockweeds serves as food for both suspension and deposit feeders. In addition, the establishment of a rockweed canopy greatly reduces the dessication factor thereby allowing many other species to survive and thrive in areas that would otherwise be unavailable to them. However, as Thomas *et al. (1983) state:* **"Unfortunately, the**

factors governing *A. nodosum* settlement, growth, and dominance have not yet been determined."

In his delightful small book in which he describes shore life between the tides, Morton (1991) also indicates that *A. nodosum* occupies the mid-littoral or intertidal zone and is "The most ubiquitous and abundant fucoid . . ".

When I was very much younger and when I lived in Scotland, I used to work on a farm during the summer holidays. One of the jobs I had was to help collect seaweed, washed up on the shore along the high tide mark after a storm with an on-shore wind. This would be forked onto a cart, pulled along by a horse, and subsequently spread over the stubble of cut wheat, oats, or barley fields prior to ploughing. This was not unpleasant work and certainly much more acceptable to one's olfactory sense than spreading "muck from the byre".

Having established the abundance of this resource in Canada, as well as in many other parts of the world, and recognizing the economic gains being made in other parts of the world through its collection and subsequent processing, why are we concerned about harvesting rockweed in the Bay of Fundy and the Gulf of Maine? Is it because we have seen species after species being exploited, perhaps to the point of extinction or is it because we now recognize that our concern for sustainability of a species cannot be focused narrowly on the population dynamics of that species alone but that we have to use an eco-system approach, **especially if the species in question (like rockweed) is one of those at a low trophic level!** Indeed, it was more the question of harvesting species at low trophic levels that generated the idea for this workshop at the Global Program of Action Coalition (GPAC) Meeting held in Portland, Maine in November, 1998. The concern over harvesting krill, another low trophic level species, was also raised but as this had been ruled out by Fisheries Regulaters, whereas the harvesting of rockweed was continuing **without any third-party monitoring**, the present workshop was designed to focus sharply on rockweed and only rockweed.

Concerns related to sustainability of species were raised at a workshop held in September 1996, the Proceedings of which were edited by Wallace and Braasch (1997). In the Executive Summary, Wallace (1997) states:

> ". . . identification of appropriate mechanisms that result in consistent, truly meaningful integrated activities leading to practical, cost-effective, environmentally-sound decisions have yet to be identified, despite repeated pleas to do so."

Also identified by Wallace (1997) are the importance and needs of monitoring: both *in situ* monitoring of variables affecting nutrient dynamics (more plausible at this time) as well as contaminants, which still presents a formidable challenge. In discussing the importance of inter-relationships, Peter Partington (1997) commented on a recent proposal to harvest krill, pointing out that: "before we wander too far down the road of new developing species, we should understand the interrelationships within the ecosystem". In the same publication, Robin Alden comments that the degree of uncertainty in every single fisheries decision is overwhelming, and that: "Our ignorance is so profound, that even common sense may not be a good guide, because common sense requires an understanding of the basic frame of reference."

Every good story should have a beginning, a middle, and an end. If you will allow me to make the following analogy, I would start: Once upon a time, a long time ago, men and women were hunters and gatherers. They hunted with clubs and stones, graduating to spears and bows and arrows, pits and traps, and other devices to help catch wild animals for food. They gathered fruits and nuts, berries and leaves and other consumable vegetation. But always, there was some uncertainty as to where the next meal would come from. Over the years, the hunters and the gatherers found less uncertainty if they kept animals captive and grew the plants they wanted to eat. They became less nomadic keeping their own "tame" animals from wildstock such as sheep, cattle, horses, goats, and deer among many other species. They grew rice and wheat, fruit trees and various vegetables. From the "hunter and gatherer" had emerged the "farmer".

Also, once upon a time but **not** so long ago, men and women were fishers. They went out on rafts and in boats and caught fish using various devices. They became so sophisticated that with bigger boats and bigger nets and better equipment, they were able to catch whatever they wanted and soon there was not much left to catch. For a long time, in warmer climes, plants have been grown in the water as well as on land and so have fish been grown in the water as well as mammals and birds on land. Is this the scenario we see developing in our more northern climes? Are we turning to mariculture to replace our traditional fisheries and should we be culturing the algae we need instead of harvesting wild plants?

I suspect that the end of our story will show that as we have turned from hunting wild animals to animal husbandry on farms with "hunting" being relegated to a recreational pastime for most peoples, so we shall turn from traditional fishing of wild stock to aquaculture of various species and that "fishing" will also be relegated to a recreational pastime.

This will not be an overnight phenomenon but I think it will undoubtedly unfold in this way. We have not maintained the wild stock of animals we once had access to. Gone are the passenger pigeons and the vast herds of bison roaming the north american plains. Gone are the fish that used to be so plentiful that "you could walk across the Miramichi on the backs of the salmon". Gone, or perhaps going, are the Northern cod stocks and other once-plentiful species. Arrived are the herds of cattle and flocks of sheep. Arrived are the millions of aquacultured Atlantic salmon and other species in seawater and millions of *Tilapia* and other species in freshwater. Arriving are the thousands of haddock, halibut, and other fishes, aquacultured in seawater.

And in the plant Kingdom, arrived are the various grain crops, fruits, berries, and vegetables grown on land. Arrived are the many aquatic species of plants cultivated in warmer places. Arriving are the plants that can/should be cultivated in our more northerly climes.

To make this transition smoother, we should perhaps heed the wise words of Bill Ayer (1997) when he stated:

> "As scientists and managers, we will probably not have the luxury of being able to gather more data and conduct more research in the future that is neither practical in terms of funding, nor contemporary considering the magnitude of the issues facing

the Gulf of Maine. There is a compelling need to review the scientific/management interface and to link science to the decision-making process."

Over the next couple of days, we have a wonderful opportunity to learn from each other what problems, if any, exist with respect to the continued harvesting of rockweed in the Gulf of Maine. We have present among us experts in different areas of rockweed biology who have promised to speak in English (without their irritating scientific jargon) so that even I can understand. We also have present Government scientists and regulators from both sides of the border who are here to contribute and to listen as well as a number of knowledgeable and concerned individuals representing either their own views or those of the non-governmental organisation which they represent. And last, but by no means least, we have members of the rockweed industry here to explain the facts about the harvesting process. In essence we have the ideal mix to determine *"Quo vadis"*. Where should we go and how do we get there?

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SESSION TWO: ROCKWEED AS HABITAT -- STATE OF KNOWLEDGE

Chair: Gerhard Pohle, Huntsman Marine Science Centre

Impacts of Grazers on Rockweeds and Macroalgae
Robert Vadas, University of Maine

Habitat Architecture and Invertebrates of *Ascophyllum nodosum:* a summary
Glyn Sharp, Robert Semple & Ian Barkhouse, Fisheries & Oceans Canada

Aquatic Macrophytes as Foraging and Refuging Habitats for Fishes
Robert Rangeley, Fisheries & Oceans Canada

Community-Level Interactions Between Birds and Aquatic Macrophytes: Lessons for a Rockweed Harvest?
Diana Hamilton, University of New Brunswick

Impacts of Grazers on Rockweeds and Macroalgae

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Summary

1) There are two major groups (genera) of rockweeds in the northwest Atlantic Ocean (*Fucus* and *Ascophyllum*)

2) There are three major classes and six taxonomic groups of invertebrate grazers that potentially influence intertidal seaweeds in the northwest Atlantic Ocean (Echinoderms, Molluscs and Crustaceans) and (sea urchins, gastropods, chitons, limpets, gammarids and isopods)

3) Gastropods (Littorinids) and Crustacean mesograzers (gammarids and isopods) appear to have the greatest impact on intertidal benthic algae

4) Grazing affects early post-settlement phases (EPS) and/or adult stages of rockweeds

5) Some algae contain chemicals or have tough thalli, which reduce grazing impacts

6) Some algae have an escape in size, age and/or numbers from grazing

7) Individual rockweed species have individual responses to specific herbivores, some algal-herbivore interactions may have evolved together

8) Sessile invertebrates (e.g., barnacles) appear to facilitate recruitment by rockweeds

9) *Ascophyllum* does not appear to be a normal stage in intertidal succession, with or without grazing

10) There is considerable variability in rockweed (and seaweed)-grazer interactions

11) Grazing can have a major impact on rockweeds and on intertidal seaweed communities or assemblages

12) Paradigms developed for New England shores in the 1970's regarding herbivore control do not apply to all rockweed species and shores

Habitat Architecture and Invertebrates of *Ascophyllum nodosum*: A Summary

Glyn Sharp, Robert Semple & Ian Barkhouse
Fisheries and Oceans Canada
Science Branch, Bedford Institute of Oceanography
Dartmouth, N.S.

Summary

Structure of the Habitat

Although there is a high level of unoccupied primary space in the rockweed zone, algal species forming a canopy including rockweed provide a complex structure of floating fronds that support a large number and variety of meso and micro-invertebrates. Differences in diversity and abundance of seaweed epifauna can be related to thallus types of seaweeds particularly between bladed and branched thalli (Coleman, 1940, Weiser, 1952). Highly branched *Ceramium nodulosum* supports a higher abundance of ostracods than 3 other red algal species. The amphipod *Gammarellus angulosus* is higher in abundance in more branched and filamentous algae than those with foliose or leathery morphologies (Hacker and Steneck, 1990). Algal mats provide structure that increases diversity and abundance of invertebrates (Dean and Connell, 1987). Increased complexity in a habitat can provide more niches, less predation, and greater food resources. Active selection of substratum at settlement or enhanced passive entrapment also contributes to higher faunal abundance with greater complexity. Physical factors associated with increasing complexity can be more important than biological factors. Harpacticod copepods and amphipods colonize artificial substrata with more folds or convolutions than structures with a simpler geometry (Jacobi and Langevin, 1996).

A range of algal morphology (excluding foliose) is found within rockweed canopy despite the lack of algal species diversity. A rockweed bed is an assemblage of dichotomous and laterally branched shoots within clumps. There is a wide range of spatial components including the number, and size of spaces between shoots and branches. Structural components are the number of branches both lateral and dichotomous on each shoot plus the length and thickness of shoots. The number of shoots in clumps and their characteristics create complex structures varying greatly in length, width and weight. The density of clumps within a patch provides another level of complexity at a spatial scale of meters. The finest and smallest structure of the habitat is within epiphytes on Ascophyllum fronds most commonly the tufted structure of *Polysiphonia lanosa. Polsiphonia lanosa* is most common in the distal region of damaged shoots (Lobban and Baxter, 1983). In wave sheltered areas where shoot breakage is less, the attachment point for the epiphyte is commonly receptacles (Levin and Mathieson, 1991.

The floating canopy of *Ascophyllum* changes structure with the tide level from fully extended clumps at high tide to recumbent at low tide. The spaces available at high tide include the basal structure of the plant sheltered from light and wave action and closest to the substrate. In the lower reaches of the plant there are a large number of spaces between primary shoots in a clump and larger spaces between clumps. The middle region of the plant has the most complex structure lateral and dichotomous primary branches with or without associated epiphytes. The most distal region is less complex with few laterals and new meristematic tissue with few epiphytes. However, as the clump develops in size above 80 cm the majority of the biomass becomes more distal as does the region of peak complexity. Complexity can change between sites by variation in density of shoots, thickness of shoots, numbers of branches, density of shoots in clump, density of clumps in a bed as well as degree of epiphytism. Wave exposure affects the morphology of fronds and degree of branching, thus changing characteristics of the habitat for invertebrates (Cousens, 1982).

Abundance and Diversity of Invertebrates

The sampling method including the mesh size of collectors or of sample processing sieves influence the diversity and abundance of faunal groups captured from *Ascophyllum*. Harpacticoid copepods are dominant collections made with mesh sizes in the .06 mm range (Johnson and Schiebling, 1986). Mesh sizes above .5 mm collect samples dominated by mesoherbivores (Pavia et al, 1999). This factor aside, the assemblages between widely separate UK and Canadian study sites and 50 years apart were similar with twelve phyla in common (Coleman, 1940; Johnson and Scheibling, 1987) . Expressed in numbers per 100 g Ostracods, Copepods and Halicarids were the most abundant in Coleman's (1940) and Johnson and Scheibling's studies (1987). These assemblages are also similar to those captured from diverse and disparate algal epifauna (Weiser, 1952 Coleman, 1940. Meso-invertebrates in harvested and unharvested areas of the Bay of Fundy have very similar assemblages of species (Sharp, 1999). However, geographical variation in abundance can be significant within regions. A wide range of sites sampled in the summer had a wide variation in numerical dominance of mesoinvertebrates groups between sites (Sharp, 1999). Copepods in Coleman's (1940) study exceeded 50,000 m^{-2} at an *Ascophyllum* biomass of 8 kg m^{-2}. Isopods exceeded 8000 m^{-2} in Ascophyllum at mid tide level in August in southwestern Nova Scotia (Sharp,1999). In contrast meso-invertebrates collections from Swedish *Ascophyllum* beds had a total abundance of all species (greater than .3mm) of 2200 m^{-2} (Pavia et al , 1999). This low abundance was a result of low *Ascophyllum* abundance at these sites. Meso-invertebrate settlement stages can greatly exceed these values. Juvenile *Mytilus edulis* reached 22,000 m^{-2} in a New Brunswick site (opp cit.). These abundances are in the range of meso-herbivore densities in a wide variety of locations and algal species around the world (Brawley, 1992).

There are seasonal changes in relative community composition and disappearance of some species. However, the major groups have representatives year round except Nemertinea, Gastropoda, Amphipoda and Isopoda that are rare or absent in the winter (Johnson and Scheibling, 1987). Total abundance of epifauna is lowest between December and February (opp cit). At an estuarine site in New Hampshire with a *Fucus* and *Ascophyllum* canopy Copepods were dominant in the fall, mites in the winter and isopods in the spring (Mc Bane and Croker, 1983). Distinct peaks of abundance in gastropods, amphipods isopods and Mytilus edulis occur in the summer months (Sharp, 1999).

The abundance of meso-invertebrates can vary greatly between sites. Amphipods reached over 200 kg^{-1} in a wave exposed offshore *Ascophyllum* bed in Southwestern Nova Scotia a factor of 5 above other all other sites (Sharp,1999). In contrast, density was 1000 kg^{-1} at a extremely sheltered estuarine *Ascophyllum* bed (op.cit.). Within site variability was very high, usually 50% of the mean value even when the size range of sampled clumps or tide level was limited in the sample.

Three sites sampled for mesoherbivores in Swedish *Ascophyllum* beds ranked *Littorina obtusata* highest in abundance followed by two amphipod species (Pavia, et al 1999).

Underlying substrata can influence the abundance of some faunal groups, amphipoda being more abundant near gravel and sand substrate and isopods over bedrock (Sharp,1999). Tide level was a factor affecting abundance of some groups and species. *Lacuna vincta* is a gastropod that occurs only in the lowest tide level samples (Sharp,1999). Halicarids are well separated by species depending on their degree of terrestrial or marine characteristics ((Puch and King, 1985). Species of amphipoda were tidally stratified in U.K. populations of *Ascophyllum* and *Fucus* (Coleman, 1940)

The presence and abundance of epiphytes, primarily *Polysiphonia lanosa* was strongly corelated to the abundance of major taxa (Johnson and Scheibling, 1987). *Gammarus locusta* a mesoherbivore of *Ascophyllum* in Sweden was significantly more abundant on plants with epiphytes than those without (Pavia et al, 1999). There is a higher diversity of mesoinvertebrates at high tide than at low tide in *Ascophyllum* (Thonney, 1993). Day versus night sampling did not detect significant differences in mesoherbivore densities (Pavia et al, 1999). However, several studies of mesoherbivores associated with other alga recorded more feeding and mating behavior at night (Brawley, 1992). The structure of seaweed beds can be important; isolated clumps of *Pelvetia* had different diversity and abundance from groups of clumps (Gunnil, 1982). Recolonization experiments, with *Ascophyllum* clumps within the range of 3 to 12 clumps $0.25m^2$, did not detect differences in abundance (Sharp, 1999).

Dynamics of *Ascophyllum* Canopy Invertebrates

Movement

The faunal components of the *Ascophyllum* habitat have a range of mobility that to a great extent defines their ability to deal with daily and seasonal changes in environmental conditions. Most canopy invertebrate fauna are mobile. Recolonization experiments suggest even gastropods can reoccupy canopy space within 24 , hours (Sharp, 1998, Pavia, 1999. Movement from the top of canopy to the moist and cooler regions of the lower canopy layers occurs within a tide cycle. Gammarids can move from 1 to 4 m min^{-1} allowing them to travel extensively both horizontally and vertically during the tide cycle (Brawley, 1992).

