CHARACTERISTICS AND CONSERVATION OF FISH HABITAT

Proceedings of the

Fish Habitat Awareness Seminar

Acadia University
22-24 June 1988

Organized by

Canada — Minister of Fisheries and Oceans

NOVA SCOTIA — Minister of Fisheries

Financed by the Economic Regional Development Agreement.

ISBN 0-662-17176-4

Catalogue No. FS23-148/1588E

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Editor's Preface

The preservation of fish habitat is a major challenge facing government and industry in Canada as a result of decades of abuse and mismanagement. Success in the future depends upon development of the political will to do so- -something which, as Jim Gourlay stated during the Forum, requires an aware and committed public. It is my strong impression that this Seminar on Fish Habitat Awareness was a singularly important step in promoting that awareness. Although not all invited guests chose to attend, particularly some from important industries, those that did enjoyed an open and stimulating exchange of facts, ideas and opinions. It is our hope that this volume will extend the benefits of the Seminar to many others.

These Proceedings were prepared partly from manuscripts provided by contributors, and partly from the video and audio records of the seminar. I have assumed some editorial license in order to reduce duplication of material in the prepared texts, and to render the free-flowing discussions more readable. I am indebted to a number of people for their assistance in the running of the Seminar and preparation of these Proceedings: Dr. Mike Brylinsky and Dr. Sherman Boates kindly chaired sessions; Ivi, Keir and Lia Daborn, Mike Shaffelburg, Jeff Monchamp, Debbie Clarke, Diane Amirault and Peter Comeau assisted with organisation and registration; Natalie Basaraba prepared a photographic record. The video and audio tape records were prepared by Annapolis Studio Associates Inc.

I very much appreciate Dr. Alex Colville's willingness to participate in the Seminar at the Banquet. Last, but certainly not least, Darlene Feener of the Estuarine Centre was indispensible: she completely retyped the Proceedings and prepared them for publication in their present form, and overcame many obstacles with her customary efficiency and tact.

To all these people I am most grateful.

Graham R. Daborn
Acadia Centre for Estuarine Research

December 18, 1988

ORGANISING COMMITTEE:

Frank King (DFO) Graham Daborn (ACER) André Ducharme (DFO)

Chairman's Introductory Remarks

André Ducharme

This seminar on Fish Habitat Awareness is dedicated to a broad spectrum of industries in Nova Scotia. I am happy on behalf of the Department of Fisheries and Oceans to host this event in conjunction with Acadia University. The seminar is funded by the Economic Regional Development Agency (ERDA). During the next two days, you will hear a wide variety of presentations concerning fish habitats in both freshwater and marine environments. These range from Mr. W. Rowat, Assistant Deputy Minister, with a theme presentation outlining government policy and its historical background, to Dr. Alex Colville, world renowned artist, Chancellor of Acadia University and member of the Order of Canada, in an address in which he recommends all participants to continue in their efforts to conserve "the Habitat Legacy for future generations."

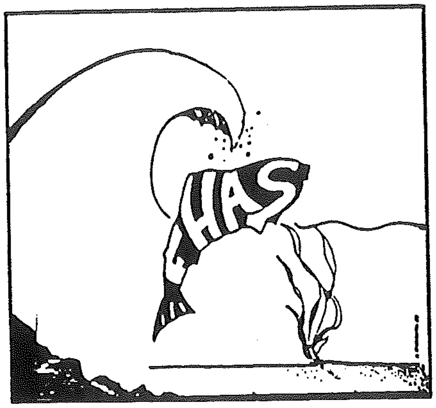
The Federal Department of Fisheries and Oceans is responsible for the management of the commercial and recreational fisheries of Canada which represents a multi-billion dollar industry and an important traditional occupation for thousands of Canadians. This renewable fish resource depends on a finite, albeit vast, realm of aquatic and marine habitats which must also be managed. Recent concern for the gradual erosion of the habitat resource of Eastern Canada, in spite of our conservation efforts, led DFO to review its traditional habitat protection and conservation methods. This resulted in the Honourable Tom Siddon, Minister of Fisheries, endorsing and formally releasing DFO's Fish Habitat Management Policy. Concurrently, a new National Habitat program was elaborated to implement all aspects and prescriptions of this policy.

The policy identifies and delineates the tasks to be performed in order not only to stem the erosion process but to regain lost ground through restoration of damaged habitats and development opportunities. It prescribes that DFO habitat managers actively seek and rely on support from the Canadian industry and indeed the public to accomplish the desired objectives. But in order to enlist your support we felt that first it was incumbent upon us to review with you and for you, the ideological, technical, ecological and legal aspects of freshwater and saltwater fish habitat management. We also wish to outline and discuss with you the issues related to the unavoidable conflict between development imperatives and preservation of fish habitat.

Much thought was given to the planning of this seminar by the organization team composed of Acadia University and DFO staff. We are proud to have achieved a fair balance of technical presentations by university, private sector and government scientists who have strived to outline for you the present knowledge of what constitutes fish habitat and how it is vulnerable to human activities of all types. Whatever the program may have omitted we hope will be compensated by the open discussion planned for the last session of the seminar relating to the responsibilities of government and industry.

I do wish to express our appreciation on behalf of the Department of Fisheries and Oceans to Acadia University for their tremendous cooperation. I especially wish to thank Dr. Graham Daborn who has done a terrific amount of work and without whose experience it would have been difficult to plan, organize and deliver this seminar.

May I remind you that this seminar is but the first of a series and that we have learned a lot by it just as we hope you will. We propose to expand this activity to the province of New Brunswick and to other sectors in a near future.



Introduction to Fish Habitat Management

William A. Rowat

ABSTRACT

The commercial and recreational fisheries of Eastern Canada contribute several billion dollars annually to the Canadian economy. The valuable stocks of fish depend for their existence on an extensive and varied habitat base contained in our lakes, streams, rivers, estuaries, coastal zones, and the high seas with their rich fishing banks (Grand Banks, Georges Bank, etc.). During the last decade officials of the Department of Fisheries realized that traditional habitat protection measures were proving insufficient to protect adequately the habitat resource of Eastern Canada. This prompted a review of habitat management systems which resulted in a systematic, somewhat radical reorganization of the department's policies and practices in ensuring the protection and conservation of the habitat resource. A new policy has been formulated, with the overall objective of a "Net gain of productive habitat." The policy features new strategies to curb the erosion of habitats and eventually realize a net gain, either through the restoration of damaged areas, the enhancement of existing areas or even the creation of new habitat. In addition, new emphasis was placed on the old traditional way of protection and conservation. A complete, comprehensive program focused on the implementation of the New Policy for Habitat Management was elaborated. The habitat management infrastructure in the many regions of Fisheries and Oceans and central Ottawa administration was reorganized to facilitate the delivery of the new habitat program. The major components of this infrastructure are; a formally constituted hierarchy of committees to keep the habitat program on track and to guide departmental officials responsible for its delivery; a new internal organization that ensures authoritative review and control of all aspects of the habitat program delivery, including particularly the continuation of habitat research and the provision of expert scientific advice; and finally the attribution of specific habitat management roles and responsibilities to the operation and science sectors of Fisheries and Oceans. The current habitat program is based on the use of old management tools like Protection and Compliance, research, and new management strategies such as Integrated Resource Planning, Education and Public Information, Cooperative Action and Consultation. The Fisheries and Oceans Habitat Management Program has built-in flexibility. It can be positioned to take advantage of opportunities for habitat restoration and enhancement, or to cope with new perils for our habitat resource.

INTRODUCTION

I am pleased to welcome you to this first major seminar introducing the subject of fish habitat and the federal program to manage this valuable Canadian resource. I wish to begin with a simple statement on why the Department of Fisheries and Oceans (DFO) thinks it is vital to make serious efforts to manage our fish habitat. I will follow with a brief history of our concerns for being able to deal with habitat problems in the federal regions across the land. I will next describe the current initiatives of our program and how we hope to achieve our objectives.

The commercial and recreational fisheries of Canada contribute several billion dollars annually to the national economy. Fish and the habitats they depend on are also a valuable tourist attraction generating local income quite apart from fishing activities. Furthermore there are social benefits that flow from the fishery resource such as support for traditional lifestyles in coastal, and remote and native communities (salmon fishing, lobstering). Finally, the simple presence of fish is a strong indictor of a healthy environment.

HISTORY OF DFO's CONCERNS

The government of Canada has experienced a growing concern in this latter half of the century with the quality of the environment and has noted the growing awareness of citizens, both in Canada and globally, about environmental issues. In Canada, this heightened awareness has been and is being reflected in an increase in both the level of resources and the accountability for "managing" the Canadian environment, including fish habitat. This is being accomplished through existing law, (such as the Fisheries Act which dates back in one form or another to the British North American Act of the last century), and through the creation of new laws (such as the Environmental Protection Act being sponsored by the Minister of Environment), as well as through a growing number of "Accords" or agreements between the federal government and the provinces. Presently, the bulk of federal environmental protection law and responsibility rests with two Departments: Fisheries and Oceans, and Environment Canada. However, while the Minister of Fisheries and Oceans remains responsible to Parliament for both the physical habitat and chemical pollution provisions of the Fisheries Act, by agreement with Environment Canada, that Department administers, on a day-to-day basis, the "deleterious substances" provision of Section 33 of the Fisheries Act and so the responsibility is shared to that extent.

At DFO the 1980's are characterized by a bursting awareness of the need to provide better management of our marine and freshwater fish habitats. Recent controversies over Georges Bank, the fixed link to PEI, and the Rio Algom tin mine, are examples of this awareness. The Pearse commission report on Pacific Fisheries published in 1981 pointed out DFO's traditional role in Habitat Protection: "The stance taken by the department with respect to its responsibilities for fish habitat has been mainly defensive." The same report suggested the adoption by DFO of a more positive, aggressive and flexible approach to habitat management. The state of affairs in the Pacific fishery as described in the Pearse report holds true for the Atlantic coast. In spite of our efforts to react to proposals through complex referral systems, to minimize habitat damage through constraints and modifications of projects and our continuous enforcement of habitat laws, we face mounting evidence that these necessary activities have been insufficient to curb the gradual erosion of fish habitat and the resulting losses of income and recreational opportunities. The case of acid rain in Nova Scotia may help to illustrate this point: Thirteen formerly productive Atlantic salmon rivers are now considered dead (devoid of salmon) because of critically high acidity levels (Figure 1). Domestic pollution (sewage) is another form of habitat degradation which has eluded the control measures hitherto employed by DFO. A look at a map of the soft shell clam closure areas for Nova Scotia and the Bay of Fundy (Figure 2) gives insight as to how much income may be lost to Nova Scotians every year. The true value of this lost clam harvest may never be known.

Indeed, the damage caused so far is severe. **But it is not necessarily irreversible.** In the Atlantic regions habitat degradation has affected primarily the rivers and streams, estuaries and coastal areas. While offshore habitats are threatened by long range transport of chemicals, organochlorines and minerals, and the many hazards related to oil and gas development and transport (should it occur), they are as yet intact.

Thus the outcome of the introspective 80's was DFO's realization that strong leadership is required to curb the flood of habitat erosion. As well, we realized that continued enforcement of habitat laws is not of itself sufficient to bring an end to habitat erosion. Many of the recommendations contained in the Pearse report would also have to be seriously considered. After much deliberation, DFO determined to:

(1) place new emphasis on education, consultation, cooperation and integrated resource planning;
(2) establish habitat data banks and research opportunities for habitat rehabilitation and enhancement;
(3) seek appropriate compensation from those who cause habitat damage; and of course,
(4) continue to limit habitat damage at project sites and enforce habitat laws.

FORMULATION OF A POLICY

Work on a new management approach began at the national headquarters in 1981 on the production of a draft document entitled: "Toward a Fish Habitat Management Policy for the Department of Fisheries and Oceans." In September 1982 the Atlantic Fish Habitat Task Group was established to review current habitat management programs in the Gulf, Newfoundland and Scotia-Fundy Regions. Areas of enforce-

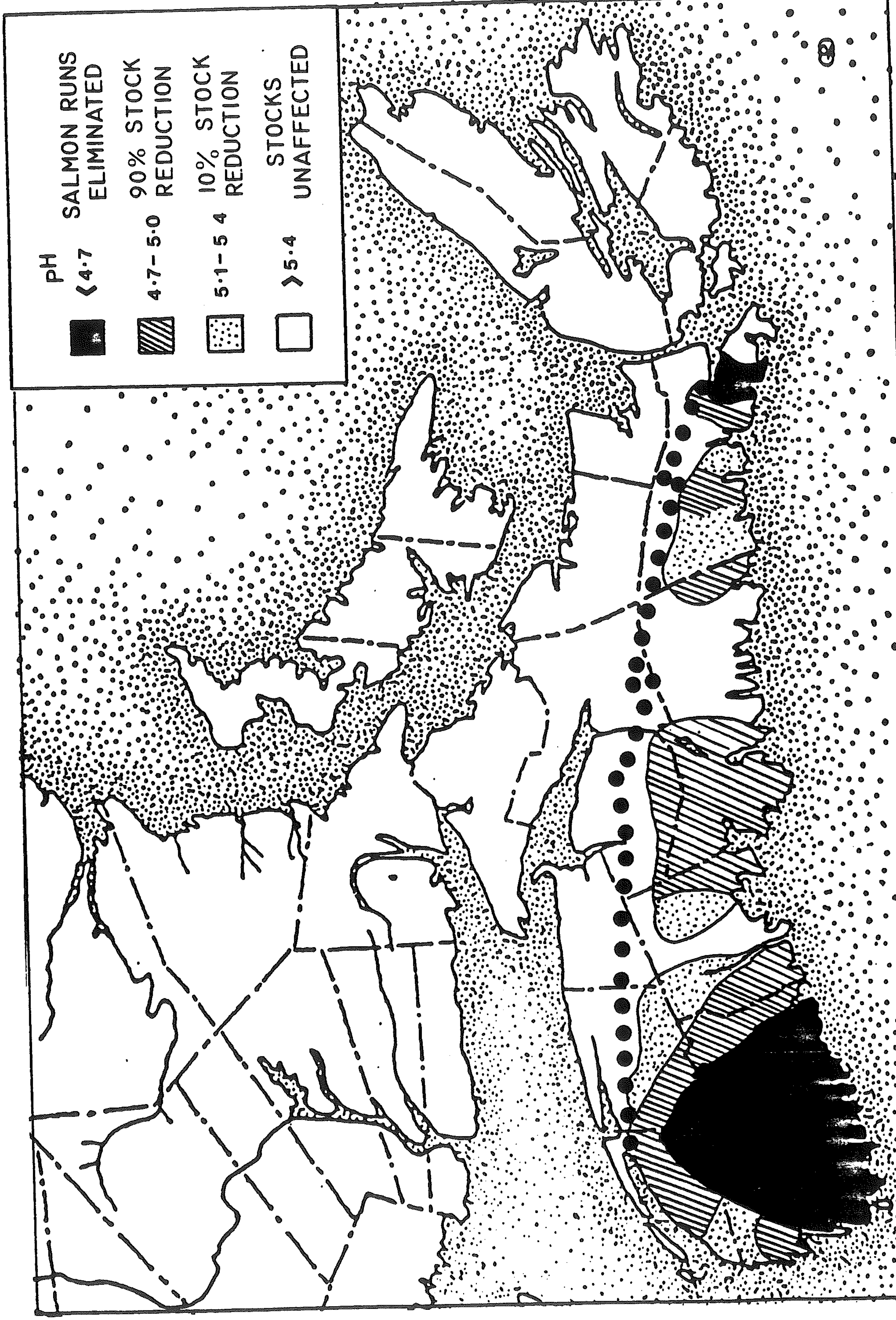


Figure 1. Mean annual pH values of Atlantic salmon rivers of Nova Scotia. (Based on 1979-1985 data)

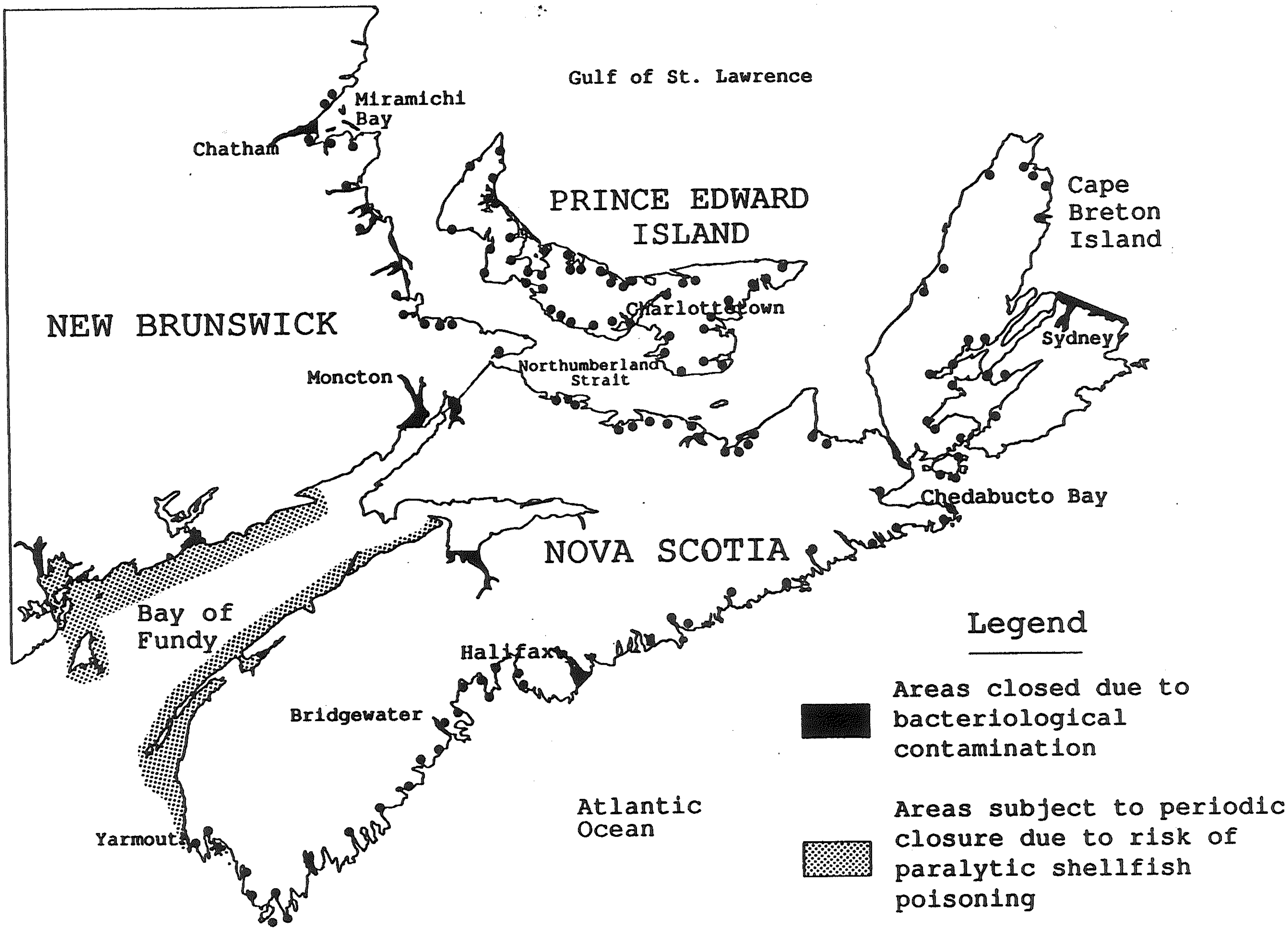


Figure 2. Closures of clam growing areas in the Maritime Provinces caused by bacterial contamination or Paralytic Shellfish Poisoning.

ment, research, improvement, communications, and external consultations were being considered. Initially DFO planners were assailed by difficult questions. What should the overall objective be? How best can we achieve this objective? Where should we start? All together we worked at elaborating a master plan or road map that would be the guide for all present and future DFO habitat managers as well as convey a clear message to the private sector regarding DFO's intention to work cooperatively to resolve problems, and conciliate conflicting interests, while increasing the habitat base of our fishery resource.