Evidence for mobility is the range of distribution of canopy species in other habitats either adjacent or distant from the *Ascophyllum* bed. Few species of invertebrate species are found only in *Ascophyllum* but normally they can occur in other Fucoids and a range of other seaweed habitats (Johnson and Scheibling, 1987, Coleman,1930). *Gammarus angulosus* is present in *Ascophyllum* canopy but larger animals are most abundant in Chondrus fronds and can be found down to –6 m (Hacker and Steneck, 1990). *Idothea balthica* is common in the canopy and is considered an omnivore but is is more commonly associated with Fucus species by feeding selectivity (Schaffelke et al, 1995). While some amphipod species are closely associated with epiphytes, isopod abundance is higher on the vegetative thallus of Ascophyllum (Pavia et al, 1999). The common amphipod *Hyale nilsonni* is a large 20% to 70% portion of *Ascophyllum* meso-invertebrate population in New Hampshire (McBane and Croker, 1983). It prefers the epiphyte *P. lanosa* but in its absence occupies ephemeral algal species (opp. cit.). Since epiphyte biomass declines dramaticly during the winter species that over winter as adults must move to the thallus or out of the zone.

Diptera larvae are seasonal occupants of the zone and can appear in large numbers in synchronous hatches. They are herbviores with limited mobility but they can have a significant impact on ephemeral species (Robles and Cubit, 1981).

More sessile animals bryozoans and sponges are associated with the basal area of the fronds. Some species are very site selective, the bryozoan selects crevices or indentations on the thallus near vesicles. *Littorina littorea* normally inhabits the understory space being unable to hold on to the upper portions of the thallus in wave action. In contrast *L. obtusata* the smooth periwinkle can remain in position in strong water movement in the canopy.

Crustaceans are capable of long distance movements and some species of amphipods such as *G. oceanicus* move in and out of the substrata and the intertidal zone with each tidal exposure. In general residents of the epiphyte biomass; worms, copepod and mite species are able to make short distance movements to stay inside the canopy through the tide cycle (Weiser, 1952). Crabs particularly *Carcinus meanus* can move up into the canopy but are rarely captured due to their mobility. Mysids and Crangon are frequently observed in large numbers near rockweed beds but are rarely captured using active sampling methods (Sharp, 1999).

Clumps or patches of fronds are essentially islands in an area of other habitats. The movement of animals between clumps can follow the principals of island colonization reaching some equilibrium of addition and extinction of species. Large clumps or patches are then more diverse than small ones. However a patchy distribution of clumps that leaves gaps in habitat over several meters is not common in southern New Brunswick rockweed beds due to the continuity of suitable substratum.

Turnover

Turnover of canopy invertebrate populations is very high. The invertebrates dominating the fauna of *Ascophyllum* can be characterized as having very high reproductive capacities, a short life span and the potential to emigrate rapidly. Harpacticoid copepods have very protracted or continuous reproductive period and a generation time of less than one year (Johnson and Schiebling, 1986). With the exception of reproductive females they can migrate between plants during high tide (Wieser, 1952). *Gammarus oceanicus* can produce a number of broods in the spring and summer. This species is dormant between August and November, thus young are not present in the winter (Steele and Steele,1971).

Most of the invertebrates inhabiting *Ascophyllum* have very high juvenile mortality rate and early age of maturity (Gooselin,1997). Gastropod mortality can reach 90% within days of first settlement (op. cit.). Settlement can be highly variable and unrelated to the size of adjacent adult populations (Underwood, 1979). Settlement on *Ascophyllum* by bivalves does not result in an adult population due to movement to a secondary settlement site for the sessile adult stage.

Both positive and negative interactions between mesoherbivores and the algal host have been described for a number of alga/invertebrate associations (Brawley, 1992). However overgrazing by mesoherbivores of *Ascophyllum* has not been reported although some associated species, I balthica and L. vincta dramatically reduced Fucoid biomass (opp cit). *Littorina obtusata* grazes directly on the thallus but has not caused direct mortality of the fronds (Williams and Seed, 1992). The reduction of epiphyte biomass burden by amphipods and isopods is an advantage to the host macrophyte. The mesoherbivores *Idothea granulosa* selectively feed on Ascophyllum apical meristems while closely associated amphipods feed on the epiphyte Ceramium nodulosum (Pavia, et al , 1999).

Ascophyllum habitat and its associated epiphytes is constantly changing structure by loss of tissue by breakage, replacement of tissues. This is very dynamic environment allowing more competition between very diverse species as new surfaces and spaces are being developed (Seed, 1997). Increasing complexity simular to this dynamic habitat measured fractaly can also influence body size of associated invertebrates (Gee and Warwick, 1994) . In general more biomass provides higher complexity and carrying capacity. Predation rates can also be affected by the degree of complexity in a algal habitat (James and Heck, 1993; Dean and Connel, 1987).

The wide variety of spaces and surfaces can provide the physical characteristics needed either for avoidance of light or tenacity (opp. cit.). Amelioration of temperature, light and desiccation is provided by a canopy to permitting soft bodied invertebrates to remain in-situ through the tide cycle.

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Aquatic Macrophytes as Foraging and Refuging Habitats for Fishes

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Introduction

The importance of aquatic vegetation as a habitat for small fishes, particularly juvenile stages, has been demonstrated in numerous studies (see Heck & Crowder 1991). In marine systems, studies have focused on the importance of marsh grasses (e.g. Kneib 1984), seagrasses (e.g. Sogard 1992) and kelps (e.g. Holbrook & Schmitt 1988). Macroalgae in the rocky intertidal zone plays a similar role, but the use of this habitat by fishes is poorly understood (Wheeler 1980; Gibson 1986; Rangeley 1994a). The three main points of this presentation are:

1. Rockweed (*Ascophyllum nodosum*) is an important fish habitat that shares many general habitat features with other aquatic macrophytes;
2. Little is known about potential impacts of habitat structural changes and habitat loss on fish populations;
3. Current methods of assessing fish populations have a low probability of detecting changes in abundance; alternative conservation approaches are required.

Rocky shores are highly productive areas which are subject to fluctuating environmental conditions (Gibson 1998). In the outer Bay of Fundy and Gulf of Maine, the high tides and rocky shoreline create large areas dominated by fucoid algae particularly rockweed, *Ascophyllum nodosum,* which is a habitat for hundreds of organisms including many fishes. The rocky intertidal zone in the Northwest Atlantic has moderate species richness with an average of 18 species per site and a total of 17 families being represented (Prochazka et al. 1998). In Passamaquoddy Bay, the current estimate of species richness is 31 species from 19 Families and 9 Orders (Table 1). A number of the fishes were present as juveniles (19 spp.) and some of those occurred at more than one life-history stage, including young (age-0+) or older (age-1+) juveniles or adults (Rangeley 1994a,b). The occurrence of fishes in the rocky intertidal zone is high relative to the 104 indigenous species (47 Families) occurring in the Bay and adjacent waters (Scott 1983).

Movements

Fishes occupy virtually all intertidal habitats and use them for a variety of purposes, the most common of which are feeding, refuging and spawning (Gibson 1998). Resident species seek shelter and remain in the intertidal zone; they are generally small benthic forms with limited powers of locomotion (Gibson 1998). In many places these species may dominate the fish fauna but in the Northwest Atlantic they are not as well represented. An example of one of the few resident species in this area is the ubiquitous rock gunnel (*Pholis gunnellus*).

In contrast, visitor species are those that regularly enter and leave the intertidal zone, usually with the tides. They have good locomotory abilities and cover greater distances and move rapidly. Individuals may migrate intertidally on each tide or only diurnally or nocturnally or only on day or night spring tides. They may enter as juveniles, stay for the spring and summer, then leave in winter or when they grow and mature. These seasonal movements are most pronounced at higher latitudes where fish are virtually absent from the intertidal zone in the winter. Most pronounced movements are usually made by juveniles of species that use rocky shores as nursery grounds. The young stages recruit to the shore in spring and move to deeper water in the winter (Gibson 1998).

An example of this migration pattern is shown in pollock (*Pollachius virens*), a marine gadid fish. Following offshore stages as eggs and larvae, juvenile pollock arrive in subtidal and intertidal habitats along the Atlantic coast of Canada and northeastern USA in May where they grow from about 4 cm to about 17 cm fork length in their first summer. They move offshore by late fall and return briefly only in their second year (Bigelow and Schroeder 1953, Scott and Scott 1988, Rangeley 1994a,b). Use of rockweed as a nursery habitat for juvenile pollock has been studied in detail in Passamaquoddy Bay. Pollock showed a density-dependent preference for rockweed habitats when large schools in the subtidal zone moved into the intertidal algae and dispersed as small groups or solitary individuals. On the falling tide, pollock left the intertidal zone in schools and remained schooling in the subtidal zone until the next rising tide (Rangeley and Kramer 1995a,b; 1998).

Diet patterns

Among the major intertidal habitats, the rocky intertidal probably presents the greatest taxonomic breadth and functional diversity of potential prey for intertidal fishes (Norton & Cook 1998). Small mobile crustaceans are important components of the diet of many rocky intertidal fishes. The populations of these mobile crustaceans fall or rise in conjunction with changes in primary production and especially in response to fluctuations in detrital food webs (Laur & Ebeling 1983). The short generation time and direct development of many crustaceans (e.g. amphipods and isopods) allows populations to respond quickly to local fluctuations in productivity (Griffiths et al. 1983; Field & Griffiths 1991). Unfortunately, very little work has been done on profitability of different prey for intertidal fishes.

Small crustaceans (harpacticoid copepods, gammarid amphipods, isopods, shrimps and crabs) are clearly the predominant prey items in the diets of rocky intertidal fishes from several sites around the world: e.g. Chile (Varas & Ojeda 1990), South Africa (Bennett et al. 1983), California (Grossman 1986). There are also consistent patterns in the ontogenetic diet shifts among fishes of the rocky intertidal zone. Often, harpacticoid copepods are the dominant prey by number and small gammarid amphipods are the dominant prey by weight or volume in the diets of the smallest fishes. Both groups drop out of the diet as the fish age and grow (see refs in Norton & Cook 1998). With age, prey species richness increases as does food intake. Increase in energy is accomplished by eating fewer but larger prey (rather than eating more small items) by either consuming larger prey taxa or larger individuals of the same prey taxa.

Diet composition of all fishes sampled in the rocky intertidal zone in Passamaquoddy combined consisted of over 100 invertebrate prey with the greatest frequency of occurrence represented by crustaceans. Prey included many of the species that are closely associated with rockweed algae (Cheng 1976, Hayward 1980, Johnson & Scheibling 1987). As fish grew through the summer period, harpacticoid copepods dropped out of the diets of most fishes and larger individuals of the amphipod *Gammarus oceanicus* increased in occurrence. Diet breadth increased as well. Of the eight fishes examined in detail, all had relatively large numbers of prey from algal habitats in their stomachs (Atlantic tomcod, pollock, white hake, threespine stickleback and longhorn sculpin) and, with the exception of alewife, herring and winter flounder, prey from algae comprised the greatest average volume in stomachs.

Predation

Major community structuring forces such as predation and competition have not been well studied for intertidal fishes. Predation from within the resident component of the fish community seems relatively unimportant (Gibson & Yoshiyama 1998 p 289) but predation pressure imposed by external predators such as visiting subtidal fishes, seabirds, wading birds and terrestrial mammals may be considerable (Gibson & Yoshiyama 1998; Rangeley 1994b; Rangeley & Kramer 1995a).

The role of aquatic vegetation in reducing predation risk from fish predators has been demonstrated repeatedly. In Passamaquoddy Bay, juveniles and small fishes in the intertidal zone were likely exposed to some level of risk from at least 16 species of predator. Small fishes were partially or wholly in the diet of nine fishes foraging mostly nocturnally. The activity patterns of the large piscivorous fishes suggested avoidance of foraging birds. During the day, seven species of piscivorous birds were actively foraging at all stages of the tide. Behavioural responses of fishes to predation risk include refuging in structured habitats and schooling. The availability of rockweed, or some other vegetated habitat, as a predator refuge may be essential for juvenile fish survival as demonstrated for pollock (e.g. Rangeley & Kramer 1998).

Piscivorous birds foraged throughout the tidal cycle and visited the algal habitat twice as frequently as the open intertidal habitat. Foraging strategies included those used by divers pursuing fish underwater, a wading-ambush predator, plungers in shallow water and those that dip into the surface waters for their prey. Seven piscivorous bird species were foraging in the intertidal zone of which three, kingfisher, tern and Bonaparte's gull, were present only in late summer. The loon and cormorant, the two divers, were the only species which foraged significantly in the intertidal and shallow subtidal zones. These two plus the great blue heron were the most active predators and showed strong intertidal habitat preferences for the fucoids. Two of the three plunging birds, osprey and kingfisher, showed a preference for the open intertidal zone, while the common tern foraged in the algal habitat. The Bonaparte's gull foraged almost exclusively in fucoids (Rangeley 1994b; Rangeley & Kramer 1995a).

Impact assessment

The major hurdle in any impact assessment and particularly for fishes is the high natural variability in density. Estimates of the variability of fish densities in the rocky intertidal zone are useful for demonstrating the relationship between variability and conducting a meaningful (i.e. powerful) impact assessment for habitat loss. Sources of variability include seasonal, diel and tidal patterns in the use of intertidal zone habitats and highly dynamic patterns of distribution. For example, pollock both dispersed in rockweed and schooled in the open habitat. Winter flounder (*Pleuronectes americanus*) were patchily distributed in rockweed but more evenly distributed on the mud and sand substrate of the open habitats. Atlantic herring (*Clupea harengus*) formed small schools in rockweed habitat and very large schools in open habitats.

Statistical power analysis was performed on the density data for these three species. Analyses were conducted for a range of temporal and spatial scales using a number of catch methods (seine, trap & gill nets and transect surveys). Regardless of the contrasts performed the general conclusion holds that large sample sizes (n=200-1300) are required for even a simple impact assessment to attain statistical power in the required 0.8 - 0.95 range.

Current methods of assessing fish populations have a low probability of detecting significant changes in abundance, should they occur (Peterman 1990). This finding is consistent with studies reported in the literature for other systems Lester et al. (1996). Estimates of variation and power analyses must be taken into account in designing powerful impact studies. However, an inescapable consequence of high natural variability in fish densities in the intertidal zone is that lengthy studies (~5-15 years) may be necessary to detect changes. Shorter term research studies on functional relationships and on reducing sources of error will be a valuable complement to future impact assessments.

Ecosystem level considerations

Limited evidence suggests that the intertidal fish community may exert considerable predation pressure on some prey and foraging by fishes may play a major role in structuring the intertidal zone community. Most prey consumed by fishes in the rocky intertidal zone are produced *in situ*. This represents a tremendous contribution to coastal production as intertidal fishes grow and transport this energy elsewhere when they emigrate (or are consumed by their transient predators).

Habitat preferences for some rocky shore fishes are known but we know little of how distribution patterns are affected by spatial arrangement and scaling of habitat patches within and among nursery production areas. Determining patterns of spatial scaling in habitat use is critical for understanding population structure and recruitment processes. This is the landscape ecology perspective where at spatial scales substantially larger than what one individual encounters, the landscape experienced by the population represents a mosaic of good and bad places for the species. The growth, or lack thereof, of the population is determined not only by the quality of the individual patches occupied, but also by the spatial and temporal distribution of suitable and unsuitable patches of habitat (Meffe & Carroll 1994).

Population impact assessments are problematic due to high sampling costs and long time series. Alternatively, precautionary approaches have the advantage that conservation measures can take effect immediately and be revised with the accumulation of new information. For example, these measures could be based on preserving the functional role of the habitat in productive nursery areas.

Given the complexity of the system, the best conservation approach may involve a coordination of monitoring and research studies in a coastal management program. This would require a system of data management, quality control and the construction and maintenance of a geographic information system (GIS) database for research and resource management purposes.

Questions:

Population impact assessments:

- Should assessment of large-scale (e.g. fisheries level) impacts be attempted?
- Should smaller-scale assessment of impacts to nursery areas be attempted?

- If so, can we justify conservation measures to these areas under that assumption that the breeding population or fishery recruits will be protected?

Precautionary approaches:

- How would a functional role of the habitat be defined and measured? and for what species?
- How much habitat loss and/or change in habitat structure is too much?
- How can hierarchical levels of population processes, from behavioural to landscape features, be implemented in conservation strategies?

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Table 1. Fishes sampled in the rocky intertidal zone in Passamaquoddy Bay, NB, Canada. J = juvenile, A = adult. Relatively rare species were eel, salmon, cod, ninespine stickleback, pipefish, cunner, radiated shanny, sand lance, shorthorn sculpin and grubby. Classification based on Scott & Scott 1988.

Order	**Family**	**Scientific name**	**Common name**
Rajiformes	Rajiidae	*Raja radiata*	thorny skate (A)
Anguilliformes	Anguillidae	*Anguilla rostrata*	American eel (J)
Clupeiformes	Clupeidae	*Alosa pseudoharengus*	alewife (J,A)
		Clupea harengus	Atlantic herring (J,A)
Salmoniformes	Salmonidae	*Salmo salar*	Atlantic salmon (A)
	Osmeridae	*Osmerus mordax*	rainbow smelt (J,A)
Gadiformes	Gadidae	*Gadus morhua*	Atlantic cod (J)
		Merluccius bilinearis	silver hake (A)
		Microgadus tomcod	Atlantic tomcod (J,A)
		Pollachius virens	pollock (J)
		Urophycis tenuis	white hake (J)
Atheriniformes	Cyprinodontidae	*Fundulus heteroclitus*	mummichog (J,A)
	Atherinidae	*Menidia menidia*	Atlantic silverside (J,A)
Gasterosteiformes	Gasterosteidae	*Apeltes quadracus*	fourspine stickleback (A)
		Gasterosteus aculeatus	threespine stickleback (J,A)
		G. wheatlandi	blackspotted stickleback (A)
		Pungitius pungitius	ninespine stickleback (A)
	Syngnathidae	*Syngnathus fuscus*	northern pipefish (A)
Perciformes	Labridae	*Tautogolabrus adspersus*	cunner (A)
	Zoarcidae	*Macrozoarces americanus*	ocean pout (J,A)
	Stichaeidae	*Ulvaria subbifurcata*	radiated shanny (A)
	Pholidae	*Pholis gunnellus*	rock gunnel (J,A)
	Ammodytidae	*Ammodytes americanus*	American sand lance (A)
	Scombridae	*Scomber scombrus*	Atlantic mackerel (A)
	Cottidae	*Hemitripterus americanus*	sea raven (J,A)
		Myoxocephalus octodecemspinosus	longhorn sculpin (J,A)
		M. scorpius	shorthorn sculpin (J,A)
		M. aenaeus	grubby (A)
	Cyclopteridae	*Cyclopterus lumpus*	lumpfish (J,A)
		Liparis atlanticus	Atlantic snailfish (J)
Pleuronectiformes	Pleuronectidae	*Pleuronectes americanus*	winter flounder (J,A)

Community-Level Interactions Between Birds and Aquatic Macrophytes: Lessons for a Rockweed Harvest?

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Introduction

We know very little about the relationship between birds and rockweed (*Ascophyllum nodosum*), particularly with regard to the potential effects of rockweed harvest on birds, because few studies on the subject have been done. Community-level studies involving aquatic birds in general are still quite rare, though there is evidence that birds can be important members of both marine and freshwater systems (e.g. Wootton 1995, Hurlburt and Chang 1983, Bazeley and Jefferies 1986, Hamilton 2000). We know that birds in other communities are capable of suppressing macrophyte abundance (Sondergaard *et al.* 1998) and controlling and delaying macrophyte colonization in lakes (Lauridsen *et al.* 1994). Similarly, bird species composition and abundance is often controlled by the macrophyte community (Hoyer and Canfield 1994), either because birds consume macrophytes directly (Anderson and Low 1976), or because they feed on invertebrates associated with the plant community (Hargeby *et al.* 1994). Hence, it stands to reason that birds and rockweed may interact and that rockweed harvest may alter the nature of this interaction.

In the intertidal zone, rockweed provides 3-dimensional structure and habitat for invertebrates and fish. While birds in this region do not eat rockweed, they may interact with it in the following ways: 1) They may consume invertebrates found in association with rockweed. 2) They may consume fish that use rockweed as habitat. 3) They may consume other birds that associate with rockweed in one of the above ways. Therefore, to assess the possible effects of rockweed harvest on birds, we need to understand the effects of harvest on other components of the intertidal community, and the relationship between birds and the rest of the community. It is also important to consider that birds influence community structure, and if rockweed harvest somehow affects them, there may be resulting indirect effects on the rest of the system.

Species involved

Birds that consume invertebrates commonly associated with rockweed include Common Eiders (*Somateria mollissima*), Black Ducks (*Anas rubripes*) and Mallards (*A. platyrhynchos*), and Purple Sandpipers (*Calidris maritima*). Others, including Bufflehead (*Bucephala albeola*), scoters (*Melanitta* spp.), and several sandpipers (Scolopacidae) and plovers (Charadriidae), probably also eat some invertebrates from rockweed, but do not use it as their main foraging habitat.

Common Eiders have received the most attention in relation to rockweed harvest. These birds breed locally on islands in the Gulf of Maine and the outer Bay of Fundy. Following hatch, ducklings are moved in crèches to rearing areas, largely on the mainland and Grand Manan, where they feed on invertebrates (*Littorina* spp., amphipods) associated with rockweed (Minot 1980, Hamilton 1997). They appear to be dependent on these prey for at least the first 2-3 weeks of life (Hamilton 1997), after which their ability to dive improves (Cantin *et al.* 1974) and they become able to eat small blue mussels (*Mytilus edulis*) (Swennen 1989). Eider ducklings feeding locally do not appear to be food limited (Hamilton 1997), so a reduction in food following a rockweed harvest would not necessarily pose a problem for them (though search time may increase somewhat, causing a reduction in feeding rate). However, if harvest results in a reduced canopy height, rockweed would float at the surface for less time during each tidal cycle, and feeding opportunities for ducklings may be limited. This could pose a significant problem for eiders in view of the fact that in recent years, this species has suffered extreme mortality from Black-backed gulls (*Larus argentatus*) (Mawhinney *et al.* 1999). Ducklings are most vulnerable to predators during the first two weeks of life. If their feeding opportunities are reduced at that time and their growth rate slows, or they are weakened by lack of food, this window of vulnerability may expand and mortality may increase. Similarly, physical disturbance by harvesters may both limit feeding opportunities for ducklings and increase their risk of predation (Åhlund and Götmark 1989). Disturbance of eider crèches has been shown to disrupt duckling behaviour for 20 to 35 min, and water-based disturbances elicit the strongest reactions (Keller 1991). Therefore, to avoid putting eiders at additional risk, detailed surveys should be carried out to identify the most important rearing areas for ducklings. Harvesters should avoid working in these areas while young ducklings are present (early June to mid-July), and if rockweed is harvested there at all, efforts should be made to avoid uniform reductions in canopy height.

Adult eiders may also interact with the rockweed community, particularly where rockweed is found in proximity to blue mussel beds. When blue mussels settle on rockweed, they weight it down and eventually kill it if not removed (Lubchenco and Menge 1978, Lubchenco 1980). Eiders remove mussels from rockweed, and, as such, may contribute to its maintenance (Hamilton 1997). Although unlikely, harvest may affect this relationship. This possibility should be considered in future harvesting experiments.

Black ducks, and to a lesser degree Mallards, also feed on invertebrates (primarily littorinids and *Gammarus oceanicus)* associated with rockweed (Jorde and Owen 1990). They use this habitat only during winter, so ducklings are not affected and disturbance by harvesters is likely to be less of a problem. However, in recent years, there has been concern about a decline in the Black Duck population in the Maritimes (e.g. Parker 1998). Therefore, to ensure that we are not contributing to the decline by eliminating feeding habitat, in areas where Black Ducks feed, effects of rockweed harvest on their prey should be assessed. Purple sandpipers also feed on invertebrates in algae-covered rocky areas of the Bay of Fundy between October and April. They appear to be fairly common in the Lepreau area (Christie 1983). We need more information about their dependence on this type of habitat and specific food habits in this area before we can assess the possible effects of rockweed harvest on them.

Birds that consume fish that use rockweed habitat include Double-crested Cormorants (*Phalacrocorax auritus*), Osprey (*Pandion haliaetus*), loons, Great Blue Herons (*Ardea herodias*), Bonaparte's Gulls (*Larus philadelphia*), terns, kingfishers, mergansers, and grebes. Double-crested Cormorants feed commonly on intertidal fish in this region (Rangeley and Kramer 1998). While there may not be a great deal of concern about the well being of this species, given that it is often thought of as a nuisance bird, it is still important to consider possible effects of rockweed harvest on it. Changes in the food habits or population of cormorants could lead to other community changes. Cormorants are opportunistic predators (Rail and Chapdelaine 1998, Warke *et al.* 1994), so if their usual prey decline in response to harvest, they will switch to other fish species. This in turn could have substantial effects on the system (*sensu* Wanink and Goudswaard 1994), and the possibility should be considered. The opportunistic nature of cormorant predation may provide a method of monitoring effects of rockweed harvest on fish populations. If a shift in the cormorant diet was detected in harvested areas, it would suggest that perhaps the system was changing and that further study was warranted.

Osprey also eat intertidal fish. However, they are not as wide-ranging and opportunistic as other species (Christie 1983). Therefore, declines in their food base resulting from harvest should be carefully monitored. Dependence of other species on intertidal fish will vary with season and location. Possible effects should be assessed on a case by case basis, both out of concern for the bird and for indirect effects on the rest of the system.

Black-backed gulls and Bald Eagles (*Haliaeetus leucocephalus*) feed on eider ducklings, in addition to scavenging for other prey. They are joined as scavengers by other species of gulls and crows. Because these birds are highly opportunistic, rockweed harvest is not likely to directly cause a problem for them. However, a change in food habits could lead to other indirect effects on the system, so these birds should also be monitored. As with the cormorant, monitoring of food habits of these birds could also provide information about changes in the community following a rockweed harvest.

Information from other systems

Because there is very little information available about the relationship between birds and rockweed, it is difficult to make predictions about effects of harvest on the avian community. One approach to this problem is to take information about the relationship between birds and aquatic macrophytes/communities from other systems and try to apply it to this community. Such an analysis would suggest things to watch for during the harvest, and would help to direct researchers studying bird-rockweed interactions. Below, I identify several relationships between birds and macrophytes (or communities dominated by macrophytes) that might also apply to birds in a rockweed-dominated system. This is not an exhaustive list, and more of this type of analysis should probably be done.

1) Long-term effects of rockweed harvest on the community should be considered. When geese were excluded from a salt marsh, permanent changes in species composition of vegetation resulted (Bazeley and Jefferies 1986). When the exclosures were removed, the geese did not return to feeding there. If the structure of the algal canopy is changed following rockweed harvest, birds may not be able to use it, and it may be permanently lost as feeding habitat. Therefore, an effort should be made to determine how long it takes (if ever) following harvest for the canopy and community to return to an undisturbed state.

2) Many birds concentrate their foraging efforts where there is the most food. Anderson and Low (1976) found that ducks feeding on sago pondweed removed disproportionally more tuber biomass from areas with a high standing crop than from less productive areas. They then rotated to other areas, allowing the old feeding sites to recover. If rockweed harvest reduces prey abundance and makes harvested sites less attractive to foraging birds, they may concentrate their efforts elsewhere. This may become problematic if harvest reduces foraging area to the extent that feeding

sites do not have an opportunity to recover prey biomass. Therefore, activities of birds in harvested and unharvested sites should be carefully monitored to assess this possibility.

3) Bird predation can be extraordinarily important in structuring communities, in some cases generating trophic cascades or acting as keystone predators (Wootton 1995, Hamilton 2000). Wootton (1995) found that algal abundance was 24 times higher in areas where birds fed than where they were excluded. If rockweed harvest changes predation by birds (e.g. if eiders stop eating mussels off of harvested rockweed), community-wide changes may result. Therefore, as indicated above, activities of birds in harvested and unharvested areas should be monitored using a combination of experimentation and observation.

4) Other species can also be key determinants of bird abundance and community structure. Hanson and Butler (1994) found that after removing fish from a prairie lake, the water cleared, macrophyte and invertebrate abundance increased, and diving ducks became far more abundant. They concluded that zooplanktivorous and benthivorous fish were the key determinants of resource availability for these ducks. Therefore, to accurately predict the effect of rockweed harvest on the bird community, we first have to determine how the system is structured (e.g. top-down versus bottom-up), and whether there is a keystone species or group present. We then have to determine the effect of harvest on this species or group through observation and experimental manipulation.

Future research

There are clearly many questions relating to birds and rockweed that should be studied before the rockweed harvest is expanded. As I have alluded to above, there is a specific need for a combination of short-term manipulative experiments and long-term monitoring. This lack of information is not unique to this system; Savard *et al.* (1994) describe "an urgent need" for experimental approaches to bird-habitat studies, and highlight the problems associated with interpreting correlative studies. It is certainly useful to use information about food habits and habitat use to isolate potential problems associated with harvest, but without experimentation, all conclusions will be speculative. These experiments should also explicitly consider the temporal and spatial scale of the question. Particularly when dealing with both mobile prey (invertebrates or fish) and predators (birds), unless the magnitude and timing of the experimental manipulation is similar to the actual disturbance being investigated, results may not be particularly helpful (e.g. chapter 4 in Hamilton 1997).

Finally, before we initiate more experiments to determine the effect of rockweed harvest on the intertidal community, there are several things that I think should be considered. First, we should define the question. Are we interested in only direct interactions between species, or in the community response as a whole? In my opinion, it is absolutely necessary to take a community-level approach, carefully measuring the response of all species to manipulations. Unanticipated indirect effects can arise in any experiment. Sometimes these obscure main effects (e.g. Hamilton 2000), and unless responses of all species involved are monitored, erroneous conclusions can result. Second, we should consider what level of disturbance to the system is acceptable. It is inevitable that some disturbance will result from removing a large quantity of algal biomass. We need to decide how much change we will tolerate (e.g. a disturbance that persists for a certain amount of time, or a certain percentage change in abundance of key species) and then design experiments to detect change beyond that level. Third, we have to decide what kind of answers are acceptable. For example, in concluding that rockweed harvest was not a problem, would it be reasonable to simply not detect an effect, or should we have to demonstrate that there were no negative effects? This question relates to statistical power and the relative importance of type 1 and 2 errors (Toft and Shea 1983). In my opinion, we should have to demonstrate that harvest is not a problem. Therefore, experiments should be designed with adequate statistical power to do so.

We clearly need more information about birds and rockweed. We know that eider ducklings may be at risk from a harvest, though effects should be fairly easy to mitigate, as described above. We have no such information for other species. However, by carefully observing this system, conducting manipulative experiments, and drawing knowledge from other systems, we should be able to develop reasonable predictions about the effects of rockweed harvest on birds and the rest of the intertidal community. Many of the relevant questions, such as the relative importance of top-down and bottom-up forces and responses of communities to disturbance, are also of fundamental ecological interest. Hence, this system provides an excellent opportunity for fundamental research with an important applied component.

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SESSION THREE: WHAT ARE THE CRITICAL GAPS IN OUR KNOWLEDGE OF ROCKWEED AS A HABITAT?

Working group sessions

Facilitator for Group A:
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Facilitator for Group B:
Maria Buzeta, Fisheries & Oceans

Facilitator for Group C:
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Knowledge Gaps

The following is a compilation of questions that arose during the plenary and working group sessions, edited only for clarity. To avoid excessive redundancy, the main recommendations resulting from the workshop are reported in the final section of the Summary.

A large number of questions and issues were raised during the workshop on what is known and what is not known about the impacts of harvesting on rockweed population structure, on organisms that are directly or indirectly dependent on rockweed, and on ecosystem processes. There was also a considerable amount of discussion on the topic of managing rockweed harvesting and its impacts on the environment. A number of recommendations for future research and management goals are presented in the final section.

Some of the topics presented here have already been the subject of research and reviews of the relevant information were made available in written and/or verbal presentations. In some cases, workshop participants considered the research results either inconclusive, preliminary in nature or convincing, but only in a limited context. For example, survey, monitoring and experimental results were highly variable and the factors measured were too limited. More data, particularly on greater temporal and spatial scales, were deemed necessary for conclusions to be convincing. It was clear that identification of knowledge gaps did not necessarily reflect criticism of the quality of work by individuals but rather there has been insufficient effort, probably due to a lack of commitment to allocate sufficient effort and resources, to important research and management issues.

Rockweed population biology

There was considerable discussion on the role of harvesting on recruitment processes for rockweed. While it was widely acknowledged that overharvesting or denuding a rockweed bed is unacceptable and unlikely under reasonable management practices, there were conflicting opinions on rates of recolonization. While there are many published studies on recruitment and vegetative regrowth there still exists some important knowledge gaps on these fundamental processes.

- What are the mechanisms that lead to successful recruitment into the population, under different physical and biological conditions?
- How does the loss of reproductive vesicles during harvesting impact recruitment success?
- What is the importance of grazers on the survival of early post-settlement phases of rockweed in different geographic areas?
- How does harvesting affect the physiology, biochemistry and morphology (structure) of rockweed and associated algal species? and how do these factors vary seasonally, annually and geographically?

- How is the loss of rockweed holdfasts during harvesting affected by different rock substrates and wave exposures among harvesting areas?

- How is regrowth and plant structure affected by the different seaweed harvesting methods used in the Gulf of Maine?

- Are there significant genetic differences among populations? And if so, do they respond differently to harvesting?