In October of 1986 the Minister of Fisheries endorsed and formally released DFO's Fish Habitat Management Policy.

The first step toward improved habitat management (I am tempted to say revolutionized Habitat Management!) had been taken. This policy, four years in the making, has for its ultimate objective a "Net Gain of Productive Fish Habitat." It promotes the use of Management tools, old and new, to assist habitat managers in their program planning and day to day operations. For example, habitat laws will continue to be enforced, but a strong new emphasis will be placed on public information, education, consultation and cooperative action.

I need say no more about the details of this policy which is discussed below, but the fact that DFO has a habitat management policy, and knows where it wants to go with its habitat program, should be viewed by the industry sector of this province as a good omen. This is because industry will now be dealing with an organization with alternatives to law enforcement, an organization intent on cooperation and consultation, an organization less likely to be inconsistent because of the definitive nature of its program.

POLICY IMPLEMENTATION FRAMEWORK

With a policy in place, the next important step for DFO was to lead quickly to the implementation of the many strategies of that policy and to organize a framework for the step by step planning, execution and evaluation of a habitat program capable of delivering all that the policy promised DFO would do to provide better habitat management. This was accomplished through the following actions.

(a) Formally constituted mechanisms. From within the department a framework of interrelated national and regional committees was established to overview the planning of policy implementation, evaluate implementation projects and activities, and provide a forum for problem resolution within the overall habitat program. Figure 3 gives an outline of this committee structure.

(1) The Atlantic Director General's committee pre-dates the Habitat Policy. It is chaired by the Assistant Deputy Minister Atlantic and is a forum for the full gamut of Fisheries and Oceans activities in the Atlantic zone. The CCAHM and CCHP committees were made accountable to this more senior committee.

(2) Coordinating Committee on Habitat Policy (CCHP), an Ottawa-based Committee chaired by Mr. David Tobin, Director-General Atlantic Fisheries. It brings together all sectors of DFO at a very senior level to coordinate departmental activities related to the implementation of the new habitat policy. A main function of this committee is to review and advise on DFO Science and Management sectoral implementation plans.

(3) The Coordinating Committee on Atlantic Habitat Management (CCAHM), is chaired in rotation by the Regional directors of the Fisheries and Habitat Management Sectors of the four Atlantic Regions. This is the true forum for habitat related business or problems common to two or more of the four Atlantic Regions.

This framework of committees ensures continuity between national and regional aspects of the program. They guide the many people who work at implementing the policy and keep higher management informed of program progress and/or diffi-

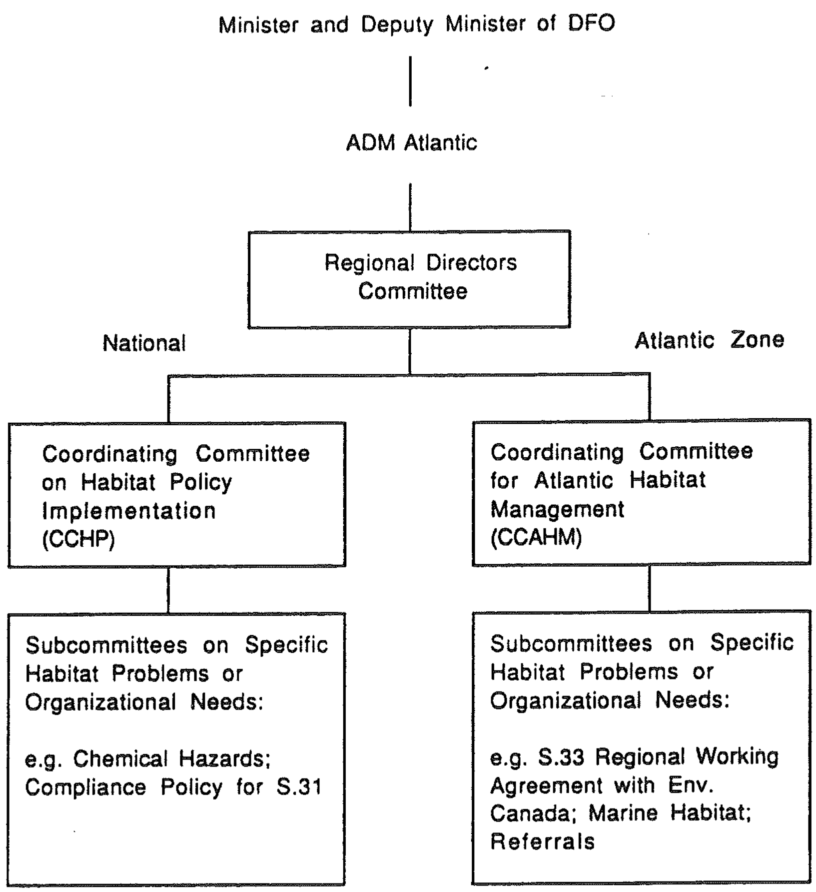


Figure 3. DFO Infrastructure for the Implementation of the Habitat Management Policy.

culties. They also ensure consistency of purpose across DFO regions and help maintain the momentum of the federal habitat program. They also, believe it or not, get things done, by imposing deadlines on implementation projects, deciding how the policy is to be used in day-to-day operations, focusing the efforts of the participants to the habitat program and through a tracking system for a multitude of activities.

(b) Internal Reorganization. Prior to October 1986 all habitat management matters other than law enforcement were housed in units of the Science Sector of DFO. Effective October 1986, ten permanent staff members were transferred from the Science Sector in Scotia-Fundy to Fisheries and Habitat Management (Operations) and the new Fish Habitat Management Branch was established. Similar transfers or allocations of new staff were carried out in the other three Atlantic regions. This new Operations unit is the focus for all habitat related matters in the region and the delivery of the regional program.

The Science Sector itself underwent a reorganization process that resulted in the creation of a habitat ecology research division and habitat freshwater research section. The organization chart (Figure 4) shows how the Habitat Management group is constituted and supported through linkages within the Fisheries and Habitat Management sector and with the Science Sector.

(c) Roles and Responsibilities Allocation. Although the focus for all Habitat Management matters was placed firmly in the fishery management sector, the Habitat Management program delivery relies on a two component approach with Science playing a leading role in the field of research and with the provision of expert advice required by managers to formulate DFO positions on important and complex issues. This division of responsibilities is outlined in Table 1.

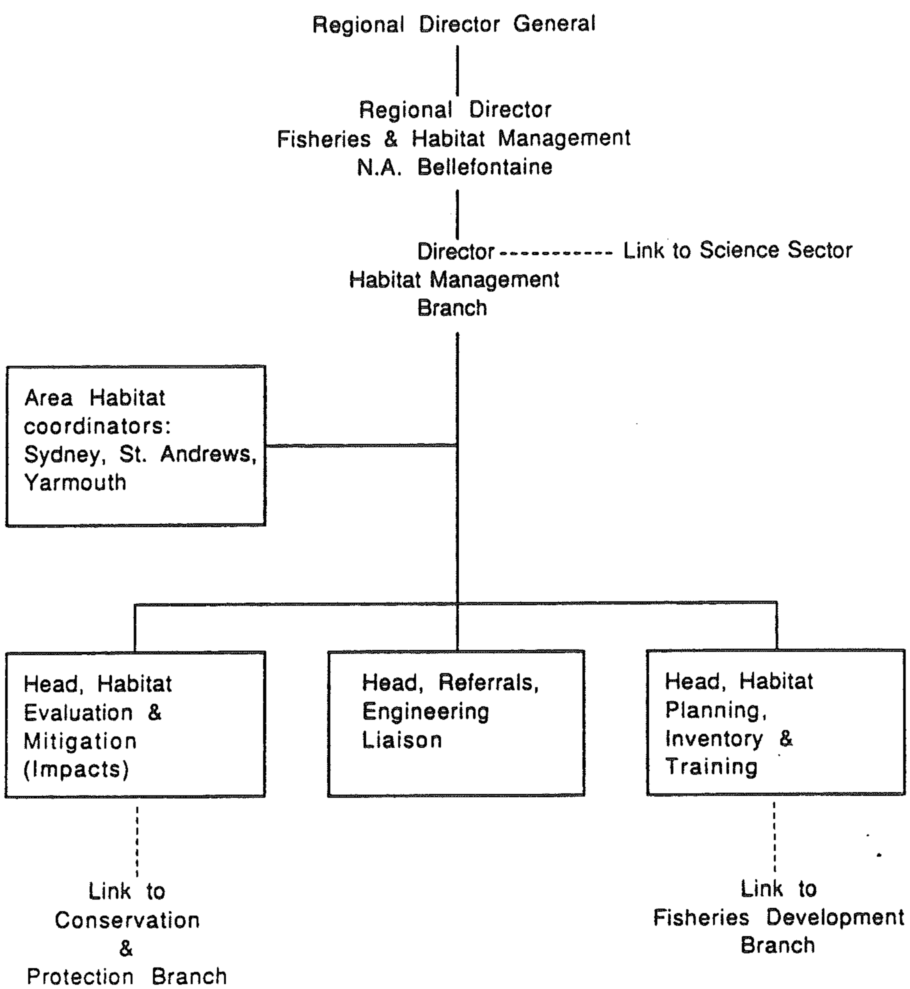


Figure 4. Organization chart of the Habitat Management Branch, DFO-Fundy region.

CURRENT HABITAT MANAGEMENT PROGRAM

The DFO habitat program is essentially a blend of habitat management techniquesold and new, with renewed emphasis. The program is closely related to the habitat policy, its components being the activities associated with the seven policy implementation strategies. The formally constituted mechanisms discussed in the previous chapter, the newly established Habitat units in the regional Management and Science Sectors, and the roles judiciously allocated between sectors, are all meant to play a role in the planning, execution, review and monitoring of this habitat program. The activities that characterize the habitat program are listed in Table 2. In addition, working agreements and compliance policies are being formulated to guide DFO officials who administer the habitat provisions of the Fisheries Act. The most important are:

(a) Section 33 Working Agreement between Environment Canada and Fisheries and Oceans;

(b) Section 33 Compliance Policy (internal document for DFO and ED officials);

(c) Enforcement and Compliance Policy for the Habitat provisions of the Fisheries Act (internal document for use of DFO officials).

The first step to reaching "Net Gain," the ultimate objective of DFO's habitat policy and program, is the achievement of 'no net loss." A nationwide procedural document for achieving "no net loss of the productive capacity of fish habitat" is in the final stages of completion. These are all signs of the nationwide commitment to the Policy, the Habitat program and the ultimate objective: a "Net Gain" of Habitat.

Table 1. Roles and responsibilities of Fisheries Management and Science Sectors for delivery of the Regional Fish Habitat Management Program

FISHERY MANAGEMENT	SCIENCE
1. Focus for regional program.	1. Plan and conduct research.
2. Implement policies, guidelines, protective measures and procedures.	2. Develop policies, guidelines, procedures and protective measures.
3. Implement technical and scientific advice.	3. Provide authoritative scientific and technical advice for habitat-impacting activities and proposed habitat improvement projects.
4. Conduct surveillance to identify dangers and prevent damage to habitat.	4. Undertake scientific/technical activities needed to provide information, evidence and advice for habitat conservation and improvement.
5. Enforce laws, regulations and guidelines.	5. Provide analytical laboratory services.
6. Assist Science in the collection of baseline information required for evaluations, research studies, or to prosecute violations of the habitat provisions of the act.	6. Develop and maintain integrated fisheries information systems on habitat.
7. Coordinate negotiations for habitat protection.	7. Plan and conduct applied research studies.
8. Be responsible for public educational activities and the coordination of internal habitat training.	8. Plan and coordinate scientific/ technical field studies.
9. Promote and coordinate community involvement in habitat protection and restoration.	
10. Be responsible for planning and liaison activities.	

INTERNATIONAL CONSIDERATIONS

The Habitat Management program of Fisheries and Oceans helps fulfill Canada's commitment to the United Nation's World Conservation Strategy, which calls for: "The maintenance of the Support Systems for Fisheries and for the control of pollution." Please remember that **habitat is the life support system for our fisheries.** Canada also addresses international concerns for fish habitat management by providing expert advice to international committees or organizations such as the International Maritime Organization (IMO), the London Ocean Dumping convention, the International Council for the Exploration of the Sea (ICES), and the Long Range Transport of Acid Precipitation (LRTAP) Committee responsible for coordinating studies and advising on the negotiation process on transfer by air pollution (acid rain).

Table 2. List of Activities of Fisheries and Oceans Habitat Management Program.

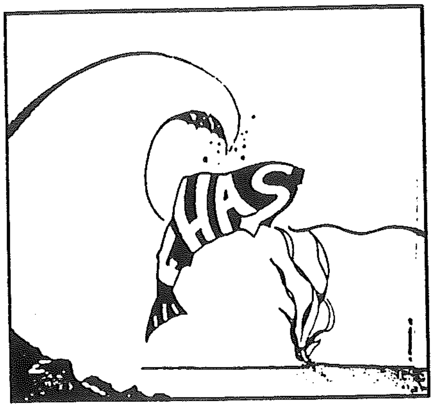
Implementation Strategies	Activities	Ongoing/New
1. Protection & Compliance	- Review, investigation and assessment of referrals	ongoing
	- Compliance monitoring	ongoing
	- Surveillance	ongoing
	- Guidelines development	ongoing
	- No Net Loss Guide	new
	- Compliance policies	new
	- Planning for international aspect of habitat program	new
2. Integrated Resource Planning	- Plan for integration of habitat objectives into fisheries management plan	new
	- Develop data base inventory	new
	- Develop national guidelines for integrated resource planning	[Science]
	- Develop a habitat information system	new
3. Research (Science)	- All aspects of habitat spectrum including expert advice	ongoing
4. Education and Public Information	- Public Information Bulletins	new
	- Provide information to public and interested groups	new
	- Promote Habitat Awareness	new
5. Cooperative Action	- Federal/Provincial agreements and MOU's* on aspects of fish habitat program delivery	new
	- Promote community involvement in habitat restoration	new
	- Establish cooperative agreements with other government departments and public sector.	new
6. Habitat Improvement (Science)	- Develop national plan and guidelines for habitat restoration	new
	- Restore and develop habitat with department funds	new
	- Promote use of other sources of funds for habitat restoration	ongoing
	- Provide guidance to others who do habitat restoration	ongong
7. Administration (National)	- Mostly tracking systems at National level	new
	- Establish program to upgrade skills of DFO personnel to deal with habitat issues.	new

*MEMORANDA OF UNDERSTANDING

CONCLUSIONS

Canada has a unique policy for the management of fish habitat. This policy was elaborated in full consultation with other federal and provincial government organizations, and with the industry and private sectors. An implementation strategy has been elaborated drawing on the full depth of expertise contained within the department. A new regional organization is in place for the efficient and effective delivery of the habitat program. Strong laws are available from the Fisheries Act and the provincial acts (Environmental Protection Act, Mineral Resources Act, Forest Improvement Act) to help in regulating environmental matters. Last, but not the least important, DFO has allies in the provincial departments of Environment and Fisheries and the Federal Department of the Environment.

The Habitat program has built-in flexibility. It can be positioned to take advantage of new opportunities and has been structured to cope with new perils threatening our fish habitats.



Policy for the Management of Fish Habitat: The Canadian Experience

Les Dominy

ABSTRACT

The purpose of this paper is to describe Canada's Policy for the Management of Fish Habitat, approved by the Minister of Fisheries and Oceans in October 1986. Implementation of several key strategies commenced in 1987 and will extend over a number of years. Highlights of the implementation approach and accomplishments will also be presented, including: (1) organization and staff capability; (2) applying the "no net loss" working principle; (3) achieving more consistent legal compliance; (4) examples of the policy in action; (5) engaging in integrated resource planning; (6) improving public awareness; and (7) finding money and people to carry out fish habitat conservation and improvement. It is concluded that the implementation of these steps will result in a stronger, more effective national program for the management of fish habitat in Canada, with resulting benefits to the fisheries resources and the people of Canada.

INTRODUCTION

Managing fish habitat is about resolving conflicts. It is the art and science of compromise, working with those whose activities affect fish habitat, to prevent damage to the resource and accommodate competing users.

To accomplish this, fisheries managers must see their own objectives in a larger context. Some of us may feel that what's good for fish is good for everybody. But of course there are many different uses for the waters fish use, and many development projects can benefit society to the detriment of fish. So fisheries agencies face a dilemma. They can on the one hand be very accommodating, accepting without question one development project after another, sitting back to watch habitat disappear. Or they can steadfastly oppose any activity having adverse effects on fish: thus they remain pure in heart, winning a few battles but losing lots more.

The latter approach does not lead to good relations with those industries and agencies which have the greatest impact on habitat. In the long term, the fisheries agency, the habitat and the fish are the losers here. We can't make gains when the odds are against us.

Instead we must set habitat priorities, recognizing that some areas are more important than others. Here is the real challenge: to protect our critical habitats while making gains elsewhere through habitat restoration and development. This means working closely with different sectors of society, by:

- helping developers comply with fisheries legislation without undue hardship;

- cooperating with other fisheries agencies and with environmental agencies to address mutual concerns; and

- providing support for citizens' groups taking on conservation projects.

Canada's Department of Fisheries and Oceans has faced many dilemmas and conflicts over resource use. We have vehemently opposed projects which could damage habitat. In some cases we were successful. In others we weren't. But overall there has been a steady decline in the quantity and quality of fish habitat.

Some of the losses have been alarming. Over the past century we have lost 15 to 20 percent of the Atlantic salmon habitat in Eastern Canada. In the Fraser, one of North America's most important west coast salmon rivers, the decline has been dramatic. Seventy percent of the foreshore habitat in the estuary has been alienated, primarily through dykeing. And there are the widespread and long term problems of acid rain, toxic wastes and damaging agricultural practices.

Clearly we needed a better way to deal with these problems. Our federal Fisheries Act provides the clout to oppose specific projects. But we needed a broader policy framework: a set of strategies and procedures to guide our staff and to influence those whose activities affect habitat.

Our solution was a new comprehensive policy on fish habitat management. The policy provides objective statements against which the department can measure its performance, and it offers a framework for more consistent administration of its habitat management program.

We developed this policy following two years of public consultation. The public's strong response made it apparent that an improved approach was needed to manage fish habitat. Clearly we needed to consider diverse and often conflicting views and concerns.