The Biological Community

A major concern of the workshop was the impact of harvesting on the community of organisms that live or visit rockweed beds. We found that there were major gaps in our knowledge of the dynamics of these populations and the importance of rockweed to their survival. Our limited knowledge on this topic is well summarised in the Abstracts. Much of the discussion during the workshop focused on the few species for which we have some information. While we were fairly confident that the groups of organisms mentioned below warrant conservation efforts, there may be other equally deserving species that were excluded.

General

- What are the geographic distributions and abundances of the species present in rockweed beds?

- What are the spatial and temporal patterns of distribution and abundance of these species and how are observed patterns affected by harvesting impacts?

- What are the dynamics of rockweed populations, other associated plants populations and plant-animal interactions? And how are these dynamics affected by different harvest regimes?

- How does rockweed function as a habitat and how will the role of rockweed as a habitat changes with different harvest levels?

- How much habitat loss and/or change in habitat structure is too much?

- What are the trophic (feeding) relationships in this community of organisms?

- What is the role of low trophic level species in affecting rates of recovery for commercially important species?

Plants and Invertebrates

The questions in this section apply to the plant and invertebrate populations associated with rockweed. Discussions focused more on invertebrates than on plants. There were limited studies on harvesting effects on various invertebrates reported in the abstracts. Rockweed habitat use by invertebrates was also inferred from diet studies of fishes.

- How should long-term monitoring of invertebrate community structure be implemented?
- What is the relative importance of resident vs. transient members of the invertebrate community?
- What are the rates of population turn-over and what are the implications for trophic relationships?
- Should key species groups be identified (e.g. littorinids, harpacticoids, gammarids, *Mytilus edulis, Carcinus maenas*) and should they be the subjects of intensive impact assessment studies?
- What are the cumulative impacts of rockweed and periwinkle harvesting on periwinkle populations? How do impacts vary among regions (e.g. the periwinkle fishery is regulated in Maine and open in New Brunswick)?
- What are the impacts on plant and invertebrate populations in coastal areas where there are a number of concurrent plant/animal harvests (e.g. rockweed, kelp, dulse, periwinkles, urchins)?

Fish

Of the fishes that are known to use rockweed as a habitat, pollock generated the most discussion because it is both a commercially important species and its use of rockweed as a habitat during juvenile stages is well known. Despite a wealth of information on pollock and other fishes, very little is known about dependencies on rockweed and how harvesting affects survival.

- Is pollock the only commercially important species that is closely associated with rockweed at some stage in its life cycle?
- What is the geographic distribution of pollock and other fishes and what are their relative abundances among different habitats? How do their intertidal zone distributions compare with their use of the subtidal zone?
- What are the feeding preferences of fishes in rockweed and how is feeding affected by changes in plant structure or invertebrate abundances resulting from rockweed harvesting?

- What are the potential impacts of habitat structural changes and habitat loss on fish populations? For example, how are the predator refuge and foraging functions of rockweed affected?

- How would a functional role of the habitat be defined and measured? and for what species?

Birds

Almost all the discussion of impacts to birds focused on eider ducks. Many other species are known to feed in the intertidal zone at various stages of the tide on invertebrates and on fishes. However, there was great concern for eiders because the young are vulnerable to disturbance and they forage on invertebrates in the rockweed canopy. Further, duckling survival is very low due to gull predation and there is concern that populations may not be able to withstand additional impacts. A considerable amount of information was presented on eider ecology but harvesting impacts have not been investigated.

1. At what spatial scales are eiders selecting their foraging habitats?

2. What are the effects of harvesting disturbance vs. impacts to canopy structure or invertebrate food abundance and availability?

3. What are the critical times, for specific locations, for avoiding disturbance to eider duck breeding and brood rearing?

4. How important is rockweed as a foraging habitat for birds other than eiders?

Ecosystem Level

Ecosystem level affects that were discussed ranged from those occurring within rockweed beds, and the import and export of nutrients and energy, to larger system effects including the whole Gulf of Maine. Of the topics discussed, there was only information on nutrient fluxes at small scales. However, a number of ecological principals and examples from other systems (e.g. eutrophication in the Baltic Sea) were drawn upon for consideration of large-scale effects.

Nutrient Cycling/Nutrient Budget

- What is the contribution of rockweed to the nutrient budget and primary production of the Bay of Fundy/Gulf of Maine system?

- What are the pathways for nutrient cycling and organic carbon fluxes in the rocky intertidal zone? What are the sources and what is the capacity of algae to uptake nutrients and how are nutrients and energy exported e.g. as dissolved organics, floating algal mats, ingestion and subsequent migration by macrofauna?

- What is the relative importance of various sources of nutrients (e.g. attached and floating algae, agriculture runoff, aquaculture and atmospheric deposition)? And what is the capacity of the system to absorb excess nutrients? How much is too much and what are the symptoms of excessive eutrophication?

- What is the relative importance of floating algal rafts and decomposing weed at the strand line? How does rockweed harvesting affect these sources of nutrients and habitat?

Climate Change

- What effects will climate change have on the rockweed populations e.g. changes in sea level or increases in ultraviolet radiation?

Other Resource Users

- What are the potential interactions between rockweed harvesting impacts and other industries; for example, aquaculture, processing plants, shipping wastes/oil spills, and wild fisheries?

- What are the long-term cumulative effects of coastal zone uses and what are the impacts of these effects under different rockweed harvesting regimes?

- Will rockweed harvesting reduce clam recruitment due to a reduction of rockweed detritus?

SESSION FOUR: ROCKWEED AND THE COASTAL ECOSYSTEM

Chair: Jill Fegley, University of Maine

Harvest of Macroalgae: A Global and Regional Perspective

Raul Ugarte, Acadia Seaplants

Seaweeds, Nutrients, and Aquaculture in Coastal Waters... Let's Put Things in Perspective

Thierry Chopin, Darrell Welles & Ellen Belyea, University of New Brunswick in Saint John

Nutrient Availability, Low-Trophic Level Harvesting and Cumulative Human Impacts on Coastal Ecosystems

Boris Worm and Heike Lotze, Dalhousie University

Harvest and Management Strategies of Seaweed: A Global and Local Perspective

Raul Ugarte
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Summary

Marine macroalgae have been harvested for centuries around the world. However, the increased need for polysaccharides in the late 1930's increased the commercial exploitation of seaweeds in that decade.

This analysis outlines the harvesting and management strategies of several commercially important seaweed resources around the world. The resources analyzed are the red seaweeds *Gracilaria chilensis* from Chile, *Gelidium sesquipedale* from Portugal, *Chondrus crispus* from Canada and the brown seaweeds *Macrocystis pyrifera* from Baja California and *Ascophyllum nodosum* from Southern New Brunswick. The selection of these species for evaluation in this comparison was motivated by the economical importance of these seaweeds in their respective countries, the world, and also due to the availability of biological and landing information for these resources.

The analysis includes the history of the harvesting of the different species and the science involved in the different management plans. The reasons for the success and lack of success of the different management strategies are discussed. These strategies are then compared with the harvest and management strategy of *Ascophyllum nodosum* in Southern New Brunswick.

It is concluded that management strategies of different seaweed resources around the world have generally failed in preventing the collapse of some of these resources. In most cases resource development preceded resource management or the government structure was inefficient to control the effort. In contrast, the harvest of rockweed in southern New Brunswick emerges as a new approach to resource management, where scientific knowledge, integration and conservation principles have been the driving forces in the development of this fishery.

Seaweeds, Nutrients and Aquaculture in Coastal Waters... Let's Put Things in Perspective

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Abstract

Marine Biology in the Western World has been historically dominated by zoologists who have fashioned the concepts of the present prevailing views regarding coastal processes and aquaculture, which, unfortunately, are frequently "kingdomly incorrect", showing an obvious animal bias. In contrast with the Asian experience, the fundamental role of seaweeds in coastal waters has frequently been either ignored or misunderstood, and rarely factored into modelling of coastal budgets.

A simple visual model will underline some of these misconceptions and will emphasize the contributions of sediments, as nutrients traps, and of seaweeds, as biological nutrient removal systems. This will also be illustrated by results on seaweed/finfish integrated aquaculture (nori/salmon) in which scallop dragging also plays a significant role (an interesting case of involuntary integrated coastal zone management at work!). Data will demonstrate that seaweeds can also be used as site-specific reliable biomonitoring tools to detect the zone of environmental influence of an aquaculture operation.

Finally, taking into consideration information on the biomass, growth, phosphorus and nitrogen contents, reproduction, and harvesting of *Ascophyllum nodosum*, and on exogenous phosphorus and nitrogen sources, such as finfish aquaculture and effluents from sewage treatment facilities, the contribution of rockweed and its harvesting will be put in perspective in the phosphorus and nitrogen budget in New Brunswick's coastal waters of the Bay of Fundy.

Nutrient Pollution, Low-Trophic Level Harvesting and Cumulative Human Impact on Coastal Ecosystems

Boris Worm and Heike K. Lotze

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and Marine Botany Department, Institute for Marine Science, D-24105 Kiel, Germany

Abstract

Rockweeds are a central and vital link in the coastal food web. These plants are the basis of some of the most productive plant communities world-wide, they harbor an extraordinary diversity of associated plants and animals and provide essential ecosystem services such as nutrient cycling and the provision of fish habitat. The impact of humans within these communities is not limited to rockweed harvesting. We show that other harmful activities such as nutrient pollution and unregulated periwinkle harvesting have to be taken into account in order to assess cumulative human impacts on rockweed populations and the coastal system. In the absence of such an analysis, increased use of coastal resources is extremely risky and should not proceed.

In this paper, we review potential interactions among various uses of coastal ecosystems and caution against increasing multiple-level harvesting and increasing nutrient pollution. First, we show how rockweed populations (*Ascophyllum nodosum*, *Fucus vesiculosus*) decline with increasing nutrient pollution. Nutrient pollution in coastal ecosystems originates mostly from wastewater disposal and finfish aquaculture, land run-off (agricultural fertilizer, soil erosion) and atmospheric deposition (products of fossil fuel burning). Following decades of nutrient pollution, 90-95% of rockweed stands have disappeared in the Baltic. Decreased water clarity and competition from fast-growing annual macroalgae (*Enteromorpha* spp., *Cladophora* spp., *Pilayella littoralis*) have caused these changes. Furthermore, these annual macroalgae now perform destructive mass blooms in eutrophic water bodies world-wide which destroy clam beds, fish habitat, benthic plant and invertebrate diversity. We present data from field experiments and surveys in the Baltic Sea, the Scotian Shelf and the Bay of Fundy that identified nutrient loading, abundance of grazers (mainly periwinkles) and rockweed cover as key variables that determine the success of bloom-forming annual macroalgae. Nutrient loading favors and grazers suppress bloom-forming algae. With increasing nutrient loading, annuals can become decoupled from grazer control. Through removal of the closed rockweed canopy and removal of important grazers rockweed harvesting and snail harvesting can synergistically favor annual macroalgal blooms. In contrast, the effects of higher trophic level harvesting on algal communities are poorly understood, but current data indicate the potential of strong, additional food-web alterations.

We conclude that nutrient pollution threatens rockweed communities and that rockweed and snail harvesting can synergistically enhance pollution effects. Multiple trophic level harvesting, as it occurs now, can cause complex, potentially dangerous changes in rockweed communities. These changes in rockweed community configuration have been shown to alter ecosystem functions and services such as nutrient cycling and habitat structure.

We propose that rockweed harvesting should remain at low levels, especially in nutrient-rich areas such as those impacted by sewage outflows and salmon farms. Furthermore, harvesting of grazers must be controlled and nutrient input reduced in order to maintain rockweed communities and to avoid similar catastrophic ecosystem changes as in the Baltic Sea. The establishment and monitoring of a representative network of no-harvesting zones (MPAs), which serve as control sites against harvested sites is urgently advocated. This approach provides the only reliable management tool that allows the documentation of cumulative human impacts on coastal ecosystems.

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SESSION FIVE: MANAGEMENT UNDER UNCERTAINTY

Chair: Carol Ann Rose, Fisheries & Oceans

Incorporating Ecosystem Objectives Within Fisheries Management Plans in the Maritimes Region of Atlantic Canada

Mike Sinclair, Robert O'Boyle, Leslie Burke and Shawn D'Entrement

. **How do We Know What is the Right Thing to do?**

Jim Wilson, University of Maine

The Difference Between Uncertainty and Ignorance: A Case Study in Initiating Management Under Conditions of Ignorance

Chris Finlayson, Maine Department of Marine Resources

Incorporating Ecosystem Objectives Within Fisheries Management Plans in the Maritimes Region of Atlantic Canada [from ICES (CM 1999/Z:03) Theme Session]

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Abstract

The Canadian Oceans Act passed in 1997 entails new obligations for oceans management. Fisheries are to be managed within the broader context of integrated ocean management of the aggregate ocean uses, ecosystem features are to be considered, and a precautionary approach applied. In response to the Act, the Department of Fisheries and Oceans has initiated discussions on the approaches to be taken. For fisheries biologists, there are two categories of challenges, 1) a new scientific perspective on conservation objectives and 2) a complication in governance. Ocean Management Areas (OMAs) need to be defined based on required stakeholder involvement for the diverse management activities, as well as the artificial boundaries of political and administrative systems already in place. The fisheries (and other industrial activities) within OMAs will need to be evaluated in relation to properties of ecosystems as well as of the target species. Ecosystem objectives need to be defined in parallel with the presently used conservation objectives of fisheries management plans. The new objectives need to address biodiversity and habitat productivity. Associated with the ecosystem objectives, indicators and reference points need to be defined. New monitoring activities and data products will be required for the indicators. Implications of incorporating the ecosystem objectives of an OMA into present management plans are outlined. Evaluation of the degree to which aggregate industrial activities are meeting ecosystem objectives, and resolution of user conflicts requires changes in governance. The nature of consultation between fisheries scientists and stakeholders will change. Some aspects of these changes are described.

Introduction

The *Canada Oceans Act*, which was passed in 1997, outlines how the Minister of the Department of Fisheries and Oceans (DFO) shall develop and implement a strategy for the "management of marine ecosystems", following three interlocking principles (integrated management using the precautionary approach to ensure sustainable development). At present there is limited policy direction for meeting the new conservation obligations of the Act. The aim of this paper is to describe an approach to incorporating ecosystem objectives into management plans for oceans industries in the Maritimes Region of DFO. There are two categories of challenges. First, there is the requirement to evolve from the provision of scientific advice on sectoral management plans to consideration of the aggregate impacts of diverse ocean uses. This requires, for Canada at least, a new scientific perspective involving specialists who have not traditionally worked together. Second, there is a need to develop new linkages amongst stakeholder and management bodies with respect to discussion of conservation issues, whilst maintaining the traditional science/industry relationships that have been slowly established during the past couple of decades. This second challenge is a problem of governance.

Should the Term Ecosystem Management be Used?

Several recent publications use the term "ecosystem management for sustainable marine fisheries"(e.g. Mooney 1998, National Research council 1999). Also, the Ecological Society of America has recently produced a report on *"The Scientific Basis for Ecosystem Management"* (Christensen et. al. 1996). The terminology has caused problems during discussion with managers and stakeholders.

There are a diverse number of marine commercial and recreational activities taking place within the Maritimes Region. These industrial sectors include marine transportation, at-sea disposal of pollutants, aquaculture, oil and gas exploitation, eco-tourism, recreational activities, and commercial fishing. In addition, land-based activities (such as bridges and causeways, disposal of industrial contaminants and sewage) impact on the coastal zone environments, and finally, airborne transport of contaminants arising from distant human activities can impact the waters of the Region. Acid rain impacts on the rivers and lakes of Nova Scotia due to industrial activities in the United States are perhaps the most dramatic example. For some of the industrial activities sectoral regulatory frameworks are already in place, including management plans with conservation objectives. It may become confusing and misleading if we use the term "ecosystem management" for each of the plans for the diverse industrial sectors. For consistency in terminology amongst the diverse regulatory activities, it would be preferable to talk about incorporating ecosystem objectives within the conservation component of the sectoral management plans. Then, for larger areas such as the southern Gulf of St. Lawrence, the eastern Scotian Shelf, and the Gulf of Maine area, the various sectoral plans may need to be adjusted to ensure consistency in approach with respect to ecosystem considerations. For those activities that are presently unplanned, efforts will be needed to develop some management framework if the ecosystem impacts are expected to be of significance. The combination of the industrial sectoral plans into an Integrated Management Plan could logically be defined as the "ecosystem management plan" for an ocean area. Nevertheless, it must be stressed that we would be managing the aggregate human activities within an ocean area, in such a manner that specific ecosystem features are sustained rather than actually managing a marine ecosystem. Perhaps the term ecosystem management should not be used. This discussion smacks of semantics, but we need to develop an accurate set of terms in order to communicate effectively with a diverse number of stakeholders. Our recommendation is to adopt the terminology of "incorporating ecosystem objectives within management plans," rather then the term "ecosystem management," even for the integrated plan.

The Present Situation in Fisheries Management

Fisheries are managed on single species basis throughout Atlantic Canada. The single species plans include several conservation and socio-economic objectives. Those for the groundfish fisheries are discussed in Angel et. al. 1994. The socio-economic objectives are:

- to maintain an economically viable fishery on an ongoing basis where viability implies an ability to survive downtimes, with only a normal business failure rate and without government assistance;

- to maximize jobs subject to the constraint that those employed receive a reasonable income through earnings and fishery related transfer payments;

- to maximize fish harvesting and processing by Canadians without competitive interference from foreign activities.

Given the focus of this paper on ecosystem considerations, the socio-economic objectives are not considered further, other than to point out that the decision-making framework needs to be able to accommodate conflicting objectives within the fishing sector and amongst the aggregate ocean use sectors. Incorporating ecosystem objectives within the conservation package may well increase the complexity of the decision-making process.

The present conservation objectives of the fisheries management plans are frequently defined in an operational manner to be the prevention of "growth" and "recruitment" overfishing. For groundfish, pelagics and several of the invertebrate fisheries, the strategy to achieve these objectives has been to maintain a constant level of fishing effort when the stock is above some minimum spawning stock abundance level. The tactics have included annual quotas, closed areas and seasons, and gear restrictions in order to achieve the constant level of effort that is consistent with the two conservation objectives. There are reference points associated with the various tactics (e.g. F 0.1 for the calculation of annual quotas and percentage of small fish in landings for the imposition of "small fish closures").

In addition to the single species conservation objectives, although not generally recognized, there are some ad hoc ecosystem considerations in the management plans and associated activities. Examples include:

1. The experimental rockweed fishery in southwest New Brunswick involves a patchwork of closed areas to ensure that sufficient habitat is available for juvenile stages of other marine species.

2. The management plan for capelin includes maintaining the biomass at a high level to ensure sufficient feed for Atlantic cod.

3. The application for a new fishery for krill on the Scotian Shelf considered the role of this species within the ecosystem. Concerns by stakeholders on ecosystem considerations were sufficient to delay decisions on any new fisheries on forage species until a policy framework has been developed.

4. The role of seal predation in the population dynamics of cod on the eastern Scotian Shelf has been included in the stock assessment for several years.

5. The Bay of Fundy fixed gear groundfish plan includes restrictions that ensure very low by-catch of harbour porpoise.

6. The Department and the fishing industry have funded multi-disciplinary studies on the impact of trawling (groundfish and offshore clam) on benthic habitat. These studies are near completion.

7. There has been the introduction of regulations on fishing gear to reduce by-catch. The motivation has usually been to limit the by-catch mortality on non-directed commercial species (e.g. reduction of cod/haddock/pollock juvenile by-catch in small mesh silver hake and shrimp fishing gear). A change in mesh characteristics in groundfish trawls has been introduced to reduce the by-catch of juvenile fish of the directed species. These new gear regulations also reduce by-catch of non-commercial species.

8. The single species assessment models include predation mortality by other species in the ecosystem, albeit in a simplistic manner. The estimate of annual predation mortality is based on life-history theory. For fast growing species like shrimp and silver hake, it is assumed that up to about 50% of the "fishable" part of the biomass is eaten by other species each year. For slower growing species like cod, haddock and pollock it is assumed that about 15 to 20 % are consumed annually by predators. The present stock assessment approach, however, has not routinely taken into account that predation mortality may change over time due to fluctuations in abundance of predators and their prey. Very recently, since the moratorium on several groundfish management units, we have been able to evaluate the degree to which predation mortality changes over time. There is strong evidence that for cod this process had increased dramatically in the late 1980s to the present.

In sum, within the present Canadian fisheries management system there has been an increasing awareness, during the past decade, of the need to include ecosystem considerations. The changes have been generated both by international/national legislated obligations and concern by stakeholders. The question, perhaps rhetorical, is whether the present ad hoc ecosystem considerations within our fisheries management plans are sufficient to meet the legislated obligations. If not sufficient, how can they be supplemented to achieve some more explicitly stated ecosystem objectives? Do we need a new departure, or can we build on present governance structures? We recommend building upon the existing management system, but in a pro-active manner that will result in real change rather than window dressing. No doubt there are others who will argue for a paradigm shift, and revolution rather than evolution!

Could Single Species Fisheries Management Achieve Ecosystem Objectives?

The International Council for the Exploration of the Sea (ICES) (1999) has answered this question in some detail. The Working Group on Ecosystem Effects of Fishing Activities (WGECO) phrase the question as follows (p. 215, ICES 1999):

> "If all fisheries were managed so that there was a high probability of achieving conservation objectives for the target fish stocks, would there be a high likelihood of achieving conservation objectives for ecosystems?"

Their answer to this question is "NO" for a number of reasons:

- genetic diversity of target species at risk
- by-catch species at risk
- dependant species at risk
- increase in scavengers may place some species at risk

Keith Sainsbury, in his concluding remarks at the March 1999 ICES/SCOR Symposium on the Ecosystem Effects of Fishing in Montpellier, France, gave the same answer based in part on the oral synthesis of paper and posters presented. There would appear to be broad consensus that the present approach to achieving conservation objectives of fisheries activities, even if successfully implemented, would not achieve yet to be defined ecosystem objectives. There is not however consensus amongst scientists on what additional restrictions are required, nor on what features of ecosystems need to be protected.

The approach recommended here is to add ecosystem objectives to the conservation component of each of the single species fisheries management plans, as well as to the management plans of other ocean use sectors. Then the aggregate activities would need to be evaluated at a range of geographic scales.

The Problem of Geographical Boundaries for the Evaluation of Ecosystem Objectives

The geographical boundaries of marine ecosystems in many situations are difficult to define in a rigorous manner. The distributions of marine populations vary enormously. The geographic scale of the ecosystem for bluefin tuna, swordfish and some shark species is the Northwest Atlantic as a whole. In contrast, the Scotian Shelf and gulf of Maine area comprises the overall distributional area of cusk. Most of the populations of plankton species cover broad geographical areas, and there may be considerable exchange of individuals between areas. In sum, the relevant oceanographic and biological features are generally large in geographic area and species specific. In contrast, the management areas of interest are defined at smaller scales within national, provincial, regional, and municipal boundaries. The definition of geographic boundaries of ecosystems is an arbitrary process dependent upon the particular interests of the ecologist. This is not to say that there is no spatial structure in the oceans, but rather that such structure varies considerably dependent upon the species and populations of interest. We will be unlikely to get ecologists to agree on the spatial definitions of marine ecosystems within the Maritimes Regions, or in Atlantic Canada.

The geographic extent of the ecosystems to be considered in ocean use management plans could be defined in a pragmatic manner, based on the required stakeholder involvement for the management activities and the artificial boundaries of the political and administrative systems already in place. For some fisheries, the Ocean Management Area (OMA) may encompass the relevant biological area. For other fisheries it will not. In the latter cases, there will need to be linkages between plans in bordering OMAs. Within the Maritimes Region (Figure 1) two large areas for consideration of aggregate fishing activities could be the eastern Scotian Shelf (4VW) and the western Scotian Shelf/Gulf of Maine (4X and 5). These areas are larger than needed for some ecosystem and fisheries considerations, and smaller than needed for others. As such, a nested approach would be required for the consideration of specific ecosystem features and associated human activities. For small-scale fisheries such as those for rockweed, clams and sea urchins, political and administrative bodies at the municipal and provincial levels of government may play a large role in the definition of spatial scale of management. In contrast, offshore fisheries on cod, haddock, yellowtail and herring on Georges Bank require a bilateral USA/Canada planning framework for consideration of ecosystem objectives. For large pelagics such as tuna and swordfish, international collaboration is required within ICCAT and with NGOs to deal with the broader ecological issues. The mismatch of geographical scales for a range of ocean use activities has obvious implications for governance of the ecosystem objectives.

For the western Scotian Shelf/Gulf of Maine OMA the following are some of the fisheries that would need to be considered. Many of the single species management plans cover a geographic area larger than this putative OMA.

Fisheries Management Areas Within OMA	**Fisheries Management Area Larger than OMA**
Moon Whelks	Squid
Soft shell clams	Pollock
Rockweed	Redfish
Sea urchins	Silver Lake Cusk
Lobster	Herring
Scallops	Mackerel
Cod (4X)	Tunas, swordfish
Haddock (4X)	Sharks
Winter Flounder	Cod 5Z (j+m)
American plaice	Haddock 5Z (j+m)
Yellowtail flounder	Right whale
	Harbour porpoise
	Seals

Within a nested approach ecosystem evaluations would need to be carried out at a range of spatial scales. Some single species management plans (such as those on the left above) would only need to be evaluated within a single OMA. The management plans for fisheries on the right would be reviewed within more than one OMA.

Ecosystem Objectives for Ocean Management Areas

The ecosystem objectives for OMAs need to be set by Canadian society. The objectives should be similar, or possibly identical, for the wide range of ocean uses. We assume that such objectives will include:

- maintenance of biodiversity
- maintenance of habitat productivity

The challenge to DFO Science is to reach consensus on performance measures and reference points that will support decision making on ocean use activities that threaten biodiversity and habitat productivity. The biodiversity objective will need to include several components; such as ecosystem and species diversity, genetic variability within species and species at risk. The habitat productivity objective will need to address directly impacted species, ecologically dependent species and trophic level considerations. For discussion purposes the above components are considered to capture the necessary ecosystem features that need to be protected in the aggregate sectoral management plans. The next steps are to provide the respective performance measures and reference points.

Performance Measures, Reference Points and Management Tools

The ecosystem diversity and species diversity component of the "maintenance of biodiversity" objective could be measured by a combination of multiple protected areas for the full range of habitat types and diversity indices. There has been exciting progress during the past few years in mapping of benthic habitat on the Scotian Shelf. For example detailed mapping of Browns Bank has identified five habitat types using a combination of macro-benthos photography and multi-beam side scan sonar. The reference points could be a percentage of each habitat type that is left in a natural state. In the initial stages the percentages and spacing could be arbitrary in the absence of a theoretical framework.

The performance measure for genetic variability within species (for the target species of fishing activities) could be a combination of number of spawning populations in the management unit, and Richard Law's so-called selection differentials (presented at the ICES/SCOR symposium in Montpellier, France). Again the reference points could be a combination of percentage reduction in spawning areas and a minimum selection differential (this measure needs further clarification with Keith Sainsbury and Richard Law).

For species at risk the IUCN and other conservation bodies have already defined a range of performance measures (including population numbers, rate of decline and contraction of geographic area of distribution). The reference point for a fishing plan could be the total permissible by-catch level of the species at risk. A concrete example is the present limit of 100 Harbour porpoise deaths per year in the fixed gear groundfish fishery in the Bay of Fundy.

The performance measures for the directly impacted species (i.e. target species and by-catch species) are well established. They include, for example measures of exploitation rate (using size and age structure), spawning stock biomass and geographic distribution. The reference points are also well defined (for example the ICES use of Minimum Biologically Acceptable Level (MBAL) of spawning stock biomass in the ACFM advice).

Reference points for forage species can include consideration of prey requirements in addition in addition to the spawning stock biomass requirements for reasonable recruitment. CCAMLAR has taken this approach for the management of the krill resource in the Antarctic (constable in press). Reference points for non-commercial directly impacted species could also be based on by-catch limits (percentage or absolute), with fisheries being stopped when the limits are reached. This approach is already well developed for many fisheries.

The choice of performance measures for ecologically dependent species is less well developed. CCAMLAR has made some progress at the conceptual level. The approach is to identify key food-chain linkages between target species in a fishery and some dependant species (for example krill and silver hake in the Scotian Shelf Basins if a krill fishery were to be initiated). For one or more "key linkages" the dependant species is monitored in some way (condition, diet composition, abundance). The trickier part is defining reference points associated with the performance measure, as cause and effect for any observed change in the performance measure for the ecologically dependant species will be difficult to evaluate in practice. CCAMLAR is taking a pragmatic approach to this challenge (i.e. start with a range of performance measures on dependent species and decide on reference points at some later time, in the expectation that understanding of the food-chain dependencies will emerge).

> "Trophic level considerations" performance measures are controversial (ICES 1999, p. 217-218). At the end of the section entitled "Biological reference points from an ecosystem perspective" they state....
>
> "the challenge is not to derive the metric, but to relate it to changes in the affected system that are of relevance to society."

The approach recommended here for the Maritimes Region of DFO is to select several performance measures of relevance to ecosystem structure to be monitored in an exploratory manner. These are:

- shape of the size spectrum of the groundfish research vessel survey (1970 to present);
- Daniel Pauley's FIB index (Pauley , in press) which measures changes in trophic level structure;
- aggregate removals at each trophic level by combined fishing activities.

For the latter measure some arbitrary percentage of biomass at a trophic level could be a second order reference point (i.e. the combined herring, mackerel and capelin landings not to exceed some percentage of the long-term estimate of biomass for this group of forage species plus perhaps sandlance). Zwanenburg et. al. (in preparation) have analyzed trends in the slope of the size spectrum of groundfish as a function of fishing effort. The results may provide justification for an arbitrary reference point for ecosystem overfishing. Daniel Pauley presented an index of trophic level balance (the so-called FIB index) at the ICES/SCOR symposium. This metric and empirical observations on how it responds to aggregate fishing effort, may also generate reference points of practical use for management. There is a need for considerable research on the performance measures of relevance to trophic level considerations. At this stage, for the OMAs in the Maritimes Region, it is proposed that a broadbased exploratory approach be taken. The first step is to describe trends in these ecosystem level performance measures in relation to natural and anthropogenic forcing. Definition of reference points can be deferred to some later date.

The suggested performance measures and their reference points are summarized in Table 1. It is important to recognize that the fisheries management tools to achieve the ecosystem objectives are the same four categories that we already have for the present conservation objectives. These are: Gear restrictions, closed areas and seasons (including Marine Protected Areas (MPAs));

annual quotas and by-catch limits; and restrictions on days-at-sea. OECD (1996) states the tools more formally as input controls, output controls, and technical measures:

Output Controls

- TAC (total allowable catch)
- Fleet and Community Quotas
- IQ and ITQ (individual quota & individual transferable quota)

Input Controls

- Limited Licences
- Individual Effort Quotas
- Gear and Vessel Restrictions

Technical Measures

- Size and Sex Selectivity
- Time and Area Closure (including MPAs)

What will be new performance measures and reference points for the achievement of the ecosystem objectives?

Monitoring Needs and Peer Review

Each of the above approaches to defining performance measures for ecosystem structure and function require monitoring. Fortunately there is a considerable amount of information relevant to ecosystem objectives that is already being collected within ongoing monitoring programs. Nevertheless, there will be the need for some additional monitoring, and the development of routine data products on descriptors of ecosystem structure and function. The specific monitoring needs will be defined in relation to performance measures for each of the ecosystem objectives. The costs of monitoring to achieve the broader conservation objectives need to be evaluated and approaches to paying them worked out.

Some extra work by the Regional Advisory Process (RAP) will also be needed. In addition to the evaluation of the conservation objectives of the target species in the single species fisheries management units, there will be a need to evaluate the ecosystem objectives for a group of management units in two OMAs. The combined evaluations will also need to consider impacts of other non-fishing industrial activities.

Some thought is needed on how the precautionary approach should be applied with respect to ecosystem objectives. There will be an increase in the degree of uncertainty when one moves from the evaluation of whether fisheries management actions will meet present conservation objectives, to the consideration of the achievement of additional ecosystem objectives by combined industrial activities. There is presently limited explanatory power in ecological theory, and several generalizations about ecosystem structure and function developed on the basis of observations and experiments within terrestrial and freshwater systems may not be applicable to marine ecosystems. Should we, as a starting point, assume that ecological generalizations having their empirical basis in terrestrial and freshwater systems apply to marine ecosystems? Such assumptions could result in our being more precautionary than required based on marine ecological studies alone. An example is the "trophic cascade" hypothesis for lakes, for which there is limited support from marine studies. (Under this hypothesis, the removal of larger fish leads to changes in the species composition of the zooplankton community.) These are questions that we have not asked within the framework of RAP evaluations of single species management units, which will need to be addressed when considering ecosystem objectives.

As mentioned above, a major difficulty in the evaluation of ecosystem objectives within the fisheries management plans is the identification of cause and effect. To a limited degree we have already had problems in the interpretation of the recruitment collapse for the cod stocks to the east of Halifax, Nova Scotia. There is presently a lack of consensus among scientists on the degree to which fishing and ecosystem change have caused the sharp recruitment decline beginning in the late 1980s. This problem will be more severe when evaluating the role of fishing on observed changes in the emergent properties of marine and freshwater ecosystems. The full range of local and distant human activities, as well as natural environmental variability, may influence the structure and function of ecosystems. There will be considerable uncertainty concerning the role of fishing on any observed changes. Thus RAP will face a new set of challenges, or at least an increase in the sort of problems presently facing the habitat sessions during which broader ecological issues are considered.