THROUGH "NO NET LOSS" TO "NET GAIN"

While considering these different views and interests, we have set an ambitious objective. We aim for a NET GAIN of habitat for Canada's fisheries resources. This will be achieved through:

- maintaining the current productive capacity of habitats;

- rehabilitating certain habitats; and

- creating and improving fish habitats in selected areas.

To manage habitat of course, we need to state clearly exactly what we mean by fish habitat. Our definition is quite broad. Under the Fisheries Act, "fish habitats" are defined as those parts of the environment **"on which fish depend, directly or indirectly, in order to carry out their life processes."** "Fish" include all life stages of "fish, shellfish, crustaceans, marine animals and marine plants." Thus the policy can apply to any project, large and small, in or near the water. Any activity which could "alter, disrupt or destroy" fish habitats, by chemical, physical or biological means is of concern.

To maintain productivity of habitats, we will follow a NO NET LOSS principle. The aim is to balance unavoidable habitat losses with habitat replacement on a project-by-project basis. By rehabilitating, improving and creating habitat in selected areas, we seek a NET GAIN of habitat.

We launched our new policy with a five-year plan which sets out seven strategies for action:

(1) Protection and compliance—protecting habitats by administering the Fisheries Act and incorporating protection measures in land and water projects;

(2) Integrated resource planning - encouraging coordinated efforts among government agencies and the private sector;

(3) Research - to provide the knowledge for conservation, restoration and development of fish habitats;

(4) Public information and education - promoting awareness of habitat needs and management options;

(5) Cooperative action - encouraging and supporting public and private efforts to conserve and improve habitat;

(6) Habitat improvement - initiating projects and providing advice in support of the net gain objective; and

(8) Administration - Each DFO region now has a clear focus for fish habitat management activities.

What do we do when a project will affect fish habitat? Our Habitat Policy is a common-sense, cooperative approach linking DFO, other government agencies and the private sector.

The goal of no net loss is kept firmly in mind. Only rarely do we veto projects outright: if it appears that a proposal will damage or destroy fish habitat, proponents are first asked to consider relocating their projects. Sometimes relocation is not possible. Then we consider a variety of mitigation techniques to avoid damage.

Relatively simple techniques include temporary channels to divert streamflow around construction areas and use of fish barriers, fishways or other design measures to minimize the extent of damage. More complex strategies might combine options such as design changes and effluent treatment. The aim in any case is to prevent impacts.

If it proves impossible or impractical to maintain the existing habitat, DFO would consider compensation.

Options for compensation, in order of preference (and increasing risk) are:

(1) Creation of like habitat at or near the development site within the same ecological unit. An example would be the reconfiguration of upland to create an intertidal marsh as compensation for marsh lost to development.

(2) Increase the productive capacity of existing habitat at or near the site within the same ecological unit. This might involve recontouring and planting a mudflat to create marsh or fencing and planting of riparian vegetation along a stream in an agricultural area.

(3) Creation of habitat, or the increase of the productive capacity of existing habitat, in a different ecological unit provided that the same stocks and life cycle stages benefit. We might for example create spawning habitat in one section of a river to compensate for losses in another section.

(4) Artificial habitat creation options require a high degree of continuing maintenance or intervention to be successful. Artificial spawning or rearing channels are examples here.

(5) Fish production from an artificial propogation facility (with the same stocks and preservation of genetic diversity of each impacted stock).

This last option would rarely be considered. There could be a Pandora's box of problems in replacing wild stocks with artificial ones. Loss of genetic diversity, lack of consistent hatchery returns, and high capital and operating costs would all be concerns.

Naturally, the department prefers to prevent damage to natural habitat and avoid losses to the fisheries resource, rather than to take court action against offenders after the fact. However, when voluntary compliance fails to achieve the objective, the Fisheries Act does have teeth. It allows the Crown to restrict or close works or undertakings. In critical situations where an offending party refuses to discontinue damage to habitat, operating equipment may be seized. Private citizens may also initiate prosecutions under the act, and the department may seek restorative measures for those damaged habitats which can be repaired.

How much control do we have? The Fisheries Act empowers us to redress damage to habitat and prevent obstruction of fish passage. We can ensure necessary flows for fish and effective effluent control and screening of water intakes.

We can do this unilaterally, and we are prepared to do so. But we first seek joint solutions with other agencies. However, our jurisdiction is not all inclusive. The Policy for the Management of Fish Habitat applies to those areas of Canada where the federal government has direct management responsibility for the fisheries. This includes the northern territories, the offshore, provincial boundary waters and six of the provinces. Those provinces which manage their own fisheries are encouraged to adopt the policy through federal-provincial agreements and protocols.

The NET GAIN objective is an ambitious one. It is a long term objective which requires long term planning. Again, cooperation is essential.

A net gain in habitat can only be achieved when habitat needs are an integral part of fisheries management. And fisheries cannot be managed in isolation. Our success in meeting fisheries objectives is affected by the plans and activities of a whole range of other resource users. A cooperative, integrated planning process is the key. This is of course easier to talk about than to put into practice.

It will be a long and complex process to achieve integrated resource planning throughout Canada. But we are making headway.

In recent years, our department has been involved in a number of multi-agency, cross-jurisdictional initiatives. These include planning for multiple land and water use in a number of west coast estuaries and preparation for Northern Land Use Planning in the territories.

One of our most exciting new ventures is in British Columbia. Thousands of hectares of forest are logged on the B.C. coast every year, with potential adverse effects on streams supporting millions of salmon. The forest industry and the federal and provincial fisheries management agencies came to recognize the need for a common sense, operational approach to protect fish habitat during coastal forest harvesting. The result was an intensive six-year cooperative program, producing the British Columbia Coastal Fisheries Forestry Guidelines.

The guidelines will enable forest managers and fisheries habitat biologists to concentrate fish habitat protection efforts where they are needed most. Fish habitats are classified for each "reach" or section of a stream according to a simplified procedure that can be used by non-biologists. Protection specifications and objectives are established for each of four classes of fish habitat. This classification system identifies a range of fisheries habitat values and is used to select forest cutting practices.

The guidelines provide the greatest protection to the most valuable fisheries streams. Forest harvesting prescriptions depend on the value of the aquatic resource to be protected. The guidelines are adaptable to allow improvements based on future research and field experience.

The program is going strong. Some 600 forest industry and government staff have now been trained to use these guidelines during the 1988 season.

This is an excellent model of the integration of fisheries objectives in forest management. An editorial in the Vancouver Sun newspaper called the program an example of "government at its best."

To integrate fish habitat concerns in a broad resource planning process requires concrete habitat objectives. Thus our department is developing its own fish habitat area or "zonal" plans. These plans will describe the fisheries resource and define our habitat protection and management priorities. Again the approach is to classify streams or stream reaches based on their habitat value.

A nationwide effort for fish habitat goes far beyond a single federal agency. Involvement is the key. Thus a foundation of our approach is to improve awareness of habitat issues.

We must stir strong public sentiment for habitat conservation and development. People are ready to listen. The polls show that Canadians have a keen interest in their environment. Outdoor pursuits account for billions of dollars in consumer spending every year. There will be benefits all round if we can focus that interest on habitat needs.

We recently commissioned a study to define key target audiences for the fish habitat communication program and to determine our current impact on these client groups. A number of needs were defined:

- "how-to" information for those who wish to protect, restore or develop habitat;

- consistent technical guidelines for industry in habitat protection; and

- a concerted effort by DFO staff to personally contact the various sectors, to promote and explain the policy.

How are we going to do all this good work for fish habitat?

MEETING THE COSTS OF THE POLICY

Our dreams always seem to exceed our resources. Indeed the basic habitat management problems we face can be overwhelming! But I believe that several years of fiscal restraint have made us more clever. We have been forced to look to new and innovative ways to find the dollars and share the work load.

Looking first within the federal government, we see such potential funding sources as the Western Diversification Office and the Atlantic Canada Opportunity Agency. A better fishery is surely an important component of regional development. We must build a strong case for investing in fish habitat.

Federal Fisheries and Oceans shares many common objectives with the provinces. Indeed we have had close working relationships with our provincial counterparts for many years. Thus I see great promise for sharing tasks and resources under a new set of federal-provincial fishery agreements.

The private sector is becoming an increasingly important force for habitat. Fisheries agencies and resource industries both have much to gain from closer working relationships. There are opportunities here for joint research. Together we can develop better and more cost effective techniques to protect habitat.

Conservation groups offer a major source of enthusiastic labor and, in some cases, dollars for habitat. The Department of Fisheries and Oceans is beginning what we hope will be a very rewarding association with Wildlife Habitat Canada. Wildlife Habitat Canada is a non-profit foundation dedicated to conservation, restoration and enhancement of wildlife habitat. Its primary focus to date has been on waterfowl. But about one-third of its projects so far (worth some $3.5 million) have had a fisheries component.

We have just signed an agreement with the foundation to explore the potential for greater non-government funding of more fisheries habitat programs.

There is plenty of energy in the private sector. We cannot lose by tapping into it.

You and I are shaped by our experiences. We learn from our successes and our failures. These lessons make us more thoughtful and sensible, and hopefully better prepared for the next challenge.

Experience has led our department to develop a thoughtful, common sense policy to resolve conflicts over fish habitat. But while we talk of compromise and cooperation, we do have an ambitious goal: a significant net gain in the productive capacity of the habitats which support Canada's fisheries. To achieve this goal we need vision. We need a clear picture of a better future, so we can take steps in the right direction.

We foresee a stronger fisheries resource in all parts of Canada. But of course there are many steps down that road.

We need an improved federal Fisheries Act. Today we have a legislative patchwork as far as habitat goes. We need a more comprehensive, unified law which will incorporate all the main points of our Fish Habitat Policy.

In moving toward integrated resource planning, the department must complete its own fish habitat zonal plans. These should emphasize fish production rather than simple protection of areas. We must classify the various types of habitats—food supply areas, rearing and migration areas, and we must identify threats to habitat. Especially important, our plans should identify opportunities for habitat restoration and development.

The computer will be an increasingly important part of fish habitat management. More efficient record keeping and improved techniques of data processing and display are among the many potential benefits here.

To realize our net gain, we'll need procedural and technical guidelines for all aspects of habitat protection and improvement.

We must have a better informed public so that we can gain the support needed for expanded habitat programs. And we must develop meaningful cooperative agreements between government agencies and with non-government groups.

The task before us is a very big one, but a stronger fisheries resource is an achievable and worthwhile goal. There are Canadian success stories we can point to here. The Atlantic salmon had disappeared from the St. Croix River (New Brunswick), but now they are back, along with alewives and shad. From my own experience in New Brunswick I've seen the Big Salmon River, where some fifty salmon rose to several thousand within a few years. And there are very real plans for restoring the fisheries of Lake Ontario.

You know, it's exciting to think that our efforts today will lead to the success stories of tomorrow! The challenge is to sustain our successes, to reverse the declines in quantity and quality of habitat. We will achieve this not by seeking conflict, but by pursuing our own vision of a brighter future.

QUESTIONS

When we make artificial islands for wildlife habitat we are in essence destroying fish habitat. How does that blend in with the concept of integrated resource planning, where you are benefiting one group such as wildlife, but perhaps lessening the habitat of fish?

Dominy: I have to react by saying that that's not a very good example of integration of conflicting uses. If in fact the fish habitat is productive and we are dealing with a productive clam area, mussel area, lobster area (etc.), then I think we are getting the raw end of the deal. If on the other hand it is of mediocre value and if you can enlarge the littoral area by creating an island then there may be some benefit in doing it. It depends on the circumstances. That's why I emphasize the development of the habitat classification: eventually we will be able to classify and identify what is important and what is not. The alternative is to go out and look at each site individually.

How are you presently looking at every project individually? You mentioned that you don't want to have any net loss of production capacity. If someone comes to you with a proposal do you go out and look at it? Do you have any objective, consistent, economical and efficient test to determine the production capacity of a body of water? How do you make judgements if you cannot determine production capacity?

Dominy: You don't need to determine the production capacity in each individual case. If you ask any scientist how to measure production capacity, you won't get a good answer. We have been searching for the answer to that question a long time and you end up moving further away from the fish themselves. Very often productive capacity is measured in terms of caloric content or the number of organisms in the area of interest. We have a hard time converting those indices into fish flesh, so our approach is to say "Does the area support fish and shellfish or any of their life stages?" Usually we can answer those questions. Once we have identified an area as fish habitat it is our responsibility then to apply the kinds of prescriptions that will avoid damage or will compensate for the lost habitat. We must distinguish the kinds of damage, physical or chemical. If it is chemical the habitat policy states that the waste must be treated so that it is not harmful to fish. Chemical problems do not lend themselves to the question of net loss: if it harms the fish or affects consumption by humans, then it is a problem. On the physical side we may be able to quantify it in terms of area. In the examples that I showed of bridges and highways affecting the area where fish are spawning or feeding, there is an importance attached to it from the fisheries point of view. If we agree that there is a net loss resulting from the activity then the compensation options come in.

Do you find that industry plays a game of "Prove it to me"?

Dominy: If we got into that kind of a debate I'd have to say "look this is the evidence." If we are dealing with a known salmon or trout stream, there could be no argument because the facts are there. Then I, as a biologist, would state that this is where the fish food is being produced or this is where they rear and we are not prepared to see that destroyed. If proponents would like to argue against this, it would be at their expense to gather evidence.

Are there restorative and active management plans for the streams of the Eastern Shore of Nova Scotia?

Dominy: In reference to acid rain, if we are smart enough and have enough money then we should restore. But acid rain problems are not easily corrected.

With regard to the no net loss concept, what kind of time frame are you looking at? Are you looking at net loss over one year or four to five years? How do you deal with problems where a net loss occurs on a short term basis but on a longer term results in better habitat?

Dominy: The approach that we have adopted is no net loss on a project by project basis and that deals with the here and now. Temporary loss of habitat depends upon how serious it is. If it is truly a temporary loss it may be possible to accept that loss and other circumstances may produce a net gain.

Regarding the no net loss on a project by project basis, I wonder in the long run if the policy will not fall apart. You might look at what is called a "bubble concept," whereby you accept tradeoffs between projects so that the ultimate bottom line is no net loss.

Dominy: Since projects rarely take place simultaneously, to get one developer to compensate for losses from a previous project would be very difficult. Therefore, a project by project approach is more likely to work.

Does your policy of no net loss apply equally for all species of fish?

Dominy: I mentioned the salmonids because we know a lot about them and they are so easily affected by our activities. The policy applies to all species.

If one species is affected negatively, but another is affected positively, how do you decide between the two?

Dominy: The agency responsible for fish must make a decision as to which species the river will be managed for.

Does the management policy take into account uses other than those of the target species? For example, other fish species, wildlife, and human recreation?

Dominy: Management policy is the result of an integration of the Fisheries Management Plan, Habitat Management Plan and consultations with users.

Most habitat improvement projects I have seen have been specific for one species or even one life stage of one species. What about the other species?

Dominy: A decision will be made as to which species the river is best suited for. A management plan will then be drafted and upon consultation with users may be revised to take other species into account. The policy states that we cannot protect all species but must focus our attention on those from which we derive the most benefit. I don't think that it is possible for any fisheries agency to protect all species. We may not always agree with that but it's the most practical solution.

Can you explain how habitat use and classification will come about?

Dominy: We don't have the knowledge to make a classification at present. As a matter of policy, we have to start developing that kind of information so that we can make the classification that is satisfactory to all parties.

Has any research been started on this?

Dominy: There are projects under way which are evaluating the productivity of habitats. We're not going to get too fancy with our planning until we are able to classify fish habitats adequately.

Does DFO use at present a sophisticated geographic information system in digitizing all the habitat information or is it left to the individual regional offices to utilize, depending on their priorities and funds?

Dominy: There is no national geographic information system, so it is left up to the regional offices.

You said that the policy is not retroactive but the department is looking at existing developments or situations. How does that actively relate to the policy?

Dominy: Any retroactive activity I'm familiar with involves a cooperative effort. The only time we deal with that is when there has been a faulty design and we are trying to alleviate a problem and work towards corrective measures.

Do you prepare or accept proposals for the development of a management plan for a particular stream?

Dominy: We would welcome any initiative like that, but to come up with a management plan we need a good existing data base.

Characteristics of Freshwater Fish Habitats

André Ducharme

ABSTRACT

The characteristics of freshwater fish habitats in lentic (lakes) and lotic (streams) environments are described by analysing the relationship between fish and the physical and biological constituents of typical pristine freshwater lakes and streams.

Lakes present a great deal of diversity, but some elements common to all lakes relate to fish life support. The quantity and quality of these elements vary enormously and so does fish productivity. Lakes stratify thermally in the spring and may remain stable for months until fall when a phenomenon called **turnover** takes place and lakes become homothermic. The major habitat zones of a lake are: the shoreline, the open areas (**epilimnion**) and the profundal areas (**hypolimnion**). The most important from a fish production viewpoint is the littoral or shoreline zone where many species of fish reproduce. Next in importance is the epilimnion or limnetic zone where larger fish roam in quest of food and where much of the primary production takes place. The profundal areas are also used by fish species during spring and fall turnover. Bottom features are preeminent in determining the suitability of a lake shoreline as habitat. Slope and type of substrate material, presence of rooted vegetation, water level, dissolved oxygen and turbidity all affect spawning and rearing success of species like small mouth black bass (*Micropterus dolomieui*), alewife (*Alosa pseudoharengus*) and even speckled trout (*Salvelinus fontinalis*). Next to bottom characteristics, the food chain and food production capability of a lake, such as plankton production and the bottom organisms typical of shoreline areas, determine the quality of the habitats of a lake.

Rivers and streams contrast with lakes in that they are narrow, shallow channels in which the entire body of water moves continuously in a definite direction. Rivers drain lakes and are therefore affected by the physical and biological conditions of the lakes from which they rise. They benefit from the residual food production as planktonic organisms produced in the lakes are discharged with the excess water. The importance of physical factors in the stream environment is greater than in lakes and their equilibrium is much more fragile. Water flow is the common denominator to all rivers and streams. It ensures both high oxygenation in uncontaminated waters and relatively uniform temperatures. Swiftness of current and shallow features of streams, create a tendency for the water to follow ambient air temperature closely. Erosion, transportation and sedimentation are also inseparable accompaniments of stream currents. Strong flood flows may carry away large segments of the bottom as well as fish and fish food organisms. Recolonization with most benthic organisms is rapid, a matter of weeks, but fish take much longer to return. On the basis of substrate size and swiftness of current, freshwater species of fish select their spawning, nursery and rearing areas. Eggs are buried in shallow, light gravel beds, and newly hatched juveniles remain in close contact with the substrate and the food elements within. They also use the interstices between stones and back eddies created behind boulders as protective cover against predators and against entrainment during freshets. Most streams except very large and slow moving rivers, do not manufacture within themselves basic food organisms, comparable to lake plankton. In a stream environment fish food is supplied from three major sources: the benthos or stream bottom fauna, terrestrial or arboreal insects that fall on the water surface from overhanging trees, and planktonic organisms and other organic detritus discharged from the lakes which form part of the "stream drift." Major elements in the diet of salmon juveniles and trout in a stream include stone-fly larvae (Plecoptera), black-fly larvae (Simuliidae), caddis-fly larvae (Trichoptera) and may-fly nymphs (Ephemeroptera), all of which are common members of the bottom fauna of Eastern Canadian streams. The two most important species occupying stream habitats in Nova Scotia are the Atlantic salmon and speckled trout. Several other species cohabit the stream but occupy different niches although there may be competition for food. The salmonids in a stream are strongly territorial and their feeding behaviour is adapted to a sedentary life style where the stream current brings the food elements within close reach.