The Governance Challenge to Achieving Ecosystems Objectives

RAP is presently structured to absorb the new demands for advice (even though there is already a workload problem). In contrast, the governance structure as a whole, of which RAP is a part, will require substantial change. A major challenge is involving the appropriate range of stakeholders and managers as we move from consideration of present conservation objectives of sectoral management plans (including the single species fisheries management plans) at a range of spatial scales, to explicit consideration of the additional ecosystem objectives at the geographic scale of the two OMAs. There will be the need for area advisory committees that cross commercial fisheries, as well as, other ocean uses (e.g. First Nations, oil and gas, aquaculture, transport, eco-tourism and recreational fisheries). Analyses of the state of the ecosystem in relation to the aggregate human activities which are or should be managed will need to be carried out on a multi-year cycle. New institutional structures that involve municipalities, provincial departments of two provinces, other federal departments, First Nations, NGOs as well as representatives of the relevant commercial interests need to be developed in a cost effective manner. Fortunately, as is the case with monitoring, there is already in place a range of institutional structures that can be used. The principle functions that need to be achieved are the audit of the degree to which the sectoral management plans are being implemented in relation to the overarching conservation objectives, as well as the capability to resolve conflicts amongst competing users. DFO is presently developing an integrated management plan for the eastern Scotian Shelf as a pilot. During this pilot initiative the governance challenges will be addressed on a trial and error basis (learning by doing).

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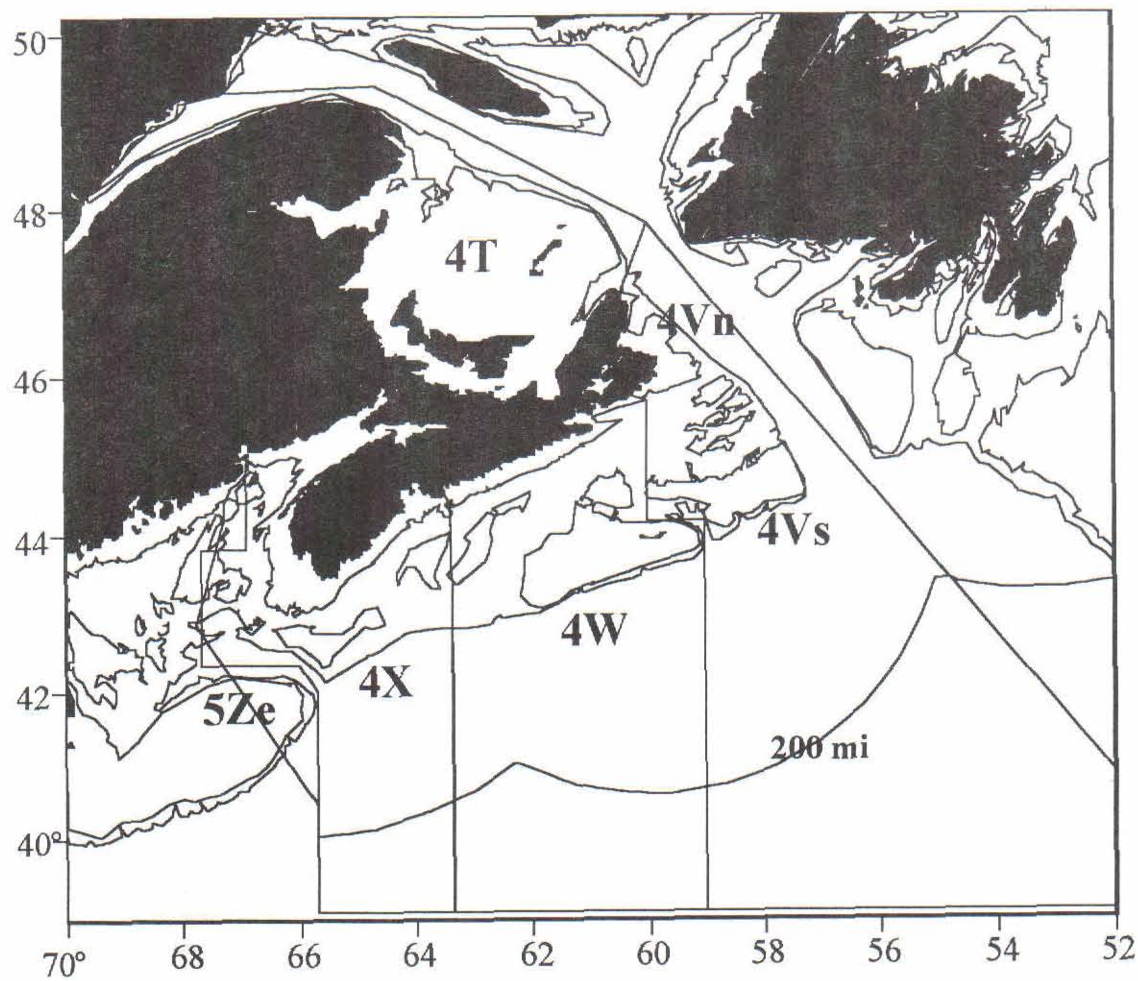

Figure 1. The DFO Scotia-Fundy area of Atlantic Canada includes NAFO statistical divisions 4VWX and part of 5Ze.

Table 1. Examples of Ecosystem objectives, performance measures and reference points for Ocean Management Areas (OMAs)

Objectives	Performance Measures	Reference Points
Maintenance of ecosystem and species diversity	Areas of the continental shelf disturbed by fishing activities	Percentage of each habitat type that is undisturbed
Maintenance of genetic variability within species	Number of spawning populations of targeted species Selection differentials	Percentage reduction in spawning areas Minimum selection differential
Recovery of Species at risk of endangerment	Number of individuals of the species at risk Geographic area of distribution	Maximum by-catch annually Percentage of distributional area relative to period of moderate abundance
Maintenance of directly impacted species	Fishing mortality Spawning stock biomass Area of distribution	F 0.1 Minimum stock biomass necessary for recruitment and forage Percentage of distribution relative to period of moderate abundance
Maintenance of ecologically dependent species	Abundance of key predator Condition of key predator Percentage of prey species in diet of predator	Minimum abundance level of predator Minimum condition level of predator Minimum percentage in diet of predator
Maintenance of trophic level balance	Slope of size spectrum Pauley's FIB index Aggregate annual removals by fishing for each trophic level	Minimum slope Minimum level for index Percentage removal from a trophic level

How do We Know What is the Right Thing to do?

Jim Wilson, University of Maine, School of Marine Sciences

Notes

Almost always we address the question of what is the right amount or way to harvest, with the presumption that we know the relevant cause and effect relationships. To the extent that we recognize our ignorance, we believe we can capture it in statistical confidence limits. Under certain circumstances, this is not a bad way to try answering the harvest question.

Generally, those circumstances occur when the species is basically independent of other species in the system and we understand or can control reproductive success.

To the extent that the species interacts with other elements (biotic and abiotic) in the system this approach becomes problematical.

The so-far insolvability of the recruitment problem, which probably occurs because of the many interactions of young fish with the biological and physical aspects of the systems of which they're a part, makes the standard sustainability analysis questionable.

If it is assumed or recognized that we are dealing with a complex, non-linear, adaptive system, we become painfully aware of what we don't know. (Or maybe I should say what we can't predict.)

1. Complexity means that we have a lot of interacting elements in the system and a hard time tracing cause and effect relationships.
2. Non-linearity means the strength and relevance of those relationships changes from circumstance to circumstance, and
3. Adaptive means that elements in the system (especially human elements) continually adapt to maximize the good effects or minimize the bad effects of these relationships.

At the species level our quantitative predictive capabilities extend one or two years ahead at best. On the other hand, we possess at great deal of qualtitative knowledge of system behavior, and seem able to find reasonable <u>explanations after the fact</u> of most phenomenon.

The cod closure and scallop bonanza on George's Bank is a good example. After the fact, explanations of why this occurred are easy to come by and reasonable. But, as far as I know, none of them were made before the closure. And those that were made about cod were not borne out.

Given this state of our knowledge of the system and of our effects upon the system, how do we know what is the right thing to do for sustainability? The right amount to harvest? The right way? The right time?

I don't have an answer to those questions but I do have a suggestion about how we might go about finding, or learning, an answer.

In particular, the question is how do we get feedback from the system? And how do we make sure that feedback goes to the right person or group? (right in the sense that they might be able to understand and act upon that feedback)

When one thinks about learning within a complex system (as opposed to our usual single species approach) three aspects of a complex system are (socially[1]) important to any eventual solution:

1. Complexity implies a lot of ecological detail that is not now included in our analyses.

2. Complexity implies a system that operates on multiple spatial and temporal scales not the single scale that we usually incorporate in our conventional analyses.

3. Non-linearity and complexity cloak any attempts we might make to tie our actions unambiguously with any particular results in a complex system.

The major social implications are:

1. The inclusion of ecological detail generally means a lot more decentralization than we have yet built into management.

2. Multiple ecological scales means that we have to organize management also at multiple scales. (both these points are essentially efficiency arguments not political arguments)

3. Ambiguity of outcomes/relationships means that we have to be very careful about the kinds of rights to the system that we create. The scope of rights has to correspond with ecosystem outcomes in such a way that the feedback from previous actions and incentives of individuals (or managers) with regard to current and/or future actions are consistent with conservation.
   a) Species specific rights are not likely to generate the kind of feedback that will allow for the growth of accountability or stewardship.
   b) Broad rights across multiple species or the entire system might contain or encompass the results of our actions are more likely to provide appropriate feedback. There has to be restraint, but if people restrain their fishing today they have to be in the position of capturing a fair share of the benefits and the costs tomorrow.
   c) The spatial extent of rights probably has to correspond with the spatial organization of management (governance) or even more ambiguity of feedback will result.

4. Ambiguity also means management is likely to work best as a process – as democratic governance.

a) Quid pro quo can't work given the kind of predictive capabilities we possess.

[1] By socially important I mean to imply that the learning process is very much a social process upon which science is dependent. The current organization of fisheries science, for example, reflects the scale determined to be relevant by current (or past) theories of fisheries and the social organization needed to address the problem at that scale. A changing sense of scale implies a changing social organization.

b) Additionally, we should exhibit a strong preference for rule making processes that result in a high level of willing compliance without threat of police power.

- Because it is good governance, and
- Because such processes significantly widen the scope of possible rules that can be used to address the conservation problem.

c) Appropriate restraining rules can only be developed when

- incentives are aligned with conservation
- institutions generate assurances about the behavior of others
- there is a perception of some sort of ecosystem relationship between the act of restraint today and the generation of benefits in the future.

Summary

The state of our presumed knowledge of ocean ecosystems is an important determinant of how we organize management and assign use rights. Conventional, highly centralized fisheries management is a reflection of theory which presumes simple, single species mechanisms operating at large geographic scales. The (ambiguous) failure of that theory and growing theoretical emphasis on system as opposed to species and multiple as opposed to single scales, implies the need to generate a new appropriate management organization emphasizing decentralization. The same changes mean we have to rethink what we mean by appropriate user rights and bring their scope into alignment with discernable, or detectable, feedback.

The Difference Between Uncertainty and Ignorance: A Case Study in Initiating Management Under Conditions of Ignorance

Chris Finlayson, Maine Department of Marine Resources

Abstract

Uncertainty is commonly understood to be a probabilistic phenomenon akin to risk and, like risk, can be understood and managed with well-developed statistical tools. This implies that the range of possible outcomes of inputs to a system (management actions) have a known probabilistic relationship to past actions and the present state of the system. However, when future states of the system do not have a simple probabilistic relationship to the past and present and/or when one or more basic driving forces are opaque or unknown, then uncertainty becomes ignorance and statistically valid predictions of future states of the system become a formal impossibility. I argue that our relationship to marine ecosystem dynamics is better understood as ignorance than uncertainty. The case of the Maine sea cucumber fishery is used as an example.

POSTER SESSION

Rockweed as a Habitat for Invertebrates, for Fishes, for Birds… Fine, but What About *Ascophyllum Nodosum* for Itself and as a Habitat for Algae? Should the Very Species Which Defines this Habitat Not Also be Worth Investigating?

Thierry Chopin, Patricia Marquis, Brian Kerin, Darrell Welles and Ellen Belyea.

Short-term Effects of Rockweed (*Ascophyllum nodosum*) Harvesting on the Nearshore Ecosystem.

Jill C. Fegley, Robert L. Vadas & William A. Halteman.

Compliance Monitoring in the New Brunswick Rockweed Fishery (1996 -1999).

Tom McEachreon.

Structure of the *Ascophyllum nodosum* (Rockweed) Habitat and the Effects of Harvesting Perturbation in Southern New Brunswick.

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University of New Brunswick, Centre for Coastal Studies and Aquaculture, Department of Biology, P.O. Box 5050, Saint John, N.B., E2L 4 L5, Canada.

Abstract

This poster will illustrate recent data acquired on *Ascophyllum nodosum* (rockweed) and its associated species in the Bay of Fundy in terms of: 1) growth of *A. nodosum*, 2) biomass of reproductive organs in *A. nodosum*, 3) biomass of the associated species *Polysiphonia lanosa*, *Pilayella littoralis*, and *Elachista fucicola*, and 4) phosphorus and nitrogen contents in *A. nodosum* and its associated species.

It would make perfect sense to not only identify the critical gaps in our knowledge of rockweed as a habitat, but also of rockweed as the pivotal algal species defining the habitat in question. Some aspects of the biology, ecology, physiology, biochemistry, etc. of *Ascophyllum nodosum* and its associated algal species still need further study, such as: 1) seasonal, interannual, and geographical variations of biological, chemical, and physical parameters and their implications for harvesting strategies, 2) long-term evolution of the rockweed structure/architecture in harvested and non-harvested beds, 3) role of the rockweed biomass in the nutrient budget/primary production of the Bay of Fundy/Gulf of Maine ecosystem, 4) dynamics of rockweed populations in plant-plant and plant-animal interactions, 5) occurrence of rockweed populations or of one population, 6) use of rockweed (and other seaweeds) as biomonitoring tools of anthropogenic activities for integrated coastal zone management and sustainable fisheries/aquaculture.

Only a better knowledge of rockweed itself will allow for a better knowledge of the habitat it defines. There are still plenty of science and management investigations to be conducted. But, who will pay for them? Realistic recommendations must be matched by appropriate funding support, or it all remains an interesting, but futile, exercise...!

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Short-term Effects of Rockweed (*Ascophyllum nodosum*) Harvesting on the Nearshore Ecosystem

Jill C. Fegley[1], Robert L. Vadas[1] & William A. Halteman[2]

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Abstract

Harvesting of natural resources usually entails substantial removal of the target species. Where such species are dominant or important members of natural communities, their removal or loss can have important consequences for their own regeneration as well as for communities of species assemblages associated with them. *Ascophyllum nodosum* (rockweed) is a commercially important intertidal algal species in the North Atlantic and is increasingly being harvested in the Gulf of Maine. The effects of harvesting on the regrowth of adults has been studied but relatively little work has examined the effects of harvesting on the associated species that utilize this alga as habitat. A range of harvesting treatments (unharvested control; harvested 18cm from the holdfast; and at 36cm from the holdfast) has been imposed upon replicate areas within several *A. nodosum* populations. The short-term effects of the various treatments on the associated sessile and mobile (non-fish) assemblages was examined to assess possible changes in biodiversity. Analysis of one-year post harvest data reveal that both algal and invertebrate species were negatively affected by the reduction in the *Ascophyllum* canopy.

Compliance Monitoring in the New Brunswick Rockweed Fishery (1996 -1999)

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Summary

Compliance monitoring of the NB Rockweed Fishery by the NBDFA is an important aspect of the Rockweed Fishery Management Plans (RFMPs). From 1995 to 1998, this fishery has grown from a harvest of 902 to 5781 tonnes. Among the three harvest areas, the current annual maximum is 10,000 tonnes. Fishery management guidelines for 1999 stipulate that the NBDFA St. George Office is responsible for both chairing meetings of the RFMP Group and for measuring and evaluating several aspects of biological data from this fishery. The data includes the holdfast and invertebrate bycatch content of the harvest, the cutting height of shoots above the holdfast on clumps (i.e. plants) remaining in harvested beds, and a measure of harvest patchiness from selected rockweed beds in the Harvest Areas. Data from 1996 –1999 shows that there are approximately 20% of the harvest sample weights contained as holdfast & basal tissue. The bycatch (1996-1998) is highly variable, but the numbers of a commercial species (*L. littorea* – common periwinkle) are relatively low. In 1999, the experimental design changed to more precisely describe both seasonal and locale specific factors in the distribution of invertebrates. From samples collected during 1996-1998, the present harvest method and harvest tool is achieving the objective of a mean cutting height of 25 cm above the holdfast. The harvest appears to be patchy. The continuation of compliance monitoring by this Department is important for the continuation of this New Brunswick fishery as a long term and sustainable enterprise.

Introduction

Monitoring of the NB Rockweed Harvest by NBDFA offices was and is part of the terms of the Rockweed Fishery Management Plans (RFMPs) [1995-1997, 1998,1999]. These tripartite Plans developed by Fisheries and Oceans Canada (DFO), NB Fisheries and Aquaculture (NBDFA), and the licensee Acadian Seaplants Limited (ASL) followed the release of a 1992 CAFSAC report. That report recommended that a pilot scale *Ascophyllum nodosum* harvest be permitted. A controlled annual harvest of up to 10,000 tonnes is permitted. The fishery has grown steadily since 1995. Landings were 902, 3001, 4642, and 5781 tonnes from 1995-1998 inclusive (DFO, 1999). The harvest is distributed among sub-sectors in three harvest areas. This quantity is from a total standing stock of 159,683 tonnes of rockweed. The estimated *harvestable* crop, using the presently approved harvest method and cutter rake, from the total standing stock is 77,005 tonnes (Ugarte, 1998). So, over a 3 year period, approximately 48.22% of the stock was available for harvesting. This is approximately 16% per annum. The Management Plan was extended into 1998-1999 for this pilot fishery. Biological monitoring data collected and analyzed to date will be used to assist in deciding what plans can be made for the long-term sustainability of this fishery in New Brunswick.

In addition to chairing the quarterly meetings of the Rockweed Fishery Management Plan Group, the NBDFA has a person in the St. George office designated to collect and evaluate biological data from this fishery. Contact was also maintained with the harvesters, ASL Resource Manager, ASL General Manager for NB, ASL Resource Scientist, and ASL Senior Advisor (NB). Harvest operations commenced in 1995. Sampling protocols were developed by DFO, NBDFA, and ASL to monitor several aspects of this fishery. These tests were and are part of a program to ensure the satisfactory development of this fishery based on sound commercial and environmental principles. The biological characteristics for these monitoring actions included – the holdfast and invertebrate bycatch content in the harvest, the cutting height of shoots above the holdfast on clumps (i.e. plants) remaining in harvested beds, and a measure of harvest patchiness from selected rockweed beds among all three harvest areas.

Materials and Methods

During the rockweed harvest seasons 1996-1999 (June 1 – mid-October), rockweed samples were collected both from harvesters and from the beds being harvested. Triplicate samples (three, 5 kg. bags) for holdfast and bycatch content were taken either directly from the harvesters or from the fixed and mobile landing sites assigned to them. Transects were run at actively harvested beds to measure cutting height above the holdfast and harvest patchiness. Samples were to be collected from each harvest area and from as many harvest landing sites as time permitted.

Holdfast/bycatch samples taken from different parts of the skiff or bagging platform series or box at a landing site were bagged, tagged, and returned to the NBDFA office for sorting. Care was taken to minimize further breakage of shoots and clumps. From each 5 kg sample about 2 kg of rockweed was washed through a 250 micron mesh net for the collection of benthic invertebrates associated with the harvested rockweed. Samples were put in whirl-pack bags in a 70% isopropanol solution for identification at a later date. The sub-samples of weed were weighed on an electronic balance ($\pm$ 0.5 g), in order to later calculate numbers or weights of benthic invertebrate groups present per kilogram of harvest sample. From each 5 kg sample, rockweed was sorted according to three categories. These were non-basally attached portions, basal shoots, and holdfasts or "entire" clumps. Basal shoots are portions of the clump directly attached to the holdfast. Results were recorded as the number of holfasts per kg. of sample, percent by weight of holdfasts in the total sample weight, and % by weight of rockweed basal tissue in the total sample weight. Based on comments from the April/99 Regional Advisory Process, the focus of attention for 1999 samples was the percent by weight of clump and basal tissue.

For bycatch measurements (1996-1998), a portion of the preserved sample (1/4 – 1/32) was counted in a petri dish over a grid with a dissecting microscope. After a sample was initially sorted to remove detritus material, counts were made with the 0.675 X objective and 10X ocular lenses. Invertebrates were grouped into several categories. The first results to be tallied were the numbers of individuals per kg of rockweed sample. In some cases, sub-samples were also taken for dry weight measurements (12 hrs. at 70 C in a drying oven). Counts were made from 13 groups of Taxa [**1.** oligochaetes (aquatic earthworms), **2.** polychaetes (bristle worms), **3.** *Littorina littorea* (common periwinkle), **4.** *L. obtusata* (smooth periwinkle), **5.** other gastropods *(L. saxatilis, Lacuna vincta, Nucella lapillus*), **6.** *Mytilus edulis* (blue mussel), **7.** *Macoma* clams, **8.** other bivalves (*Mya arenaria, Hiatella arctica*), **9.** ampipods (primarily *Gammarus* spp. and *Marinogammarus*), **10.**

isopods (*Jaera marina* and *Idotea balthica*), **11.** other crustaceans (barnacle larvae, *Carcinus maenas* (green crab)), **12.** chironomids, **13.** other taxa (turbellarians (flat worms), nemertean worms, dipterans)].

Based on NBDFA observations of harvest activity, monthly harvest landings reports from the licensee, and accessibility to the harvested rockweed beds, stretches of shoreline (~ 100 m wide) were identified where transects could be run for the measurement of cutting height above the holdfast and harvest patchiness. In 1996, 1997 and 1998, eight locations among the Harvest Areas were selected. In 1999, a sub-sector from each of Areas A, B, and C was selected and transects were run in a selected rockweed bed. After selecting a sub-sector for cutting height measurements, a suitable place for running a transect (i.e. a bed known to have been harvested) was pinpointed by walking up and down and across the bed and searching for groups of cut clumps within 2-5 m of each other. This visual search on the ebb tide usually commenced on the low shore. Clumps cut by harvest activity could be quickly differentiated from other abrasions on the rockweed thallus. Rake activity was identified by both the sharpness of the cut surface and a tendency for a few clusters of such shoots to occur on the same clump. A transect line perpendicular to the shoreline was run by one or two people. The lines ran from a point on the low shore where rockweed became absent to the top of the rockweed zone. If time permitted more than one transect line would be run at a given location. A 10 m wide parallel buffer strip separated the lines. There were parallel points of origin at the top of the zone, in a given locale. The interval for measurements along a transect line was 1, 2, or 3 m. At each interval, a $0.25m^2$ quadrat was used to count the number of cut and uncut clumps. Clumps $\geq$30 cm were counted. If a quadrat had one or more cut clumps, the first cut clump found in the quadrat was cut at the holdfast with a jackknife. It was tagged and returned to the NBDFA lab for measurement of clump length & weight & circumference, and numbers and lengths of cut shoots on the clumps. The lengths of un-cut clumps $\geq$30 cm within quadrats with one or more cut clumps were also recorded.

In 1998, at Back Bay (B; 6-6), Grand Harbour (C; 9-2) and Ingalls Head (C; 10-2) another sample set of cut and uncut clumps were collected from the transect lines, in order to increase the sample size of cut clumps collected. Thirty-two cut and uncut clumps were collected from the first two sites. Sixteen cut and uncut clumps were collected from Ingalls Head.

Harvest patchiness (1996-1998) was depicted by recording the number of cut clumps per the total number of clumps $\geq$30cm within a series of 0.25m quadrats from the harvest site. The approximate percent of rockweed clumps cut and remaining attached on the shore was then calculated, as another estimate of harvest exploitation rate.

Results

Holdfast content (clump and basal tissue content as a percent of harvest sample weights) varied according to harvest crew location, over the interval 1996-1999. There were also differences among years. Numbers of clumps were highest in 1996 and declined in 1997 and 1998. Both the number of clumps/kg of weed, and combined clump and basal tissue content as a percent of harvest sample weights increased over the interval 1996 –1997/98. They fell slightly in 1999. The bycatch content in the rockweed harvest varied according to both year and groups of invertebrates at different sites among years.

The 1998 Rockweed Fishery Management Plan (RFMP) guidelines allow for a cut height mean of ≥ 25 cm with an absolute minimum of 12.5 cm. In most cases, the mean cutting height above the holdfast is within those stipulations. From the clumps sampled in 1996, 1997, and 1998, the median lengths were 65.5, 61.5, and 65 cm respectively. The median cutting height of shoots (33 cm, 31 cm, 28 cm) from 1996, 1997, 1998 and the minimum values from 12 locales approached the lower limits specified in the RFMP. However, the percent of cut shoots from the clumps sampled is <25% of the total number of shoots in a clump.

From the 21, 13, and 23 transects run in 1996, 1997, and 1998 respectively; the harvest does appear to be patchy. With two exceptions, the median for the number of cut clumps found in any quadrat on a transect line with some rockweed clumps is zero. The percent of clumps cut, and remaining on the shore, were generally <17.1%. In one case, where the observed % was approximately 37.7 %, only part of one transect was completed.

Discussion

Differences in holdfast clump numbers among years are partly a function of clump separation after collection. In 1997 and 1998, there was improved identification and separation of holdfast and basal tissue. There were fewer clumps in 1997 and 1998. The reasons for an increase in the combined clump and basal tissue content (1996-1997/98) are not apparent. However, the 1999 value was 18.3% (i.e. 6.2% as clumps; 12.1 % as basal tissue). This shows that with an increasingly experienced core group of harvesters less near substrate rockweed biomass is being removed. A harvest objective of minimizing the clump content (e.g. ~ 10 % for a mean clump content by weight) is being met with current harvest practices.

The very high variability of the bycatch is attributed to seasonal differences in invertebrate abundances and locale specific differences linked to factors such as substrate. Numbers of commercial species such as the common periwinkle are relatively low. The numbers of large (i.e. >1cm) common periwinkle which remain in the bottom of a recently unloaded skiff after a harvest on a tide are unknown, but they could be similar to those which remains on rockweed sampled from the skiff. Data analysis on the weights and/or sizes of invertebrate groups is necessary. In 1999, the experimental design was redone. There is to be a consideration of both seasonal and locale specific factors in the distribution of invertebrate group numbers. Three locales were sampled close together in time throughout the 1999 harvest season.

The present harvest method and harvest tool is achieving the objective of a mean cutting height of 25 cm above the holdfast. Small sample sizes from clumps sampled along the 24 locales and 57 transect lines prompted the extra collections, in 1998, at Back Bay (sub-sector 6-6), Grand Harbour, and Ingalls Head. Cut shoot lengths with those larger sample sizes still showed acceptable distances above the holdfast. Even on cut clumps remaining on the shore, many shoots are left uncut. The cut clumps, in turn were >61 cm. However, the medians of cut shoot lengths are closer to 30cm. No method whereby more shoots could be cut at a shorter height above the holdfast is acceptable.

The harvest appears to be patchy, but more transects at fewer locales are strongly recommended for field work, in 1999. Time permitting, before the next harvest season, the 1999 bycatch samples from Back Bay, Digdeguash, and Ingalls Head Sites are to be measured and evaluated. There also are cutting height above the holdfast measurements from transects from Seeleys Cove (Area A), Digdeguash (Area B), and Ingalls Head (Area C) rockweed beds to be made.

The continuation of compliance monitoring by this Department is very important for the continuation of this fledgling New Brunswick fishery, as a long term and sustainable enterprise.

Additional Reading

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Fisheries and Oceans Canada. 1998. The 1998 Southwest New Brunswick Rockweed Fishery Management Plan.

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Structure of the *Ascophyllum nodosum* (Rockweed) Habitat and the Effects of Harvesting Perturbation in Southern New Brunswick

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Abstract

Clumps of dichotomously and lateral branching shoots on long-lived *Ascophyllum nodosum* holdfasts add to the complexity of the intertidal habitat. Harvesting depending on its intensity and extent alters this habitat. Habitat changes were evaluated with experimental studies, fisheries monitoring and computer simulation. The harvester using a cutter rake in winds and tides creates a patchwork of impacted clumps averaging .19 SD .18 of the total density at a 17% exploitation rate. If the exploitation rate increases the incidence of harvest increases, as does the portion of the clump removed. The branching structure of an *Ascophyllum* clump results in more the biomass in the distal portion of the clumps as it grows. Clumps over 80 cm long have 50% or more of the biomass in the upper half of the clump. The size distribution of shoots is heavily skewed below 20 cm. The cutter rake is size selective cutting 9.8 % SD 6.3 of all shoots in a clump but 41.0 % SD 23.6 of shoots over 25 cm long. A spatial model of harvesting impacts on clump length at 3 levels of harvest intensity (.15 to .43 of clump density) detected a shift of clump size in harvested patches toward the 31 to 52 cm size classes. The degree of alteration in clump length was not significant in the *Ascophyllum* bed as whole. Not all of the *Ascophyllum* resource is accessible or economic to harvest. At the end of 1998, 39 of the 64 harvesting sectors in southern New Brunswick had no harvest activity. Harvests of rockweed from the Bay of Fundy in 1998 5.5 % and are predicted to reach 8.7% in the next 3 years.

SESSION SIX: Recommendations for managing rockweed in the face of scientific uncertainty

Working group sessions

Facilitator for Group A:
Mick Burt, Huntsman Marine Science Centre

Facilitator for Group B:
Maria Buzeta, Fisheries & Oceans

Facilitator for Group C:
Linda Mercer, Maine Department of Marine Resources

Management Issues

Rockweed harvest management was acknowledged as effective and well-defined in Atlantic Canada, particularly in New Brunswick where there is active participation among two levels of government and the single licensed company. In the rest of the Gulf of Maine there are many more companies and individuals harvesting seaweed and management structures appear to be weak or non-existent. Regardless, of the intensity of management practices a number of important knowledge gaps were raised.

Harvest levels

- What is the distribution of harvest effort in the Gulf of Maine?
- Where effort is well documented, do we have confidence in present harvesting levels?
- How explicit are the criteria for setting harvest levels and over what time frame should they be allowed to increase or decrease?
- Do harvesting levels need to be site specific?
- What is the appropriate spatial scale of harvest management?
- What is the appropriate distribution of harvest effort in order to minimise impacts? For example, should any areas be intensively harvested or should harvesting be conducted at low rates over larger geographic areas?
- Should harvest areas be rotated instead of designating certain areas as either a harvest or no harvest area?

Traditional Knowledge

- To what extent can local traditional knowledge be used to fill in knowledge gaps about the resource? For example, how have rockweed beds and their associated organisms changed over time?
- What are the mechanisms for transferring knowledge from traditional sources to a management framework?

Management structure

- How flexible should management plans be in order to respond to observed changes in the system? Is an annual assessment too infrequent?
- What management structures are most appropriate to respond to the range of spatial scales over which harvesting impacts may occur? For example, can the whole Gulf of Maine be managed as effectively as at state/provincial or the local community level?

- To what extent can local community representatives be involved in the management of rockweed harvesting? What about all other potential stakeholders?

- How will new research findings be used in future resource management? Will it be possible to modify existing management plans through changes to the location, timing or level of rockweed harvesting?

Protected Areas

- What are the objectives for the development of "no harvest" zones? For example, the need for time-series of baseline data, development of useful indicators and reference points for impact assessment.

- Should closed areas apply to all resource use activities, not just rockweed harvesting?

- What criteria should be used for the design of closed areas? For example, landscape ecology takes into consideration the size, shape and connectedness (through use of corridors) in reserve design.

- Will the developing network of Marine Protected Areas be sufficient or should there be closed areas specifically for rockweed harvesting?

Management Strategies

- How can hierarchical levels of population processes, from behavioural to landscape features, be implemented in conservation strategies?

- When will BACI (Before/After Control/Impact) assessments of harvesting effects on the structure of rockweed as a habitat and on the associated species be initiated?

- How do results from small scale impact assessments scale up to the larger area affected by commercial harvesting of rockweed?

- How can by-catch (e.g. of periwinkles) during rockweed harvesting be minimised?

- What is the best set of available management tools (e.g. harvest and impact monitoring, harvesting methods, closed areas) and how are they being used throughout the Gulf of Maine?

Workshop Summary

Challenges

The objective of the Workshop was to identify knowledge gaps in our understanding of the role of rockweed as an essential habitat and the consequences of ecosystem-level changes to rockweed populations in the Gulf of Maine. It became clear throughout the workshop that determining ecologically sustainable harvest levels and management recommendations for a species at a low trophic level is a complex and difficult problem.

At present, very limited knowledge exists with which we can assess the impacts of harvesting macroalgae. There was a considerable amount of success in defining knowledge gaps and to some extent prioritising them. Nevertheless, **the final list of studies requiring immediate attention remains daunting**. Recurrent themes included grappling with scientific uncertainty with respect to harvest impacts to rockweed populations as well as the consequences for everything else, from single species to the whole Gulf of Maine system.

It was recognised that long-term studies, while always desirable, are not always feasible nor do they provide often needed short-term answers. While there was an expectation that government agencies should be responsible for funding research studies, there was the clear recognition that the challenge before us is the immediate need for a management framework that works under a broad definition of uncertainty.