INTRODUCTION

Fish habitat is defined by the Fisheries Act as: **spawning grounds and nursery, rearing, food supply and migration areas on which fish depend directly or indirectly in order to carry out their life processes.** This habitat definition may satisfy the legal requirement of courts and adjudicators, but to really understand what freshwater fish habitat is, it is necessary to dissect and analyse the physical constituents of the freshwater environment. Such an exercise soon reveals a diversified, complex, even fragile web of physical and biological elements that, when in equilibrium, composes the world of fishes. Nova Scotia's freshwater domain is characterized by a great abundance of lakes and river systems that offer diversified and plentiful quality habitat for many valuable game and commercial species such as Atlantic salmon and gaspereau.

The relatively still waters of lakes and ponds (i.e., lentic waters) present environmental conditions that contrast sharply with running (lotic) waters. Lake environments produce gradients in light penetration and in temperature that translate into the formation of a surface zone where food production takes place. Stream environments favour the mixing of waters so that temperature is uniform but tends to change rapidly to follow ambient air temperatures. Fish food in streams is not "manufactured" within but rather is brought in from other sources, including from the lakes they drain.

LAKES AS FISH HABITAT

Lakes in Nova Scotia vary in size from small ponds (1 hectare or less) to very large lakes such as Lake Rossignol (c. 150 km^2). They also vary in depth from a few meters to 20 m or more. The shoreline or littoral area varies in length and slope and this is an important consideration from the habitat point of view for many of our species of fish. In deep lakes, light penetrates only to a certain depth depending on water colour and turbidity. The temperature of lakes varies seasonally and with depth since only a relatively small fraction of the lake water comes in direct contact with ambient air and is exposed to the sun's heat. The oxygen content of lake waters can be relatively low for the same reasons. The resulting gradation of light, oxygen and temperature affect the way species utilize the habitat regions of a lake.

Thermal Stratification

Lakes have typically three distinct regions or zones, these are: the **littoral** or shoreline area, the **limnetic** or surface open water areas, and the **profundal** or bottom water area. The latter two zones may be separated because of thermal stratification, in which case they are termed the epilimnion and hypolimnion, respectively (Figure 1).

Each year lake waters undergo seasonal changes in temperature. As the ice cover melts in the spring the surface water is heated by the sun, and warms up to about 4°C. At this temperature water is at its greatest density and this sets up convection currents that mix the water in the basin. Aided by strong winds, the entire lake volume is circulated until the lake is uniformly 4°C in temperature. This is the spring turnover. During summer the heat from the sun continues to warm up the water until the entire surface layer is of much higher temperature and consequently much lower density than the deeper layers. This strong density gradient now opposes the energy of the wind and it is more difficult for the entire lake basin to mix. As a result stratification occurs and three distinct water layers develop in a typical lake:

(a) The *epilimnion* , or upper layer up to several meters deep, has warm water with a very light temperature gradient with increasing depth. Convection and wind-induced currents ensure its oxygenation and uniformity of temperature.

(b) The *metalimnion*, most frequently referred to as the thermocline, is a water layer characterized by a very steep and rapid decline in temperature at a rate of 1°C/m of depth or more. This layer can be several meters deep.

(c) The *hypolimnion* , or profundal zone, is below these first two strata. It is a deep, cold layer in which the temperature continues to drop steadily to about 4°C, and extends to the lake bottom.

With the coming of autumn, the air temperature drops and so does the water temperature of the epilimnion. This process causes the water of the epilimnion to sink by convection until the entire lake temperature is once again more or less uniform from top to bottom at about 4°C. The entire water basin again circulates and oxygen and nutrient supplies are recharged throughout the lake. This is called the fall turnover. It will last until ice forms on the lake.

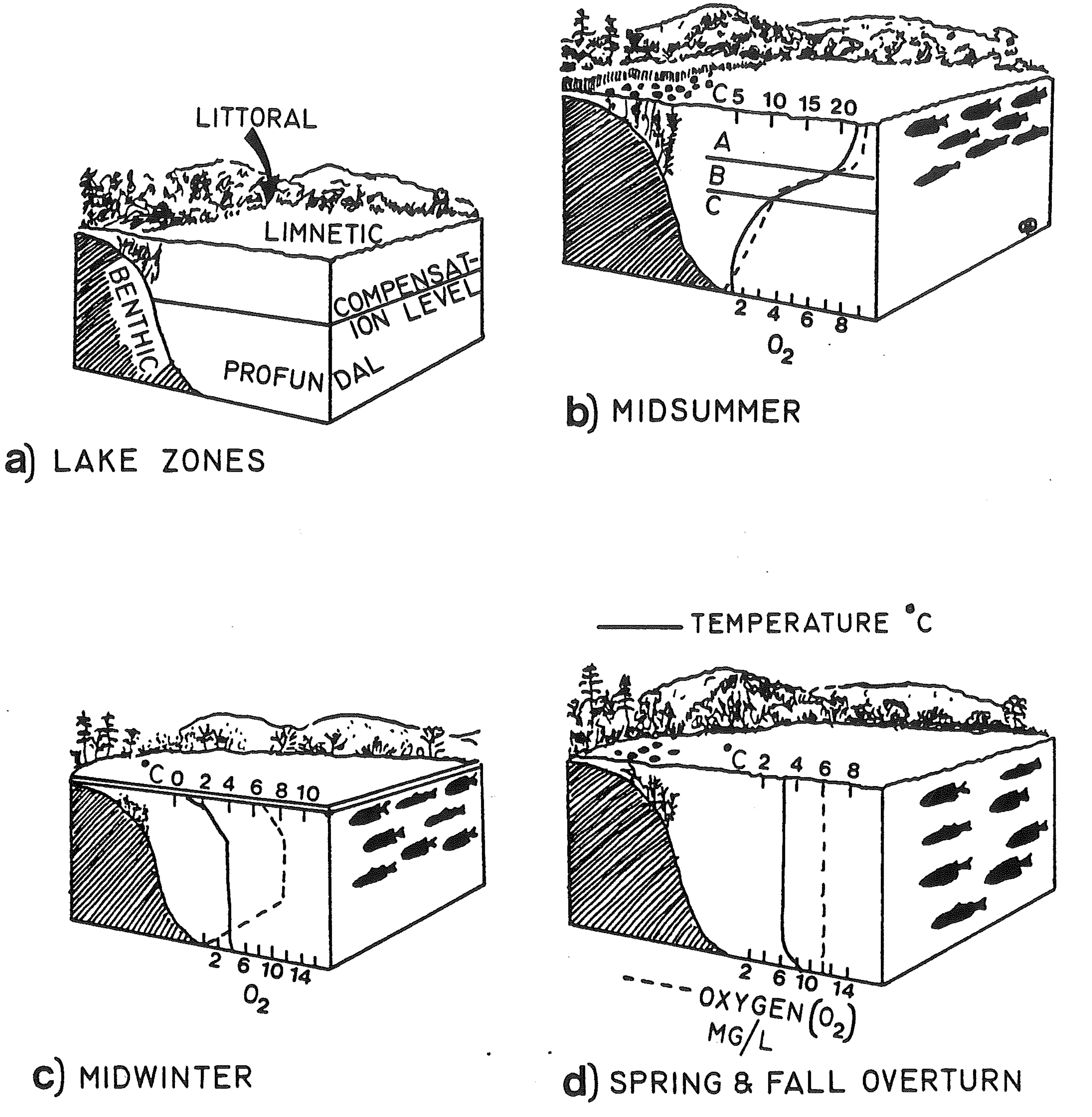


Figure 1. Seasonal changes in a temperate lake and the effects on its fauna.
a) Generalised picture of a lake in midsummer showing the major zones mentioned in the text. **Compensation Level** is the level below which light becomes too low for plant growth.
b) In mid-summer there is pronounced stratification. A = **Epilimnion**; B = **Metalimnion** (or **thermocline**); C = **Hypolimnion**.
c) Distribution of temperature and oxygen in a lake in midwinter, and its effect on fish life. The narrow fish silhouettes represent cold water species such as trout; the bass silhouette represents warm-water species.
d) During spring and fall overturns the temperature and oxygen curves are almost straight, indicating complete mixing of surface and bottom water.
(After R.L. Smith, 1966)

As the water continues to cool below 4°C, at the approach of winter, it becomes lighter, stays at the surface and there is now an inverse stratification, with colder water nearest the surface, overlying deeper water that is commonly at or near 4°C.

This is a general picture of the seasonal changes in temperature that occur in lakes. It is also accompanied by changes in dissolved oxygen which are strongly but inversely related to changes in temperature. The amount of oxygen is greatest nearer the surface in the epilimnion. The oxygen quantity in the profundal zone may become so small that fish cannot live there. This is due to three main causes:

(1) Low light penetration, so that very little or no photosynthesis, which produces oxygen, takes place;

(2) The oxygen present is being depleted by the respiration of animals, and particularly of bacteria and fungi which decompose the dead organic matter that sinks from the upper layers of water;

(3) No circulation occurs to bring fresh oxygenated waters from the surface.

During the summer, warm water species of fish (e.g., perch, bass) will live in the surface stratum of a lake while cold water species like lake trout descend to the colder waters of the thermocline or the hypolimnion if oxygen levels permit. During the spring and fall overturn periods, which may last weeks or months, fish of all species may be found evenly distributed from top to bottom of the lake, because oxygen depletion and temperature no longer present barriers to vertical positioning within the lake basin.

The Limnetic Zone

The limnetic, or open water zone, corresponds roughly to the epilimnion or surface stratum described in the previous section on lake stratification. This zone where light penetrates is the zone of photosynthesis: there a multitude of small (microscopic) plant forms called **phytoplankton** proliferate, and form the base upon which the rest of limnetic life depends. Present with the phytoplankton are numerous minute animals or **zooplankton** which graze upon the minute plants (Figure 2). Both phyto and zooplankton float more or less helplessly, moving to and fro with currents set up either by convection or strong winds. Some have adaptations for staying afloat vertically. As they die their bodies sink to the bottom of the lake where they decompose. Many small fishes or juveniles of larger species feed on plankton. Larger fish "cruise" the open water either in quest of food or in search of places for reproduction. No fish species spend their entire life cycle in this zone. Depending on temperature and oxygen availability, larger fish species may occupy the deeper area of the open water in search of cooler waters in the summertime when the lakes are stratified.

The Littoral Zone

The littoral zone, or shallow water zone, is part of the upper stratum of a lake but it is very different from the open water, and much more capable of supporting rich abundant aquatic life. Swarms of small and large aquatic insects, worms, crustaceans and snails live attached to, clinging to or burrowing among the submerged or emergent rooted aquatic plants and stony substrates (Figure 3). Fish such as the Alewife (gaspereau), smallmouth black bass, white and yellow perch, spawn in these shallow gravelly or weedy areas. Their juveniles find shelter and food among the plants and in the interstices between stones. The food in the form of aquatic insects is further enriched by planktonic organisms produced in the open water area but pushed inshore by strong winds. Oxygen is never a problem in these shallow areas because of wave action and the plants which give off oxygen, but temperature may occasionally rise significantly above the average open area temperature. The littoral zone is fragile and vulnerable, particularly to sudden changes in water levels such as occur in lakes used as reservoirs. Some species of fish use the littoral zone for spawning and the juveniles move off to other areas after a more or less lengthy rearing period. Predatory fish make incursions into these areas to feed on juveniles of other species.

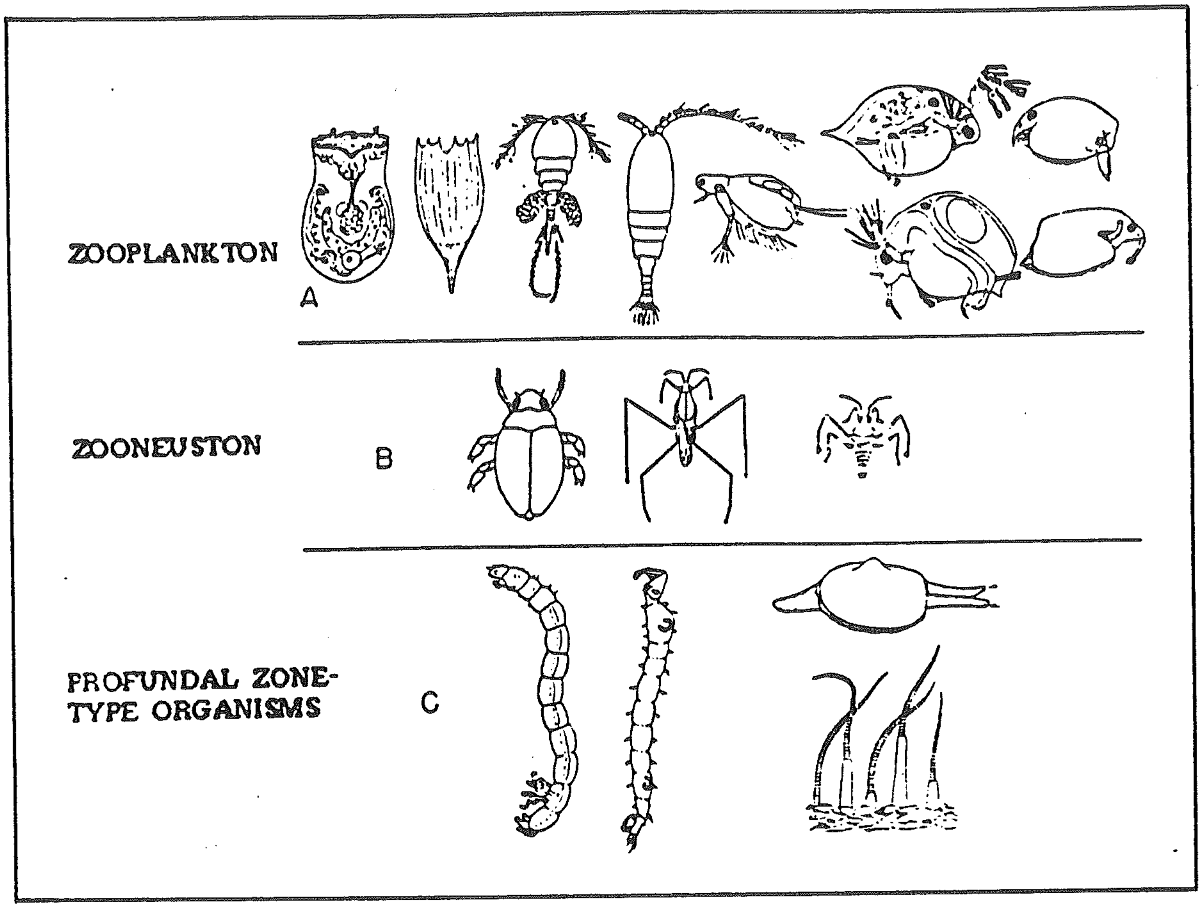


Figure 2. Typical invertebrate life forms of lakes. A - from the limnetic zone; B - primarily from the littoral zone; C - from the profundal zone.

The Profundal Zone

Below the thermocline lies the cold, often oxygen-poor, profundal zone. This area of a lake is occupied by fish during the spring and fall turnover when the lakes become "quasi" homeothermic, therefore it is part of fish habitat. During stratification in the summertime the area may often become depleted of oxygen, especially in shallow lakes. Some life forms do occupy this zone bottom: e.g., flatworms, molluscs, some plankton in vertical migration and some small crustaceans (e.g., Cladocera) that live in the bottom ooze. During spring and fall turnover this zone helps to recharge the entire lake basin with important nutrients, particularly nitrates and phosphates.

RIVERS AND STREAMS AS FISH HABITAT

Current or continuously moving water is the outstanding feature of streams. Current cuts and shapes the narrow channel and affects the behavior of all fishes and organisms that live in streams. Streams may begin as outlets of lakes and ponds or from springs in the ground, and gather momentum, augmented by tributaries along the way or by surface runoff added in varying quantity through storm events or snow melt. In Nova Scotia many important streams and rivers have their sources in a lake or drain a series of lakes through many tributaries (e.g., the Tusket River, the Shubenacadie River). These river systems are always rich in diversified fish habitats.

The common denominator of streams, current, is very variable from one reach of a stream to another, both with the seasons and even after a single rain event. Because of erosion, the transport of sediments is an inherent characteristic of streams, Equilibrium between the physical elements of a stream is always precarious at best and often broken by a single rain storm or by human activity. Fish and invertebrate communities in a stream are adapted to and can tolerate (wait out) short periods of upheaval that occur naturally, but the compounding of human induced disruptions can and does cause profound reduction in stream fish productivity.

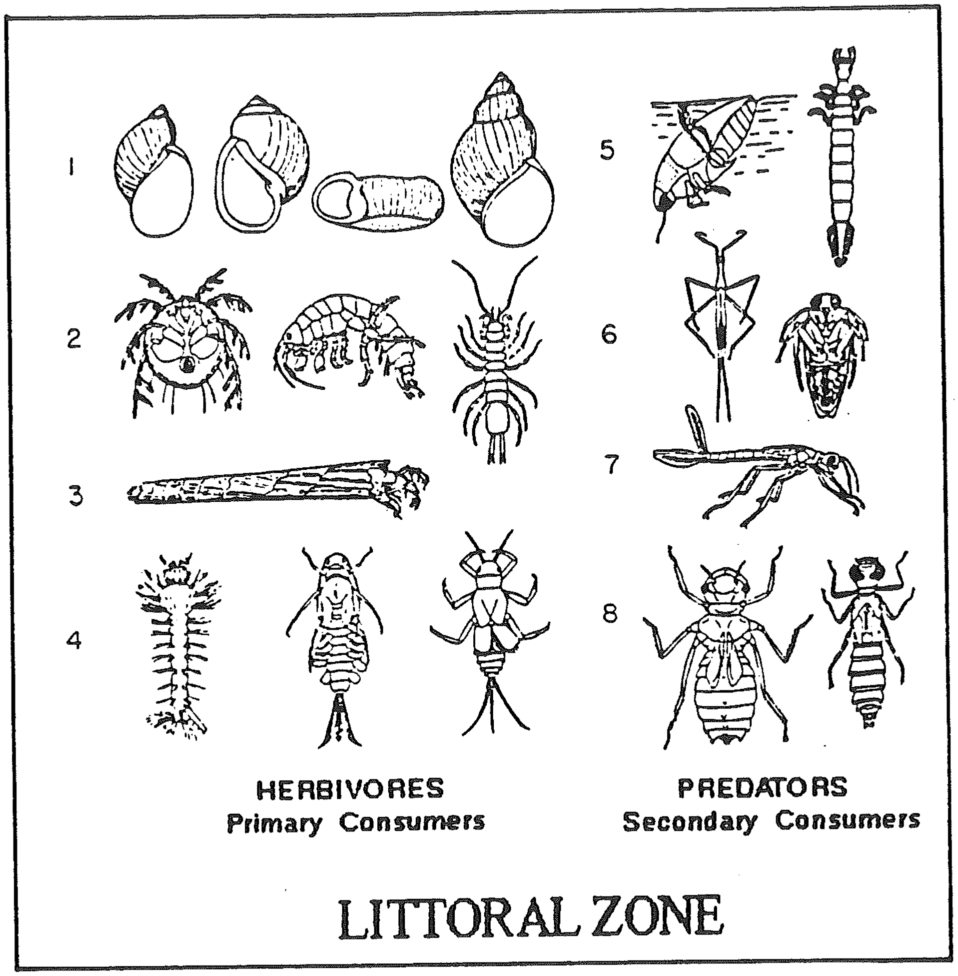


Figure 3. Invertebrates of the littoral zone of freshwater lakes. 1 - Molluscs; 2 - Mites and Crustaceans; 3 - Caddis flies (Trichoptera); 4 - Flies (Diptera) and Mayflies (Ephemeroptera); 5 - Beetles (Coleoptera); 6 - "Bugs" (Hemiptera); 7 - Damselflies (Odonata); 8 - Dragonflies (Odonata).

Thermal Characteristics

The temperature in streams is not constant. Generally small to medium streams tend to follow, with some lag, the air temperatures. Large streams with wide shallow areas exposed to sunlight are warmer than those shaded by trees such as the very small forest streams (Figure 4). This is an important consideration, as it shapes the composition of the stream fish population. The constant tumbling and swirling of waters in a stream ensure uniform (if variable) temperature, in contrast with the stratification phenomenon observed in lakes. It also ensures high oxygen content because of the greater contact with the atmosphere.

Stream - Land Interchange

Because the land/water surface junction of streams is relatively large compared to lakes, streams are more intimately associated with the surrounding land (Figure 5). For example the shade provided by a large tree near a stream has far more importance than the same shade tree would have standing near a lake. Small boulders are not only protective cover against predators, they also provide protection against being washed away by the current. Boulders and rubble in general control the velocity of the current.

Stream beds are held together against the eroding action of the current by the materials that compose these bottoms—boulders resist transport, sand moves readily—by the material that composes the stream banks, by the steepness of its slope, and by the root systems of bordering vegetation that bind the soils, and finally by the vegetation itself that absorbs the impact of rain drops and surface run-off.

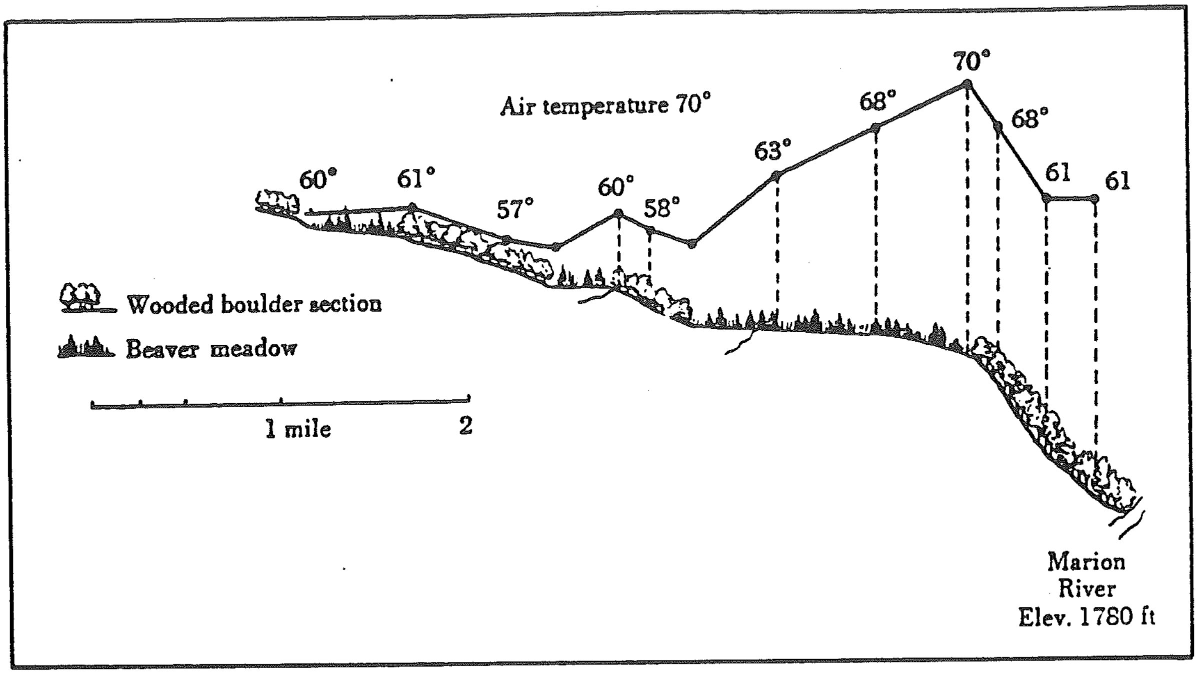


Figure 4. Effects of streamside vegetation on temperatures of a stream. Note the warming effect of open beaver meadow and the cooling effect of wooded section. Location: Bear Brook, Adirondack Mountains.
(Source: R.L. Smith 1966)

Habitat Zones of Streams

Streams exhibit two major habitat types: **rapids** or **riffles**, and **pools**. In large rivers the distinction between rapids and pools becomes less and less evident, until a deep channel type habitat is developed. The type of bottom is very important in determining the nature of the communities and the population density. Current is a major factor as well.

Riffles are areas where the current velocity is 50 cm/sec or more. At this velocity the small particles are removed, leaving behind a stony bottom ranging in size from fine gravel to small boulders. In productive waters the surface of the stones may be covered with green algae and water moss, forming a slippery cover. These plants provide a primary production comparable to the phytoplankton of lakes and ponds. In the interstitial spaces between the stones, and clinging to the vegetation, is a host of insects. These are mostly larval forms that spend part of their life cycle in the aquatic environment, and are specially adapted to life in fast flowing areas. Some graze on the algae covering the stones, others are carnivorous or feed on detritus (i.e., dead organic matter) brought by the current. A major reason for the richer aquatic life in the riffles is the current. Stream animals (insects) depend on flowing water both to aid their respiration and to bring them food.

Many species of fish select riffles for their habitat. Using Atlantic salmon as an example, the adult salmon spawn at the upstream end of gentle riffles. The nest, or **redd,** is excavated by the female and the eggs are covered to a depth of 10-18 cm. The cleanliness of spawning gravel is critical to help maintain a "percolation" flow through the substrate bringing oxygen to the developing embryos (eggs) and carrying away the metabolic waste (Figure 6). Eggs deposited in the month of October-November hatch sometime in April (after 5-6 months). The sac fry, as yet unable to swim freely, remain in the redd for several more weeks. In May the alevins surface above the gravel and remain in close contact with the substrate. Eventually they occupy the entire riffle.

Above and below the riffles are the **pools**. The environment differs in intensity of current, depth and bottom composition. The current is reduced enough to allow fine particles to settle out, so that the bottom becomes sandy. Sandy bottoms are the least productive since there is no stable surface for either plant or insect larvae to cling to. Although pools are less productive, they are an essential habitat and cannot be

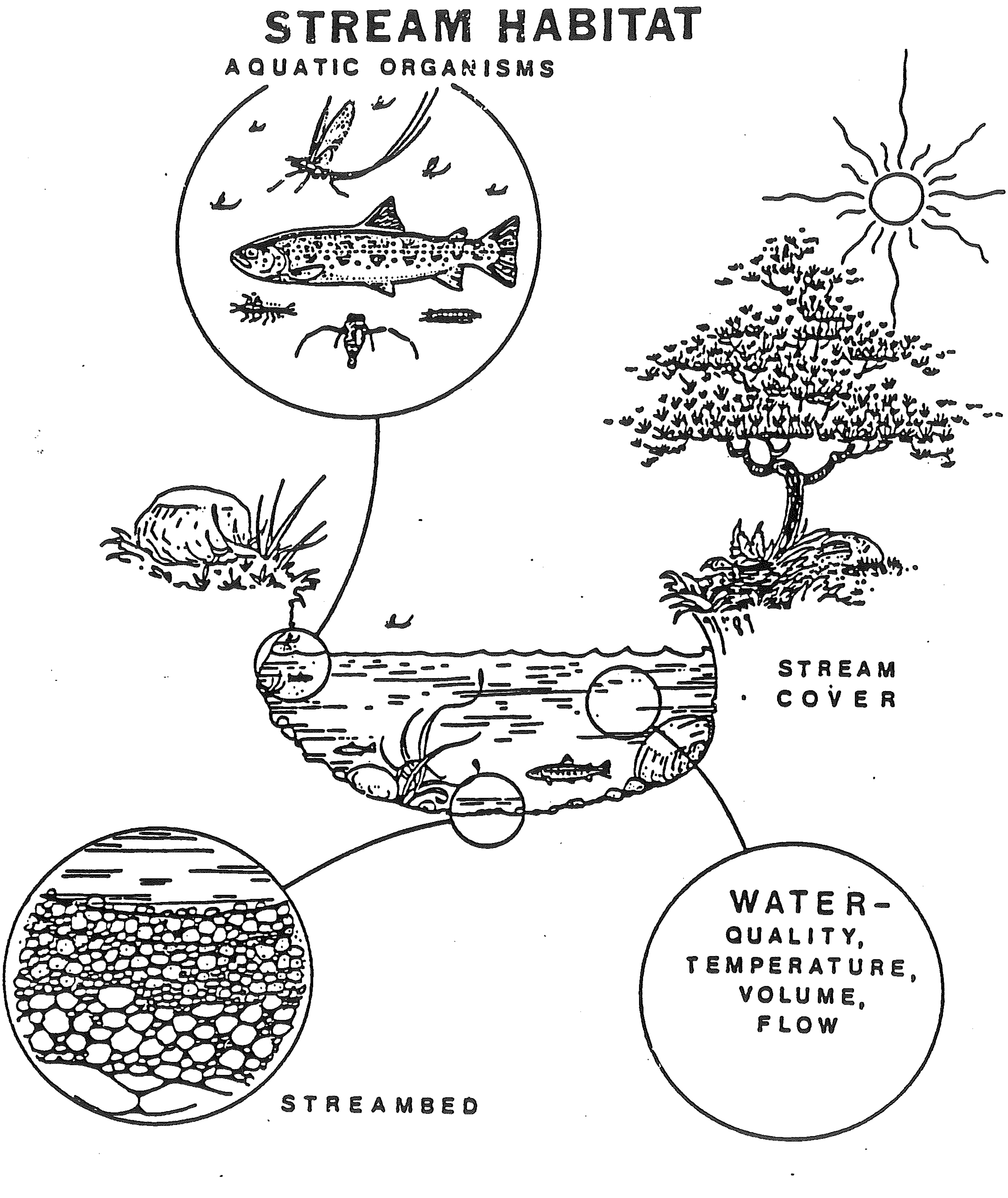


Figure 5. Interconnections between terrestrial and aquatic systems in freshwater streams.

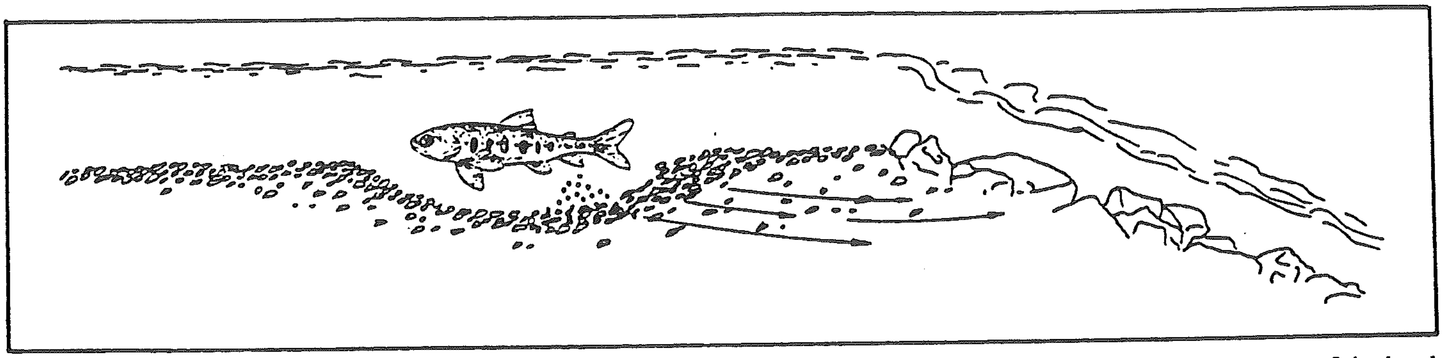


Figure 6. Location of salmon redd at the head of a riffle. Arrows indicate percolation of water over the eggs because of the head differential. For this to occur, gravel must be clean.

dissociated from the riffles because some fish (trout for example) move back and forth between riffles and pools. The riffles furnish food, the pools shelter. Also, many fish feed where riffles empty into pools. A good trout stream should be roughly 50% pools and 50% riffles. Pools are also resting places for anadromous species on their spawning run. Some Atlantic salmon lie in larger pools of rivers for several months while waiting for the fall (October-November) before moving on to the spawning grounds. Pools are also areas where inhabitants of the riffles may retreat to seek shelter during an extreme drought period. Shelter in the pool may take the form of deep shade from overhanging trees, undercut banks, submerged roots, woods, sunken logs and various other debris or boulders. Some species of stream inhabitants prefer the pools as habitat (e.g., large trout, white suckers, chubs and shiners).

Fish Food in Streams

Primary production in streams is limited to the green algae and moss that grow on the surface of stones. Some excellent salmon rearing streams don't display this growth on the stones of the riffle, which may therefore appear very clean. Plankton as such is not produced in streams, but streams do have planktonic plants and animals that originate in lakes and ponds or backwaters that drain into the streams. Fish food in streams can be divided into three distinct groups (see Figure 7):

(a) Bottom Fauna (Benthos)

This is the most important source of food for the juveniles of stream dwelling species like Atlantic salmon and trout. Gravel and rubble bottoms support an abundance of insect life forms that live in the crannies and interstices between stones. The most important of these organisms are listed below in order of importance:

Stone fly larvae (Plecoptera): these large bodied insects are very common in Nova Scotia streams. They are a staple in the diet of Atlantic salmon juveniles. They are present in good numbers throughout the year. Stoneflies are excellent biotic indicators of water quality because they require highly oxygenated waters.

Black fly larvae (Simuliidae): these are very small in comparison to the stone flies, but they are so numerous that at times they give the plants or stones to which they attach themselves a velvety or furry appearance like "black moss."

May fly nymphs (Ephemeroptera): are medium-sized insects, most abundant in rubble in fast riffles.

Caddis fly larvae (Trichoptera): these are also abundant in fast rocky streams. They construct cases of sand, small pebbles, or sticks to protect themselves from the current and predators. Other forms of insect are common to both riffles and pools, such as mayflies, caddis fly larvae, dragonflies, damselflies, water striders, and water beetles.

(b) Terrestrial Insects

It has been said by many students of the stream environment that: "next to water nothing is as useful to a fish as a tree." This common saying holds true with the input, albeit seasonal, of a significant source of food for stream dwelling fish. Trees and bushes overhanging streams harbour a host of insects. Insects

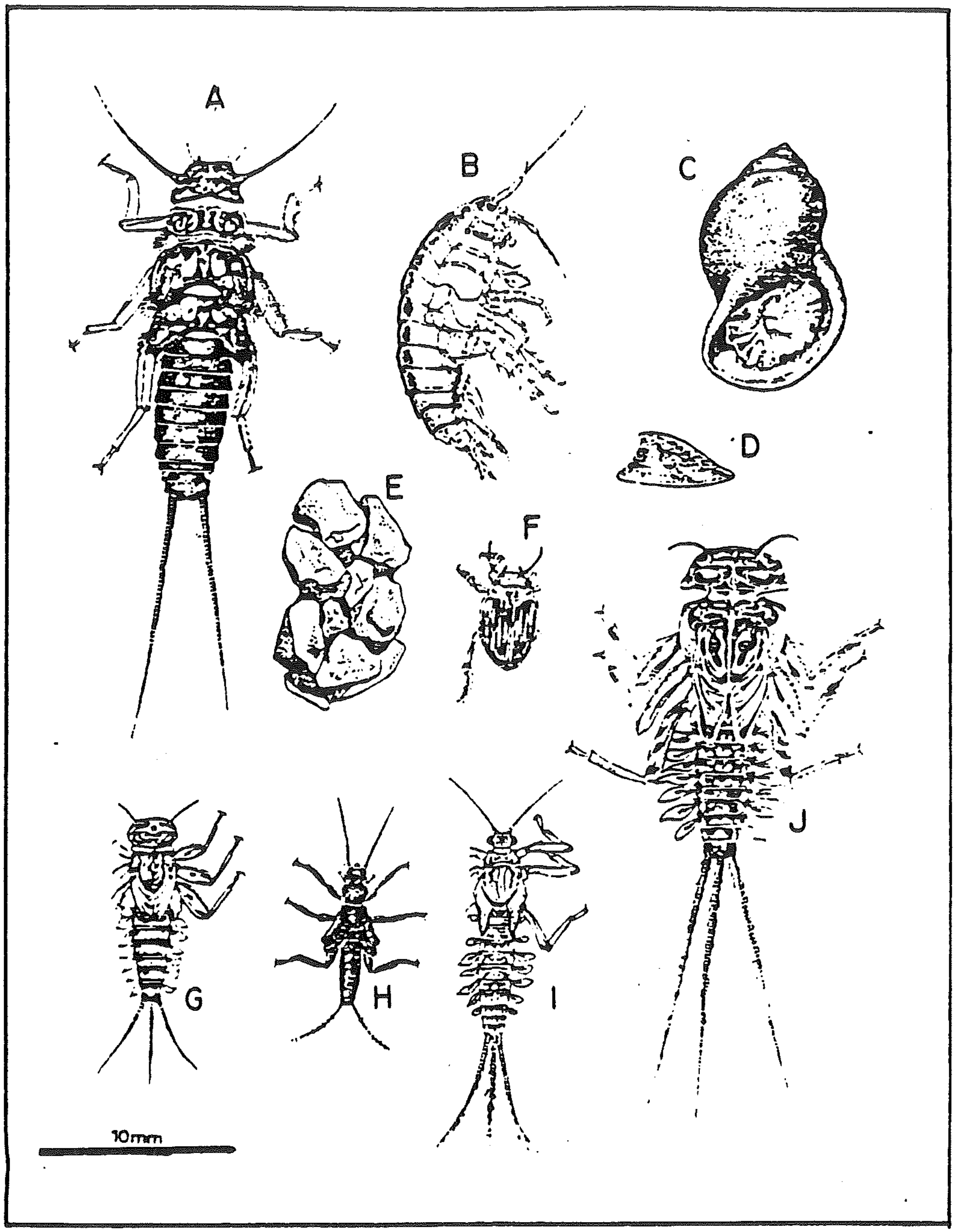


Figure 7. Invertebrates of stony (eroding) stream substrates. a, h - stoneflies; b - freshwater shrimp; c - snail; d - freshwater limpet; e - caddis larva in stone case; f - beetle; g, i, j - mayflies.

reproduce quickly and have short life spans. This effectively results in a shower of tender little morsels (for fish) on the water surface. At certain times of the year this becomes a significant source of food.