Among the major challenges, the one of least concern among workshop participants was harvesting impacts to rockweed populations. There was general agreement that at current harvest levels and current methods being used in New Brunswick, that exploitation was probably not detrimental to the resource itself. Much less data was presented on harvest levels elsewhere in the Gulf of Maine but the experience of harvesting in New Brunswick and, to some extent in Nova Scotia, generated confidence that it was possible to sustainably harvest rockweed. This was based on reports that harvesting did not remove excessive biomass from any given area, that cutting methods had minimal effects on plant height, and that the combination of patchily distributed harvesting and sufficient regrowth resulted in full recovery.

In a cautionary review of the global seaweed industry, Raul Ugarte noted that non-existent or poor management strategies were the cause of resource collapses. Nevertheless, a number of research problems were identified as still outstanding and in all situations close monitoring of harvesting practices and population responses was deemed necessary. The challenges seemed to be least for effects on the rockweed populations providing that a level of monitoring and research as applied in New Brunswick is maintained in all regions. However, **there was less confidence in the prospects of full recovery of rockweed populations under scenarios of long-term repeated harvesting, if there are large increases in harvested biomass and if harvesting methods or current management and monitoring practices changed.**

Management Issues

In Canada there are new obligations for oceans management under the Oceans Act. These will create new challenges in governance and new fishery science perspectives on conservation. The Department of Fisheries and Oceans view that is emerging is summarized in an abstract by Mike Sinclair and co-authors (oral presentation by John Neilson). They proposed that ecosystem objectives will need to be defined in parallel with the presently used conservation objectives of fisheries management plans. The new objectives need to address biodiversity and habitat productivity. Associated with the ecosystem objectives, indicators and reference points will also need to be defined and new monitoring activities and data products will be required for the indicators.

From a practical management point of view, the critical question is: how do we know when we've got it right? Jim Wilson described the problem facing managers when attempting to predict responses from complex systems. Emphasis needs to move from single species and single scales to a multiple scale systems approach. Management also needs to be decentralised and structured so as to get appropriate feedback from the system. Chris Finlayson also underscored the need for a new management framework by applying the distinction between the definition of uncertainty where risk assessment can be analysed using the appropriate statistical tools and uncertainty where we have no information, which is akin to ignorance. Perhaps, closing our knowledge gaps will reduce our ignorance of the system.

The adoption of an appropriate management framework will permit responding to system feedback in an adaptive fashion. However, specific challenges facing research studies were highlighted in a number of reviews. For example, the high natural variability in abundances and, for mobile species, the high variability in their tidal, diel and seasonal movements require very large sample sizes, and associated monetary costs, to be able to detect harvest impacts. This was demonstrated by Robert Rangeley for fishes but similar problems may dog studies for other groups as indicated by Robert Vadas, Jill Fegley, Glyn Sharp and others. Diana Hamilton emphasized that we must avoid the pitfalls of single-species studies and undertake community-level experimental research. Otherwise, unanticipated indirect effects can obscure the main effects. Researchers and society must also decide what level of disturbance to a system is acceptable and what we will accept as reasonable evidence.

Finally, the concept of integrated coastal zone management, presented by Thiery Chopin and co-authors, described, for example, the role of seaweeds as biological nutrient removal systems for balancing excess nutrients (nitrogen and phosphorus) from aquaculture and other sources. Boris Worm and Heike Lotze concluded that nutrient pollution threatens rockweed communities and that rockweed and snail harvesting can synergistically enhance pollution effects. Multiple trophic level harvesting, as it occurs now, can cause complex, potentially dangerous changes in rockweed communities. These changes in rockweed community configuration have been shown to alter ecosystem functions and services such as nutrient cycling and habitat structure. They urged that we need to act now to avoid catastrophic ecosystem changes similar to what occured in the Baltic Sea.

Recommendations

- Government agencies responsible for the marine waters in the Gulf of Maine should develop a generic policy for managing low trophic level species. Harvesting these species may present a disproportionately higher risk to ecosystem health.

- Current management of the pilot rockweed harvest in New Brunswick could serve as a model for other regions. While a number of important questions remain unanswered, there are positive attributes that should be adopted; for example, use of a cutting rake for harvesting, resource and by-catch monitoring and participation of industry, other stakeholders and two levels of government in the assessment process. In all regions there is a critical need to address research questions and closely monitor harvesting practices and population responses.

- Properly designed impact assessments and rigorous monitoring should be implemented and integrated into management plans. Public reporting of impact studies, monitoring, harvest and bycatch statistics should be required.

- Marine Protected Areas (MPAs) should be established as they can provide, "impact insurance", consistent with the precautionary approach, but a number of important questions first need to be resolved.

- A recruitment and recolonization model for rockweed in each area should be developed.

Four general areas of research that require immediate attention are:

1. **Nutrient cycling and nutrient budget**. What are the relative contributions of rockweed and other sources to nutrient cycling? A monitoring program capable of detecting excessive eutrophication is required.

2. **Invertebrate community**. A clearer understanding of how structural changes to rockweed beds impact the invertebrate community is needed. An initial focus should be on the littorinids, gammarids, harpacticoid copepods, blue mussel and shore crab.

3. **Pollock habitat use**. Pollock is one commercially important species that occupies rockweed beds in high densities yet it is not known if growth and survival of juveniles are affected by rockweed harvesting or if there are impacts to the pollock fishery.

4. **Eider habitat use**. Eider duckling survival is low due to predation, additional impacts are unacceptable. A clearer understanding of how harvesting affects their foraging behaviour in rockweed beds and the location and timing of eider use of intertidal zone habitats is required. Effects and timing of disturbance to ducklings during vulnerable stages.

APPENDIX ONE

A summary of rockweed harvesting conservation issues

Robert Rangeley, 1998

An overview of the seaweed industry

Over 3.5 million tonnes of raw macroalgae is harvested annually in diverse, global seaweed industries worth 3.5 billion US$ year^{-1} (Jenson 1993). Commercial uses of seaweed range from direct exploitation as a source of food, nutrients and fertilizer (Blunden 1991, Indergaard & Minsaas 1991) to providing important chemicals or properties for biomedical and biotechnological applications and products such as processed foods, cosmetics, and pharmaceuticals (Renn 1990, De Roeck-Holtzhauer 1991, Indergaard & Ostgaard 1991, Jensen 1993, Radmer 1996). The raw biomass of seaweed used for industrial consumption is close (43% of the total) to that used directly for food (primarily Nori, Wakame and Kombu) but the monetary value is only about 15% of the total generated from seaweeds (Jensen 1993). However, the source of seaweed differs between industrial and food uses. The supply for all the major food seaweeds and many of the industrial uses depend on commercial culturing. In contrast, exploitation of wild populations is the only source of those species that dominate the industrial products: the large brown seaweeds (Phaeophyta) which grow in cold temperate seas. These include the Laminariales or kelps, *Macrocystis* sp. and *Laminaria* sp., and the Fucales or rockweeds, *Ascophyllum nodosum* and *Fucus* sp. (Guiry & Garbary 1991, Jensen 1993).

The demand for existing and new applications of seaweed products has been expanding for decades and has led to large-scale exploitation of brown seaweeds (Briand 1991, Jensen 1993, Radmer 1996). Since the raw material comes from wild populations exploited on a repeated or rotational basis, a considerable amount of research has been devoted to minimizing harvest impacts to the plant populations through modifications to management strategies and harvest techniques (see any of the 15 seaweed symposia in Hydrobiologia e.g. 1996, vol. 326/327. Lindstrom & Chapman, eds.). Unfortunately, the impact of harvesting seaweed on associated biota and ecosystems has been greatly neglected.

The kelps and rockweeds dominate temperate zone rocky coasts in extensive forest-like growth and, like coral reefs, mangroves, seagrasses and salt marshes, these macroalgae form one of the major marine ecosystems. The kelps dominate the subtidal and the rockweeds the intertidal zones (Mann 1982, Carter 1988, Odum 1993). Most macroalgae are attached to rocks and provide physical shelter, substrate and a foraging habitat for numerous organisms. Shallow coastal habitats are also important sources of nutrients, detritus and organisms to offshore, pelagic and deep sea systems.

Rockweed harvesting

A. nodosum, is a common seaweed of North Atlantic intertidal zones. It is usually referred to as rockweed although this term is also used to describe fucoids generally. Rockweed can dominate 80% of the shore, average 5-6 kg m^{-2} dry biomass and have fronds ranging over a metre in length (Sze 1986, Keser et al. 1981, Vadas et al. 1990). With increasing shelter from wave exposure, frond lengths and plant biomass increase and the distribution of the biomass is concentrated at greater heights above the substrate (Cousens 1986).

Commercial cutting of rockweed is done with knives and sickles at low tide, when the algae is exposed, or by rakes and mechanical suction harvesters when the algae is submerged (Ang et al. 1996). These methods can remove 40-80% of the rockweed biomass in a harvest area (Sharp & Pringle 1990, Briand 1991). Maximum exploitation rates of 50% of a harvest area using cutting rakes have been recommended in Atlantic Canada (Anon. 1992) although levels as low as 17% may eventually be adopted. Other recommendations include a minimum cutting height of 15 cm above the substrate and that the incidental loss of algal holdfasts be minimized. Holdfast loss using cutting rakes has been estimated at about 15% of harvested plants (Sharp 1981). The amount of holdfast loss and the cutting height are critical variables in determining the harvesting recovery for rockweed populations. This is because rockweed recruitment success is low and regeneration of fronds from holdfasts is extremely slow (Keser et al. 1981, Lazo & Chapman 1996). Recovery of rockweed populations from denuded or heavily harvested areas can take 8 to 15 years (Keser et al. 1981). The seaweed industry is responsible for preventing these serious consequences of poor harvest practices through largely self-regulated enforcement and monitoring. Determination of a 3-year harvesting rotation depends on reliable daily harvest logs supplied by the harvesters. Harvesting decisions are potentially biased towards immediate benefits to harvesters rather than towards the long-term health of the rockweed population (Ang et al. 1996, Lazo & Chapman 1996).

Removing plant biomass and changing plant habitat structure have ecosystem-level implications. Harvesting will directly reduce the amount of breakage of long algal fronds (Lazo & Chapman 1996). These frond fragments decompose along the high tide strand line and are an important source of food and nutrients (Griffiths & Stenton-Dozey 1981, Koop et al. 1982, Vadas & Elner 1992). Liberated algal fronds also form large, offshore rafts which support a community of organisms while alive and then are a source of exported detritus. The reduction of algal biomass may result in a reduction of numerous organisms associated with the surface of the algal fronds (Hayward 1980, Johnson & Scheibling 1984) and attached epiphytes (Jarvis & Seed 1996) which provide the foraging base of many intertidal fishes and birds (Minot 1980, Wheeler 1980, Vadas & Elner 1992, Rangeley 1994 a,b, Rangeley & Kramer 1995 a,b). These organisms will not only lose habitat but they will also lose the dense cover of algae piled on the rocks at low tide that provides insulation from extremes in temperature, desiccation and ultraviolet radiation.

Structural changes to the habitat will result from a reduction of plant height which will also reduce plant width because most of the biomass is in the upper canopy (Cousens 1986). The combined effect will be a decrease in horizontal and vertical cover available to fishes. Recovery of most of the biomass will occur between harvest rotations although the time it takes a rockweed stand to attain its preharvest level of structural complexity is unknown. Structural changes will also include larger scale effects resulting from changes in the spatial arrangement and fragmentation of algal habitats in harvest areas (see Meffe & Carroll 1994 for general causes and implications). This type of landscape ecology perspective in marine systems has been virtually unexplored.

The biggest problem facing conservation efforts is detection of potential impacts. For example, because of very high annual variability, most methods of sampling have a low probability of detecting a significant change in the abundance of fish populations (Peterman 1990). Further, the problem of impact assessment for many fishes, particularly the commercially important ones, is additionally complicated when the juvenile stages are affected[2]. Many of these species do not recruit to the fishery for 3-5 years and, because of high recruitment variability, an impact could go undetected for considerably longer. Lester et al. (1996) estimated that study lengths in the order of 10-15 years would be required to detect large changes in the abundance of fishes in nearshore lake populations.

At present, very limited knowledge exists with which we can assess the impacts of harvesting macroalgae. Clearly, this will be a difficult problem to solve. Long-term studies, while desirable, are not always feasible nor do they provide often needed short-term answers. While coastal habitats constitute only a small area of the marine environment they are disproportionately important in oceanic production and as sources of food for humans. These areas require intensive conservation effort because of their high value and extreme vulnerability to sources of environmental impacts.

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APPENDIX TWO

Gulf Of Maine Rockweed
Management in the face of scientific uncertainty

WORKSHOP PROGRAM

Sunday, December 5, 1999

1800-1900 REGISTRATION: Conference Centre, Fisheries & Oceans Biological Station

SESSION ONE: Conference Centre
Chair: Robert Rangeley, Fisheries & Oceans

Opening comments
Tom Sephton, Director of the Fisheries & Oceans Biological Station

Welcome & Introduction to the workshop
Linda Mercer, Maine Department of Marine Resources
Jessie Davies, University of New Brunswick
David Coon, Conservation Council of New Brunswick
Robert Rangeley, Fisheries & Oceans

Keynote address: "The challenge: Why should we care about rockweed?"
Mick Burt, Huntsman Marine Science Centre

POSTER SESSION & MIXER (cash bar)
Anderson House, HMSC upper campus

Monday, December 6, 1999

0700-0800 Breakfast at Anderson House

SESSION TWO: ROCKWEED AS HABITAT: STATE OF KNOWLEDGE
Conference Centre
Chair: *Gerhard Pohle, Huntsman Marine Science Centre*

0830-0900 Impacts of Grazers on Rockweeds and Macroalgae
Robert Vadas, University of Maine

0900-0930 Rockweed structure and its role as a habitat for invertebrates
Glyn Sharp, Fisheries & Oceans

0930-1000 Aquatic macrophytes as foraging and refuging habitats for fishes
Robert Rangeley, Fisheries & Oceans

1000-1030 Community-level interactions between birds and aquatic macrophytes: lessons for a rockweed harvest?
Diana Hamilton, University of New Brunswick

1030-1040 Discussion

1040-1100: BREAK

SESSION THREE: *What are the critical gaps in our knowledge of rockweed as a habitat?*

1100-1230 Working groups in assigned rooms.

Facilitator for Group A: Mick Burt, Huntsmand Marine Science Centre
Facilitator for Group B: Maria Buzeta, Fisheries & Oceans
Facilitator for Group C: Linda Mercer, Maine Department of Marine Resources

1230-1345: Lunch at Anderson House

1345-1415 Working Group reports at Conference Centre

SESSION FOUR: ROCKWEED AND THE COASTAL ECOSYSTEM
Conference Centre
Chair: *Jill Fegley, University of Maine*

1415-1445 Harvest of macroalgae: A global and regional perspective
Raul Ugarte, Acadia Seaplants

1445-1515 Seaweeds, nutrients, and aquaculture in coastal waters... let's put things in perspective
Thierry Chopin, Darrell Welles & Ellen Belyea, University of New Brunswick in Saint John

1515- 1545 Nutrient availability, low-trophic level harvesting and cumulative human impacts on coastal ecosystems
Boris Worm and Heike Lotze, Dalhousie University

1545-1555 Discussion

1555-1615 BREAK

SESSION FIVE: MANAGEMENT UNDER UNCERTAINTY
Conference Centre
Chair: *Carol Ann Rose, Fisheries & Oceans*

1615-1645 Synopsis of ecosystem approaches to management
Mike Sinclair & John Neilson, Fisheries & Oceans

1645-1715 How do we know what is the right thing to do?
Jim Wilson, University of Maine

1715-1745 The Difference Between Uncertainty and Ignorance: A Case Study in Initiating Management Under Conditions of Ignorance
Chris Finlayson, Maine Department of Marine Resources

1745-1755 Discussion

1755-1800 Directions to working groups

1830-1930 POSTER SESSION & MIXER (cash bar)
Anderson House, HMSC upper campus

BUFFET DINNER at Anderson House

MIXER at Anderson House

Tuesday, December 7, 1999

0700-0800 Breakfast at Anderson House

SESSION SIX: *Recommendations for managing rockweed in the face of scientific uncertainty*
0830-1000 Working groups in assigned rooms.

Facilitator for Group A: Mick Burt, Huntsmand Marine Science Centre
Facilitator for Group B: Maria Buzeta, Fisheries & Oceans
Facilitator for Group C: Linda Mercer, Maine Department of Marine Resources

1000-1020 Break
Working Group reports at Conference Centre

1200-1315 Lunch at Anderson House

1315-1515 SESSION SEVEN: Wrap-up and final recommendations.
Conference Centre
Chair: Jessie Davies, University of New Brunswick

APPENDIX THREE

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