(c) Stream Drift

This is a composite food source since it contains organisms from both the benthos and the terrestrial insect food source. Many bottom organisms, in spite of their adaptation for clinging to stones, tend to drift downstream particularly during evening hours, to resettle some distance downstream. They form a travelling food source of great importance. The terrestrial insects showering on the riffles from the trees are swept with the current. But the stream drift is also composed of plankton organisms originating from lakes and ponds, and detritus (mostly leaves) from terrestrial vegetation. The stream drift may seem like Natures' way of "setting the table for fish" who only need to lie in wait of food that passes within easy reach.

(d) Small Stream Productivity

The width of streams influences overall production. Headwater streams 2 m or less in width are four times as rich in bottom organisms as those 6 to 8 m. For this reason, headwater streams make excellent trout nurseries. This is a fact all too often ignored by land developers and industry in general.

Territorial Behavior and Habitat

Most species of fish in the stream community display territorial behavior, but none more so than the salmonids. Juveniles of Atlantic salmon and speckled trout following emergence from the gravel migrate some distance, 1 to 7 km, up or downstream from the birth nest (redd).

They select a small area of stream bottom or take position behind a small boulder and strive to maintain that position against current, predators and members of their own species (Figure 8). The occupier of a choice position may flee from danger momentarily, but will return to the precise spot over the substrate when the danger has passed. He will always endeavor to drive away any intruder of his own species. Weak or dislodged animals may, with luck, find an empty "spot" but some may fail to survive. This is a complex and important factor of life in a fast stream that limits production and makes every square meter of suitable substrate a valuable piece of "real estate."

FISH COMMUNITIES IN LAKES AND STREAMS

Many of the fish species found in lakes and streams of Nova Scotia, like Atlantic salmon, sea run trout and gaspereau, are fish that move in from the sea to breed. These are called the anadromous species. Some, like the smelt, move into the lower parts of rivers to reproduce and quickly move out. The most important of our freshwater fishes are the salmonids. Generally speaking, Atlantic salmon juveniles and speckled trout occupy different niches within the stream. The trout

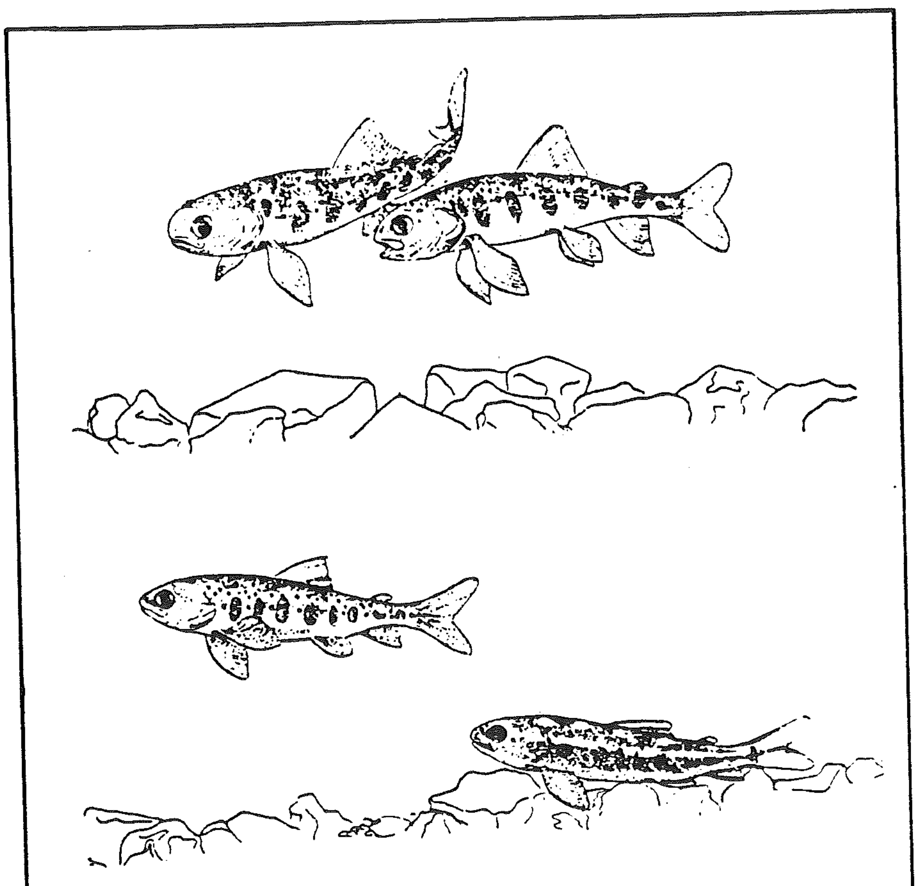


Figure 8. Territorial behaviour of young salmon. The intruder (above) is finally chased away by the original occupant of the substrate station. (From Keenleyside and Yamamoto, 1962)

juveniles are found in the upper regions of the watershed, in small cold streams with coarse rubble bottoms and plenty of cover provided by full forest canopy, deep undercut banks, roots, sunken logs, etc. The larger trout tend to occupy lake habitat or the deeper pools of intermediate streams. Atlantic salmon juveniles, by contrast, occupy open riffle areas where the shade of bordering vegetation often does not reach beyond 10-20% of the entire width. Juvenile salmon appear to make good use of interstices between bottom stones, not only to forage for food but to burrow for cover against freshets and predators. Late in the fall the fry and parr are found to spend more time deep within the substrate, an adaptation permitting great savings of energy at a time when metabolic activity is reduced and feeding is at a minimum.

CONCLUSION

The lakes and streams of Nova Scotia offer a great variety of habitat and, as yet, plenty of habitat for fish species highly prized for their recreation qualities. These habitats exist through a complex web of physical and chemical constituents more or less in equilibrium with one another. This cursory examination of the physical elements of lentic (lake) and lotic (stream) environments shows how easily this equilibrium can be lost through natural phenomena such as storm events, etc., but even more so through human intervention. This paper is meant to relay a message of caution for the protection of lakes and stream habitats for those who must carry out works or undertakings in or near bodies of water.

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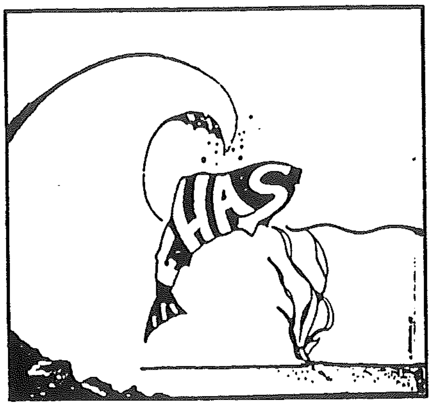

Effects of Physical Modifications on Freshwater Fish Habitat

Dale I. Bray

ABSTRACT

Useable fish habitat must be defined for a specific targetted species, for a specific stage in the life cycle of that species, and for a specific portion of the year. Fish habitat is often assessed in terms of the portion of the channel bed that has acceptable average velocity, depth of flow, water temperature, and type of substrate (channel bed material). Clearly other parameters, including suspended sediment concentration, dissolved oxygen, chemical constituents, hydraulic conductivity of the stream bed, can also be considered.

The basin above the length of the channel (reach) under study, supplies water, sediment, and organic matter in an amount and sequence that is dependent upon the local hydroclimatic regime and the geological setting. The channel geometry and the channel bed in the reach under study becomes adjusted to transport the excess water and sediment produced from the upstream drainage area. When the amount or sequence of the flow of water and/or sediment is modified through natural or man-made changes, the channel geometry and channel bed can be expected to undergo change to come into a new state of adjustment. In some cases modification to the channel downstream of the reach of interest can result in undesirable changes at the reach under study. Simple methods of estimating anticipated changes in channel slope and channel width are presented. Examples of potential impacts due to the construction of dams, gravel mining, cutoffs, channel straightening, and river diversions are illustrated.

Adequate flow of water through the bed materials at riffles is essential between the time of spawning and emergence of salmon fry in particular. Any modifications to the local groundwater flow system that results in a reduction of the hydraulic conductivity of the bed materials can be detrimental. An excess supply of sediment from upstream can result from near-stream or in-stream operations. These operations may be on an areal basis (forestry, agricultural, or major land development), or on a linear basis (highways, transmission lines, or pipelines). An outline of current research related to the influx of fine materials into gravel beds is presented.

The impacts of man need not be negative. Provided that funds and time are available, a team including biologists, engineers, managers, and special interest groups can bring about modifications to enhance or even increase the useable fish habitat for a particular targetted species. A biologically productive stream environment is one of extreme complexity and diversity resulting in interactions between the physical, biological, chemical, economic, and political domains.

Finally an outline of a methodology is presented for assessing useable fish habitat under current conditions and under proposed changed conditions.

INTRODUCTION

Productive fish habitat is dependent upon complex interactions between physical, chemical, and biological factors ranging from the macroscale of the basin to the microscale of the substrate (Figure 1). Without the physical reality of the flow of water in a channel, there would be no fish habitat. The purpose of this paper is to outline the primary physical factors that contribute to productive fish habitat and to indicate how man-made changes to the physical environment may degrade or enhance productive fish habitat.

THE DRAINAGE BASIN

The drainage basin supplies water, solutes, inorganic matter (sediment), and organic matter to a selected study reach (length of channel). Before commencing a study related to fish habitat in a reach it is important to appreciate the time distribution of each of the above variables. The **hydrograph** (discharge at a specific channel cross section versus time) and the **sedograph** (suspended sediment concentration versus time) are the most common sets of information required. The hydrograph consists of water that reaches the specified channel cross section relatively quickly from surface and near surface flows (i.e., direct runoff) and relatively slowly from groundwater flows (i.e., baseflow). An example of a typical hydrograph is shown in Figure 2a.

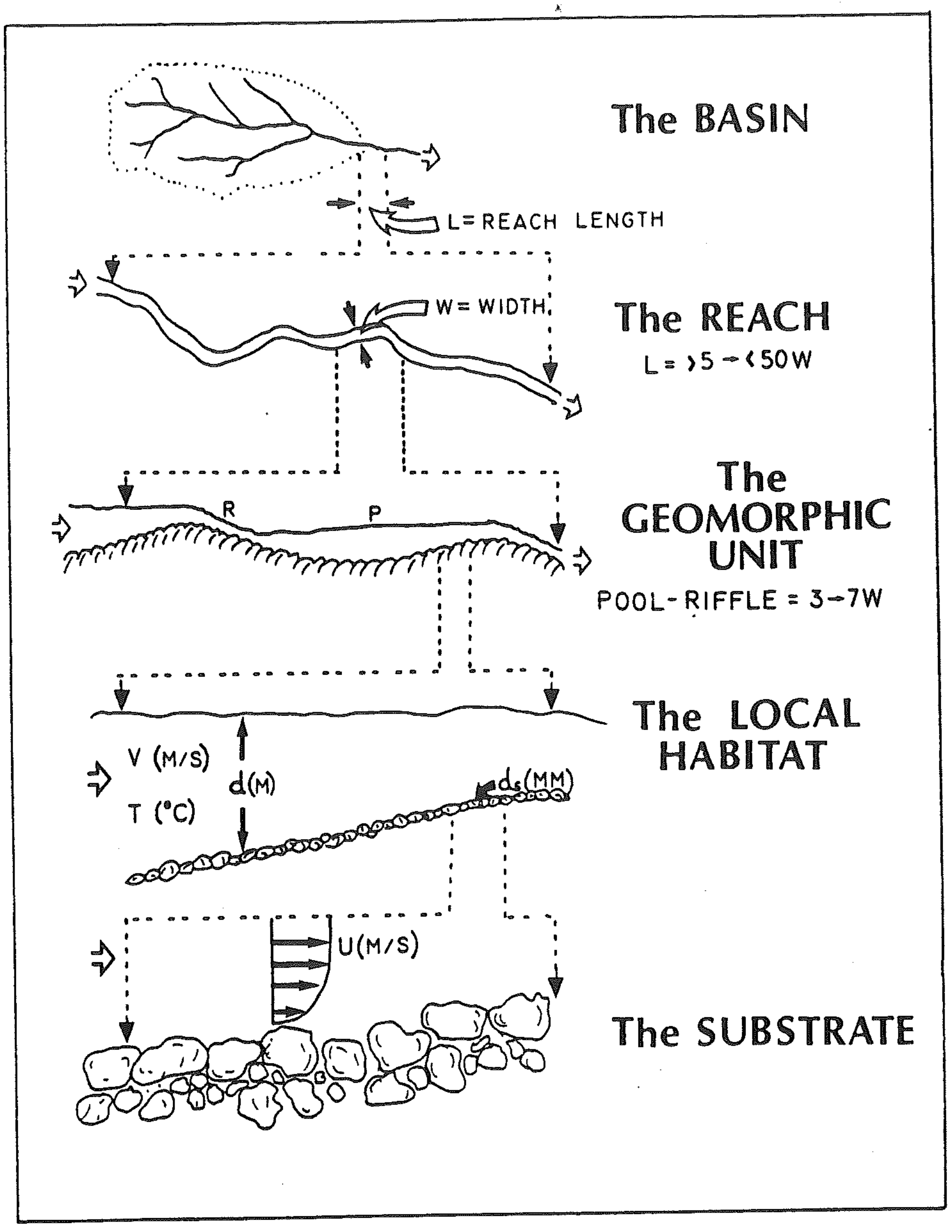

Figure 1. From the basin to the substrate: a view of fish habitat.

Another graph that is usually of assistance is the flow duration curve for all of the year or for a specified portion of the year. The flow duration curve provides a measure of the percent of the time that a particular flow is exceeded (Figure 2b). Usually hydrometric (discharge or flow) data are not available at the section (or reach) of interest and must be interpolated from nearby hydrometric stations.

The supply of sediment to the study reach from the basin is another important factor to consider when evaluating fish habitat. Sediment is primarily introduced to the channel from erosion of land surfaces remote from the channel, mass wasting (large inputs of material from hillslope failures, debris slides, etc.), erosion of the channel banks, and erosion of the channel bed (degradation).

Depending upon the size of the sediment and the available transport capacity of the stream, the sediment can be transported as bed load at and close to the bed or as suspended load in the flow. The sediment load can also be categorized by the source of the sediment. **Bed material load** is derived locally from the bed of the channel. **Wash load** is derived from sources remote from the local bed and does not normally interact with the local bed materials.

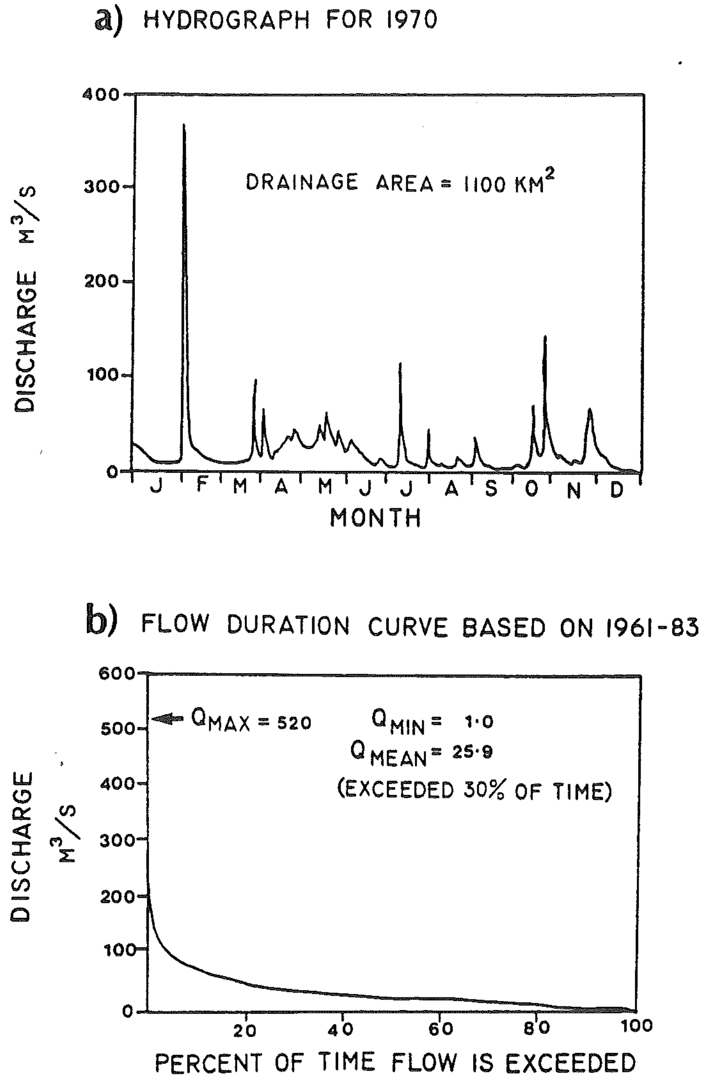

Figure 2. Typical hydrograph and flow duration curve at a hydrometric station (Kennebecasis R. at Apohaqui, N.B.).

THE CHANNEL BOUNDARY

In terms of fish habitat, the nature of the channel boundary is important. Sand-bed channels seem to be like "deserts" to most fish whereas gravel-bed channels seem to serve as "pastures" for many species of fish.

Sand-beds have particles with a relatively narrow range of sizes that typically has a log-normal distribution. Gravel-beds have a wide range of sizes that exhibit a bi-modal or a skewed distribution of the logs of the particle sizes. Gravel-bed channels are characterized by a single surface layer of relatively coarse material (normally greater than 8 mm). The large range of sizes on the surface of gravel-bed channels provides protected environments for young fish. The subsurface materials making up gravel beds have virtually no material in the clay and silt size range, that is less than 0.0625 mm. Typical grain size curves for sand-bed and gravel-bed channels are shown in Figure 3.

The surface layer (or armor layer) of a gravel-bed is categorized as either mobile armor or rigid armor. Mobile armor consists of clean material that is indicative of recent bed material transport. Rigid armor indicates that the surface layer has been immobile for some period of time. The openings between the larger particles are normally packed with fines. A rigid armor acts much like a pavement over which some coarser material can be transported but there is virtually no exchange of particles between the rigid armor layer and the overpassing sediment.

A mobile armor can commence to move (or interact with the flow) at some relatively predictable threshold for initiation of motion. It is more difficult to predict the threshold for movement of a rigid armor, but it will generally exceed that for a mobile armor by an appreciable amount.

Spawning normally takes place in gravel-size materials (2 to 64 mm). The same fish may move into cobble-bed (64 to 256 mm) or boulder-bed (greater than 256 mm) portions of the channel at later stages in its life cycle.

CHANNEL FEATURES

The pool-riffle sequence is a common feature of many gravel-bed streams. At low flows the pool (with relatively deep, slow moving water) and the riffle (with relatively shallow, fast moving water) provide a diversity of depth and velocities for fish. The riffle "controls" the water level in the upstream pool during periods of low flow, but the riffle often becomes "drowned out" at high flows. Characteristics of the pool-riffle sequence are presented in Figure 4.

Salmon place their eggs in a redd (nest) that is generally dug upstream of the control on a riffle. As a result of the drop in head across the riffle at low flows there is a subsurface flow of water through the riffle

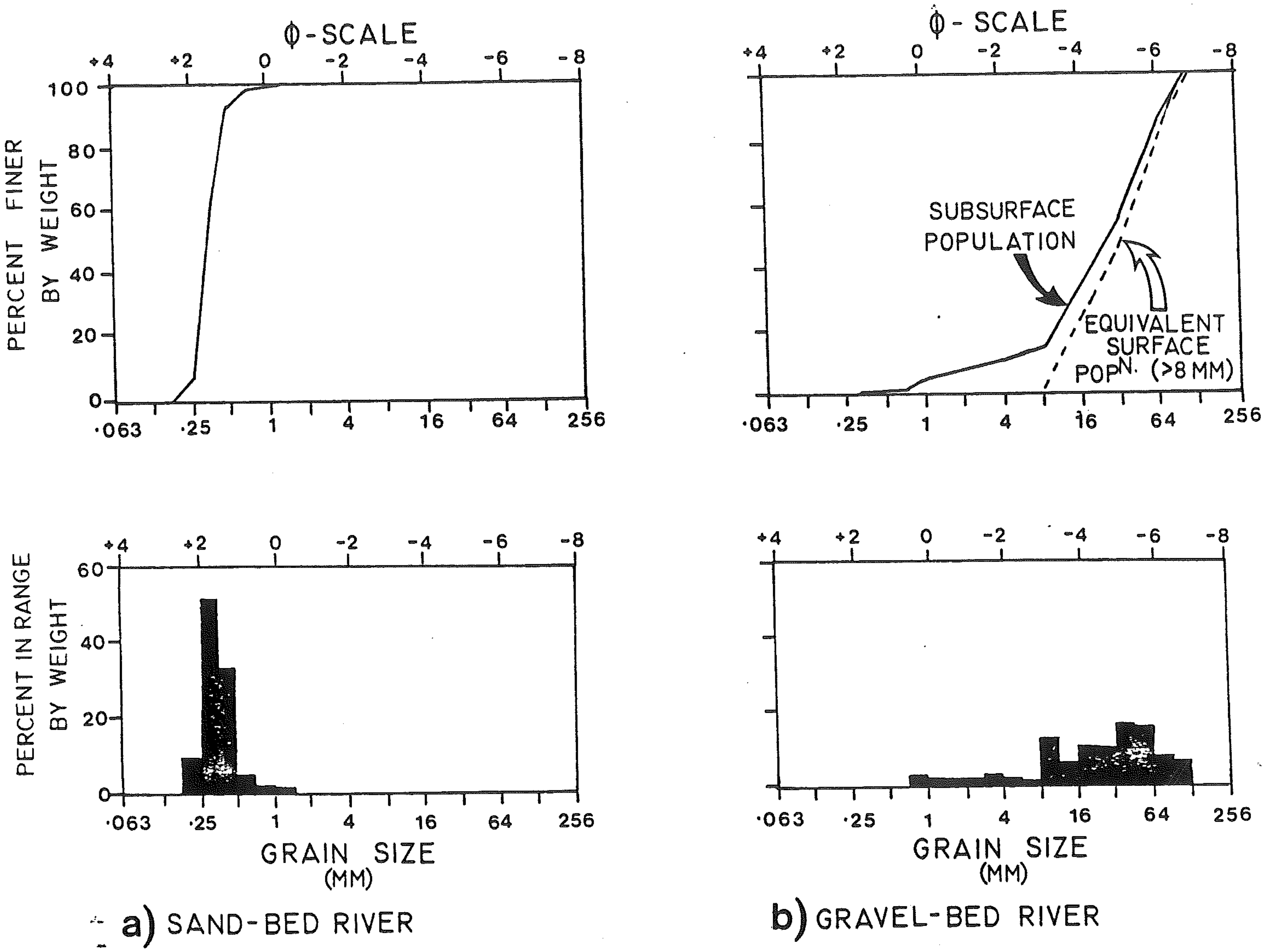

Figure 3. Grain-size distributions of bed material in natural channels. a) Sand-bed river (Saint John R. at Oromocto, N.B.); b) Gravel-bed river (Keswick R. near Zealand, N.B.).

which consists of a relatively permeable mixture of sands and gravels. This subsurface flow provides a "carrier" of dissolved oxygen and nutrients to the egg and it provides a means of transporting metabolic wastes away from the deposited eggs.

If fine material is transported downstream and infills the "open" gravels at the redd, the water cannot freely pass by the eggs. If the reduced subsurface flow is adequate for the eggs to hatch, the alevin (newly hatched fish) may not be able to emerge from the redd to the stream surface.

Although the pool-riffle sequence has been emphasized as a principal feature in rivers, the presence of obvious pools and riffles may not be too apparent in all streams, especially streams having relatively large bed material and slope. Neill and Galay (1) and Kellerhals *et al.* (2) present practical means of describing several channel features including pool-riffle sequences. Church and Jones (3) discuss bar features in gravel-bed channels.

BANK VEGETATION

The role of bank vegetation in small channels in particular is another important feature when evaluating productive fish habitat. If the root system of the bank vegetation penetrates the bank material to an appreciable degree, it can contribute to bank stability (4, 5). However, bank vegetation also is able to provide shade and to lower the water temperature during the summer months. Vegetation overhanging the channel provides input of organic material and

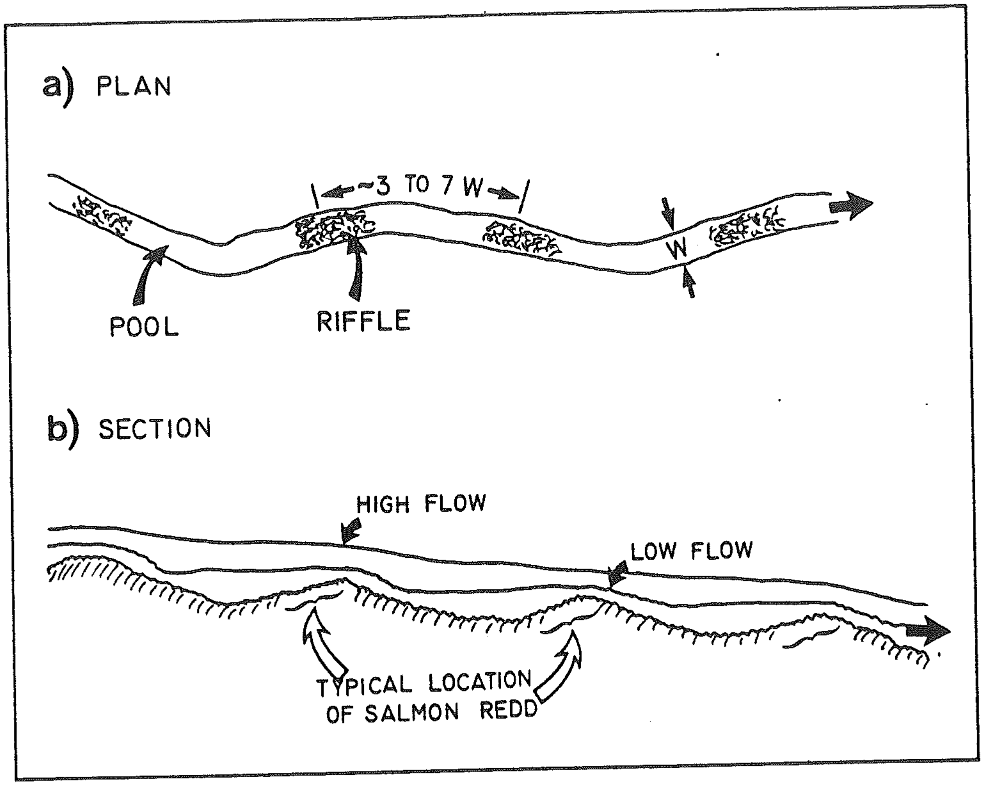

Figure 4. Characteristics of a typical pool-riffle sequence. a) Plan view; b) Longitudinal section showing water surface profile at low and high flows.

nutrients to the channel to support biota. Beschta and Platts (4) state that "detrimental changes in the productivity and composition of riparian vegetation can increase channel width, decrease stream depth, increase stream temperature in summer and decrease it in winter, and decrease fish food supplies."

CHANNEL ADJUSTMENT

Channels having mobile boundaries have adjusted their cross-sectional shape and size, longitudinal slope, and planform shape to conform to the existing hydroclimatic regime for a given geological setting. The channel at a particular site is able to transport through the specified study reach a range of flows of water and sediment associated with the particular hydroclimatic regime in the upstream watershed to establish a "quasi-equilibrium" state. If the hydroclimatic regime is changed through some natural or man-made cause, then the channel geometry and slope will normally adjust to a new "equilibrium" state. A river having mobile boundaries is dynamic, and adjustments can take place over time: hence the channel is said to be in a state of "dynamic equilibrium."

Channel adjustments can also take place in response to changes in the channel geometry or slope. Again these changes can be either natural or man-made. In most cases, man-made changes are most significant for those interested in conserving productive fish habitat.

Channel adjustments take place at several levels: formation or removal of bars; changing the channel cross-sectional properties; changing the longitudinal channel slope. The last means of channel adjustment is usually considered to be most significant since it can result in erosion or deposition of massive amounts of sediments over long lengths of the channel. The channel slope can increase by decreased channel meandering or by the erosion of sediment from the channel bed (degradation).

Lacey (6), Blench (7) and Vanoni (8) are a few among the many scientists and engineers who, over the last century, have studied aspects of river regime to develop means of predicting the response of a river to changes in the major controlling variables. One of the simplest and perhaps one of the most effective presentations to evaluate the anticipated adjustments of longitudinal channel slope in response to changes in discharge, bed-material size or bed-material load was given in 1955 by Lane (9). He presented a relationship (not an equation) as follows:

$$Q\,S \;\alpha\; d_s M_{bm} \qquad \ldots (1)$$

where: Q is the characteristic discharge of the channel (e.g., 2-year flood); S is the longitudinal slope of the channel; d_s is the characteristic bed-material size (e.g., median size); M_{bm} is the mass transport rate of bed material through the reach. The relationship indicates the direction of change that might be expected as a result of a man-made change. For example, if a dam having a relatively small storage is constructed in a channel and the characteristic discharge just downstream of the dam does not change appreciably, the bed material size remains the same and the mass transport rate decreases because of deposition in the reservoir, then the Lane relationship indicates that the downstream slope should decrease. This can occur through increased meandering or by degradation.

Lane presented six cases related to changes associated with mobile boundary channels as follows:

(1) Effect of decreasing flow by diverting flow from a river (aggradation below diversion),

(2) Effect of increasing flow by diverting flow into a river (degradation below diversion),

(3) Raising a local base level (e.g., building a dam),

(4) Lowering a local base level (e.g., draining a lake),

(5) Lengthening a channel (deposition and aggradation), and

(6) Shortening a channel (erosion and degradation).

Schumm (10) presented more complete estimates of expected changes of channel geometry and slope for sand-bed channels in response to changes in the flow of water and sediment.

Recently mathematical models have been developed to make quantitative estimates of changes in channel slope in response to changes in the magnitude and frequency of flows of water and sediment. Such models include HEC-6 (11), MOBED (12), and FLUVIAL-11 (13). These models, although based on generally accepted principles, have many limitations. Normally one will not have the data or financial resources to evaluate changes in the field on an operational basis through the use of mathematical models. In such cases trends can be established through the use of Lane's simple relationship.

Estimates of change in channel width can be made by applying the empirical regime equation for width; that is,

$$W = C\,Q^{b} \qquad \ldots (2)$$

where W is the average water surface width in a river reach and Q is the characteristic discharge. The constant "C" depends on the definition of the characteristic discharge (e.g., mean annual flow, 2-year flood, etc.), the type of material on the bed and banks of the channel, and the system of units. The exponent "b" is about 0.50 for most humid regions. Bray (14) found for gravel-bed rivers in Alberta that

$$W = 4.7\,Q_2^{\,0.53} \qquad \ldots (3)$$

where W is the reach averaged water surface width in m, and Q_2 is the 2-year flood in m^3/s ($r^2 = 0.96$ and standard error = 0.076 log units).

Such a simple relationship clearly indicates that mobile boundary channels can be expected to widen as the characteristic discharge increases (or vice versa). If the characteristic discharge is doubled, the channel width should increase by about 40 percent if it has mobile boundaries.

SOME EXAMPLES OF CHANGES TO THE PHYSICAL ENVIRONMENT

The following instances outline some of the impacts on fish habitat as a result of man-made modifications to the physical environment associated with the fluvial system. Watercourse alterations are controlled through acts such as the Clean Environment Act in New Brunswick and the Fisheries Act administered by Fisheries and Oceans Canada.

Channelization

There is a temptation to make channels straight and of constant cross-sectional shape. Long straight sections (or reaches) are characterized by flows of relatively constant depth and essentially constant velocity. The diversity of depths and velocities of the natural channel with its pools and riffles is significantly reduced in channelized reaches. Often the long straight channel (if not properly designed) will commence to meander or to degrade and revert to a channel with more diversity of flow depth and velocity.

Fish swim at a sustained speed without resting and a burst speed with rests between bursts. Each fish at each stage of development has a characteristic sustained speed and burst speed (15). If the time for a burst speed is not adequate to reach a resting place, then the channel upstream of the channelized reach is not accessible to the fish. In some cases, the placement of appropriately spaced large boulders in the channel or at the edge of the channel can provide resting places for fish (16).

Obstructions

There are many man-made obstructions to fish passage including access to culverts and fishway entrances at dams during the upstream movement of fish and passage over spillways and through hydraulic turbines during the downstream movement of fish (15). Engineering works can clearly limit passage of fish but cooperative work between engineers and biologists can usually lead to acceptable solutions.

Natural obstructions such as falls and rapids can make productive fish habitat inaccessible to fish. In this case, engineering works, such as fishways, can be constructed to increase the available fish habitat.

River Regulation

Water resource projects that result in extensive regulation of flows through the formation of large reservoirs can significantly alter the natural flow regime. The normal function of a reservoir is to store water in order to reduce the higher flows and to increase the lower flows. Since the peak flows from a reservoir are reduced, a gravel-bed channel downstream of the dam may "fossilize" because the peak flows are no longer high enough to transport the material in the bed of the main channel. The supply of sediment to the main channel from the tributaries will not change as a result of the modified flow regime in the main channel. As a consequence "alluvial fans" will form at the confluences of the tributaries with the main channel (17).

As a result of the reduction in the characteristic peak flows, the channel width will tend to decrease as predicted by the width-adjustment relationship (Eq. 2). These effects of large storages become less pronounced as one moves downstream of the dam on the main channel.

Although the area of the channel bed may be reduced somewhat due to the reduced flood peaks, the net effect of river regulation on productive fish habitat may be enhanced if the time for acceptable flow velocities and flow depth are increased.

River Diversions

River diversions can have physical effects on the aquatic habitat. The stream with increased flows will tend to widen and be characterized by greater depths and slightly higher average velocities. If the natural bed is near the threshold for transport, it may become mobile in response to the increased flows. Degradation may result under these conditions.

The fish habitat in the channel with the decreased flows is likely to be adversely affected. The lower flows will most likely result in reduced bed area having acceptable depth and velocity of flow, reduced bed material size (substrate), and increased low flow water temperature. Special efforts from a management point of view have to be made to evaluate the net effect of diversions on productive fish habitat for the desired species.

In addition to the changes in the physical environment resulting from diversions, desirable or undesirable species may be introduced to or from the diverted channels. Biologists have to address the problems associated with the colonization of a stream by a new species of fish or other biota.

Suspended Sediment

Significant quantities of fine-grained sediment (clay and silt sizes) can be introduced to the channel in response to natural causes such as contributions from gullies, mass failure of banks, etc. Man-made modification of the landscape resulting from areal developments (agriculture, urbanization), linear developments (highways, pipelines), or point developments (bridge piers, water intakes) can introduce amounts of sediment into the stream that may greatly exceed the amounts from natural processes for varying lengths of time.

In many cases associated with construction projects, the increased concentration of suspended sediments can be limited through the use of erosion control measures at the site or the use of sediment detention basins at a point before the outflow from the site reaches the receiving waters. In other cases, instream construction operations may only take place for a short period of time and may be scheduled at a time of year that results in the least disruption to fish habitat.

Suspended sediment in the water column can cause damage to fish gills, reduce light penetration and hence limit food intake for fishes that feed by sight. Normally fishes move out of areas that have concentrations of suspended sediment in excess of about 80 mg/L. Laboratory studies have shown that some types of fishes die in confined areas where the suspended sediment concentration is maintained above 80 mg/L (18). Regulations frequently set suspended sediment concentration limits in the order of 50 to 80 mg/L (19). There is often no indication if the limit is an incremental amount over the natural background concentration or if the limit is the total concentration. It is known that Atlantic salmon can successfully swim through estuaries such as the Petitcodiac River estuary where the natural concentration of suspended sediments is in the order of 50,000 mg/L for portions of each tidal cycle. Demonstration projects using caged fish should be carried out in this region to better define the upper limit and duration of suspended sediment concentrations for a specific life stage for a specific species of fish.

Influx of fines into the gravel matrix

One of the major concerns related to productive fish habitat is the control of sands and silts from entering the gravel matrix in zones where redds are formed. The influx of fine material can restrict the flow of water by the egg and can also prevent the alevin from emerging from the redd to the gravel bottom of the channel.

Research has shown that salmon select those areas of the gravel bed that are characterized by relatively high hydraulic conductivity for spawning (20). If fine material clogs the gravel, then portions of bed will be lost as productive fish habitat.

Laboratory experiments have shown that an influx of 1 to 3 mm particles into open gravels such as those found in salmon redds can result in a survival rate of only 50 percent if the fine material makes up 30 percent of the original mass of open gravels (21). Research is currently underway at the University of New Brunswick to evaluate the mechanism by which fine materials clog an open gravel matrix such as those found in salmon redds.

In some cases large amounts of sediment are introduced into the channel such that the productive gravel beds are completely blanketed (22). Normally the surface of these beds are "cleaned" during periods of peak flows, however the influx of fines between and below the upper gravel layer can have long lasting negative effects from a fisheries point of view.

Water Temperature

Fish can acclimatize to normal seasonal variations in water temperature. The temperature of the water during the low flow periods is governed by the relative contribution of the flow from groundwater and the relative shading from bank vegetation.

Groundwater enters the channel bed in humid areas with effluent streams (streams with groundwater discharge toward the stream). The groundwater has an essentially constant temperature throughout the year. In many cases, the groundwater temperature is about 2°C warmer than the mean annual temperature (23) although this depends on the depth of withdrawal and the nature of the flow system.

Zones of groundwater discharge into the stream provide warm spots during the winter and cool spots during the summer. Changes in the groundwater flow regime (although difficult to bring about) could modify the freshwater fish habitat.

The formation of shallow reservoirs causes a substantial rise in water temperature. A recent study of small P.E.I. impoundments by Thompson (24) indicates that the outlet temperature may be as much as 13°C greater than the inlet temperature.

Removal of bank vegetation along a channel not only increases the potential for bank erosion and decreases the cover for fish, but also reduces shading with an associated increase in water temperature during the summer months (25).

QUANTITATIVE EVALUATION OF USEABLE AREA OF CHANNEL BED FOR FISH HABITAT

In 1980 Karr and Dudley (26) stated that the four major components of a stream system which determine the productivity of a fishery are: flow regime, physical habitat (channel form, substrate distribution, and riparian vegetation), water quality, and energy (watershed inputs in the form of sediments, organic matter, and nutrients).

The Cooperative Instream Flow Service Group in Fort Collins, Colorado has developed a procedure for defining useable area in terms of four parameters: average velocity, depth of flow, characteristic substrate size, and temperature (27). A characteristic relationship showing relative suitability of each of these four parameters is developed for each life stage of each species of interest (28). Typical habitat evaluation criteria for a specific life stage (adult) of a specific species (brown trout) are shown in Figure 5. When evaluating useable area, the study reach is broken into small elements of area across the channel and along the channel. A weighted useable area is determined for the reach for each selected discharge by using appropriate habitat criteria similar to those in Figure 5.

When carrying out such studies, it is important to be able to estimate instream conditions for a "wet" year (during which time channel readjustment can take place), for an average year (the basis for establishment of the idealized "carrying capacity" of the stream), and a dry year (required for minimal survival conditions) (26). In addition, the modified flow regime resulting from some engineering works also has to be estimated and applied to evaluate the change in the weighted useable area of the study reach after the proposed project becomes operable.

Such techniques are time consuming to apply and are in the development stage. However, techniques like the weighted useable area method will most likely become more widely used in the future when evaluating the impact of development on the physical aspects of fish habitat (29).

SUMMARY

The physical environment has a dominant role when defining the available fish habitat for a specific life stage for a specific species of fish in a specific study reach.

The sequence of inputs of water and sediment from the basin above the study reach must be known or synthetically developed from adjacent basins. The

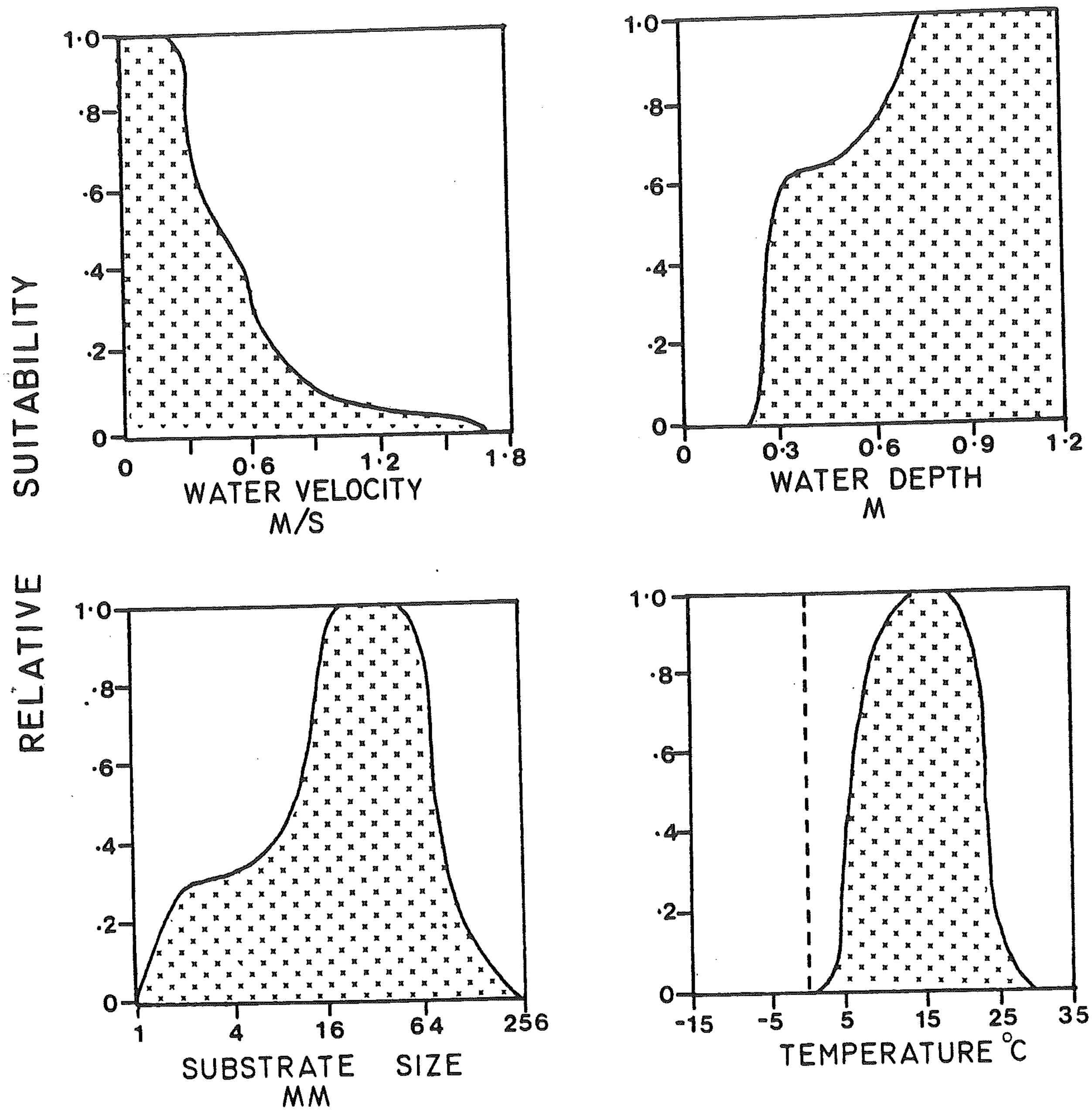

Figure 5. Typical habitat evaluation criteria for a specific life stage (adult) of a particular species (brown trout). (After Bovee 1982)

role of bed material (substrate), pool-riffle sequences, riparian vegetation must all be considered when evaluating productive fish habitat.

When changes are considered in any part of the drainage system, it is important to evaluate the probable type and extent of the physical changes expected to occur in the study reach. Simple trend estimates made by Lane's relationship may be adequate in many cases.

Many of the effects of man-made changes to the physical environment in streams and rivers can be partially or fully controlled by giving some forethought to the implications of the proposed changes.

As more time and effort are directed toward the evaluation of the physical environment in streams, quantitative approaches will become adopted to estimate the useable bed area for a specific life stage of a specific species of fish. Such methods will probably be extended to consider the chemical and biological environments also.

The shared expertise and experience of the biologist, the engineer, and the manager can be directed toward the policy objective of establishing "a net gain of habitat for Canada's fisheries resources" (30).

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The Links Between Terrestrial Vegetation and Fish Habitat

Robert J. Rutherford

ABSTRACT

Terrestrial vegetation is a dominant feature of the Nova Scotia landscape and as such plays a major role in the ecology and physical structure of the watercourses draining the province. The links between vegetation and fish habitat are explored using two categories: (1) indirect links - involving the hydrologic cycle, energy cycling, and nutrient flows, and (2) direct links - such as bank stabilization, shading, large organic debris, and cover. The value and basic theory behind riparian zones or greenbelts and their management, in connection with various land uses, are briefly outlined.

INTRODUCTION

Ecology is often studied in convenient packages selected in an attempt to limit the complexity of the study or to suit the information needs of a particular interest group. As a result people have a tendency to think of forests, lakes, streams, estuaries, oceans, farm fields, and urban areas each as their own separate ecosystems with inputs and outputs of unrecognized value or impact on the receiving systems. For example outputs from a forest ecosystem altered by cutting might include such things as increased peak runoff, increased water temperature, and decrease in litter fall, all of little importance to someone interested in the establishment of a new stand but of great importance to the aquatic environment. In resource management, which includes all types of land use, this separate system attitude has spilled over into our goals and objectives. The result has been that some resources are managed to obtain their optimum production at the lowest cost with little regard for the losses caused in other habitats. Inevitably this has led to conflicts between the various sectors and interest groups.

Habitat Management's Policy, as presented at this seminar, could be mistakenly interpreted as perpetuating the single interest view. In fact this is not the case at all.

Those studying aquatic ecosystems have recognized the fact that the health of the system is very dependent on air quality and the health of terrestrial ecosystems. Actually there are no divisions between them at all. All ecosystems are inseparably linked through physical and biological processes. Moreover, the aquatic environments reflect the developmental state and condition of the watershed, drainage streams and airshed. To truly gain an understanding of what is happening one eventually has to expand the view to the biome or planet level.

THE WATERSHED VIEW

Practically speaking we cannot manage the whole planet as one unit. Consequently, we use the concept of watershed management in relation to land. Watersheds, simply defined, are the areas of land and the airshed above it whose boundaries are defined by the movement of water into a given watercourse. In simple watersheds the movement of surface runoff and ground water define the same area and for this discussion this is all we need to consider. Most of the natural processes and cycles can be viewed as taking place entirely within a watershed unit but we must not forget that there are major interchanges between watersheds, largely through weather systems.

When we look at watersheds in Atlantic Canada their common and most obvious feature is the terrestrial vegetation. This vegetation is not just the product of the physical world, it interacts with all physical and chemical processes and exerts major controls on them.

HYDROLOGIC CYCLE

The first among these interactions has to be those connected to the hydrologic cycle (Figure 1) (1). The relationship between precipitation and the freshwater

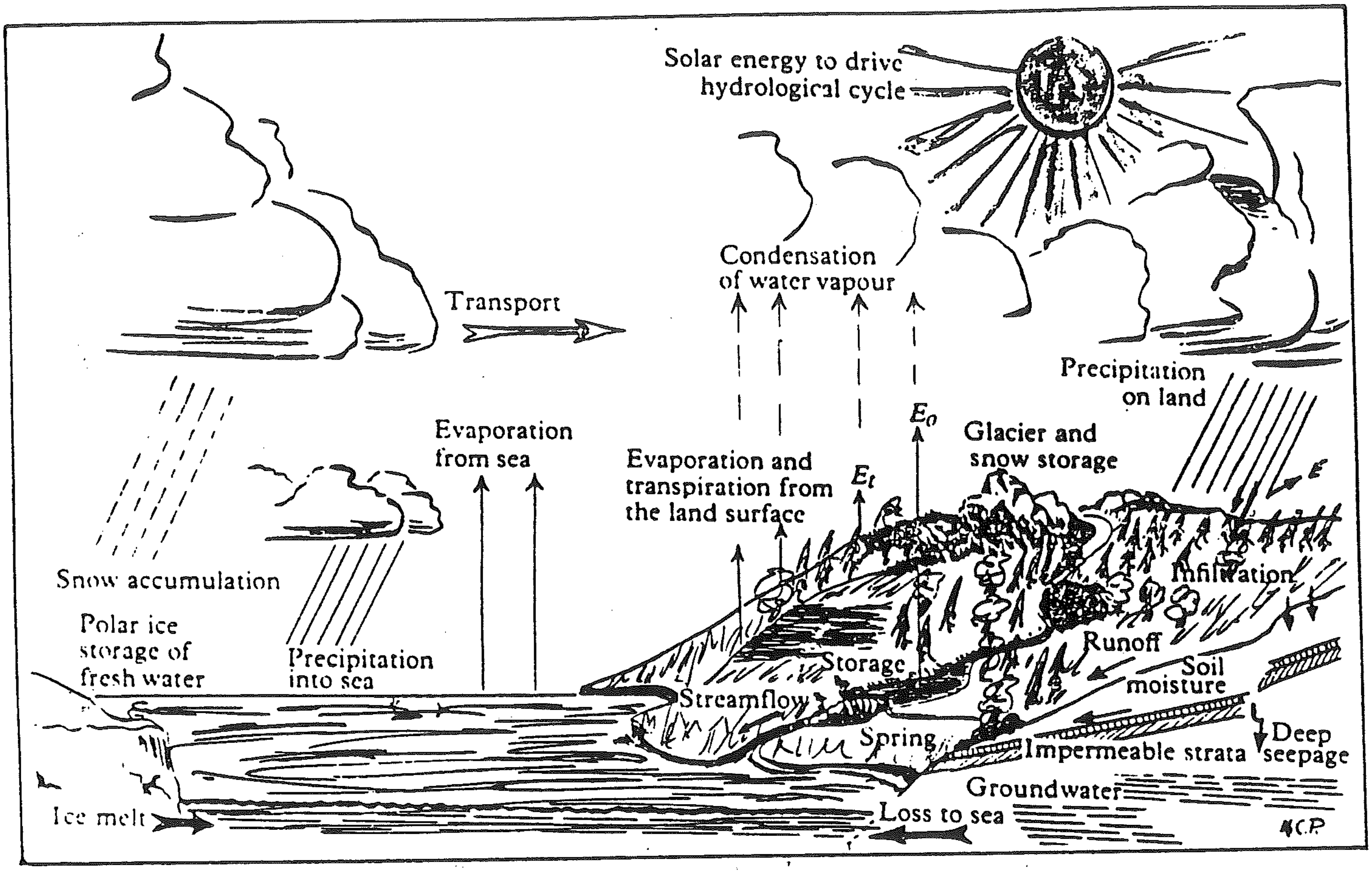

Figure 1. The hydrological cycle.

environment is obvious but the role of terrestrial vegetation may not be.

The hydrologic cycle is driven by energy from the sun. In fact, this cycle is the largest single user of the sun's energy reaching the earth's surface. The reason for this is that it takes a lot of energy to evaporate water and lift it into the atmosphere. This energy is returned as heat when the water condenses and from friction with the air and the surfaces it hits and flows over on its way to the sea. Differential heating of the earth's surface by the sun causes the movement of water through the atmosphere as weather systems. This has the effect of washing the air, since precipitation tends to condense around dust particles and to dissolve atmospheric gases. Precipitation falling on an undisturbed watershed hits either vegetation or a water-course and contributes significantly to the chemical composition of both of them. When we look at precipitation falling over land we find that one of four things may happen:

(1) Some of the water evaporates back into the atmosphere;
(2) some of the water lands on vegetation, wetting the surface of leaves and branches and evaporates;
(3) some of the water falls from layer to layer in the vegetation until it reaches the ground; and
(4) the rest hits the ground directly.

The first possibility happens in all cases, the second varies in the quantity of water returned to the atmosphere, depending mainly on the surface area presented by the vegetation. A grass pasture presents less area than a multilayered layered forest stand: as a result less water from a given storm event will reach the ground under forest cover. In the third possibility, the precipitation will reach the ground over a period of time as it drops through the layers of vegetative cover, thus slowing the rate at which the water reaches the ground and reducing the impact of the raindrops. Again this is more pronounced the more layers of vegetation present. The rest of the water hits the ground directly.

Any rain drop falling more than 7 m (21 ft.) has reached its terminal velocity of approximately 7 m/sec. (25 ft./sec.) and if we consider a storm producing 2.54 cm (1 inch) of rain, 103,000 kg (226,400 lb.) (2) of water per acre would have hit the surface. Where there is dense vegetation these forces are absorbed by the leaves, branches, or organic debris covering the ground. In effect mature forests protect the soil by mulching the forest floor. Soils unprotected by vegetation take the full impact of precipitation.

The damage caused by raindrops hitting the soil at high velocity is the first step in the erosion process. We may think of rain drops as miniature bombs. They shatter soil granules and clods, reducing them to fine particles and in turn reducing infiltration. A rain drop hitting wet soil forms a crater, compacting the area immediately underneath the center of the drop, moving detached particles outward in a circle around this area, and finally meeting sufficient resistance to be deflected upward. Raindrops hitting a soil surface that is covered by a film of water, churn up the soil so that the surface film becomes quite muddy. As this muddy water infiltrates into the soil the fine particles are filtered out in the surface layer. The infiltration of the water and the compacting and puddling action of the raindrops combine to form a layer of soil which has a much lower infiltration rate.

When the rainfall exceeds the rate of infiltration, depressions on the surface fill and overflow to cause surface runoff. During the rain the runoff is splashed and resplashed millions of times by falling raindrops. This breaks up the soil particles it is carrying into smaller and smaller sizes and helps keep them in suspension. Thus a thin sheet of water with direct impact of rain will carry a much heavier silt load during a storm.

This is often called **sheet erosion**. Sheet erosion removes the lighter soil particles, organic matter, and soluble nutrients from the land and is thus a serious detriment to soil fertility. Vegetation protects against sheet erosion by:

(1) absorbing the impact of the rain, so there is no compaction or displacement of soil particles,

(2) covering the soil surface so that wet soils and those with a film of water are not impacted by drops and thereby stopping the break down of particles and movement of fines,

(3) improving infiltration rates through increased holding capacity of organics, root channels, enhancing soil development processes which yield soil aggregates and clods, and improving habitats for microbes and burrowing creatures from earthworms to rabbits.

The infiltration of water is also improved under dense and layered growth since the slower introduction of water to the ground and increased holding capacity of the organic materials help to keep the infiltration rate from being exceeded.

As surface water accumulates it moves downslope. The surface is almost always irregular and surface areas a few feet square generally exhibit in miniature the drainage patterns of a major watershed. Each small portion of runoff takes the path of least resistance, gaining velocity as the depth of water and slope increase. The erosiveness of flowing water depends upon the velocity, turbulence, and the amount and type of abrasive material it transports. Vegetation has already acted to reduce surface runoff and abrasive materials, now roots, stems, and organic debris on the ground hold the soil, reduce velocities through ponding and stop channeling of the flow over erodible soil. Flows are slowed as they make their way to stable surface or near surface channels. Without the intervention of vegetation soil particles are transported by a combination of surface creep, saltation, and suspension, resulting in rill erosion. **Rill erosion** is the development of small well defined channels. The larger eroded channels resulting from continued erosion are called gullies.

Deposition is the end result of erosion. The soil particles deposited by flowing water are normally sorted by size as velocities drop and the heavier particles fall out. Erosional debris, deposited where it is not wanted, damages many resources through effects ranging from the suffocation of the roots of forest stands, to the damaging of crops and pastures by covering fertile soils with coarse material, to being a major pollutant degrading our water resources and fish habitats.

Not all vegetation is equally effective at controlling erosion (Figure 2) (2). Forests in rapidly growing and mature stages are the best at controlling surface erosion because of the well developed duff layer, followed closely by a healthy dense growth of grasses. The protective layer of vegetation becomes progressively less effective as density decreases to row crops and fallow or exposed soils. Grasses planted on bare soils increase the effectiveness of erosion control as the turf develops, usually reaching the seeded pasture levels in Figure 2 after four complete growing seasons without major disruption.

The water which has infiltrated into the soil changes in its chemical composition as it seeps through the soil horizons often changing in pH and dissolved nutrients, minerals, and organic compounds as it interacts with the complex soil ecosystems. Much of this water is taken up by the roots of plants, the nutrients used, and the water released to the atmosphere through a process called transpiration. The remaining water seeps in a downhill direction to resurface as soil moisture, or more importantly as springs and seeps contributing to stream flow. Springs in watercourses are important to the stream ecology by contributing nutrients, helping to regulate water temperatures, providing spawning sites for trout, and provide base flows which result from the slow long term release of water from the watershed. How much of a stream's flow comes via groundwater varies widely, depending on factors such as geology, soil depth, and soil permeability, but land use is quickly becoming the regulating factor in many of our watersheds.

ENERGY CYCLE

The sun's energy also drives another process vital to all life which is called **photosynthesis**. Photosynthesis may be defined as the process by which solar energy is utilized in the conversion of carbon dioxide and water into sugar. In almost all cases this takes place in the presence of chlorophyll, the green in green plants. This is a very simple view of a very complex process which in ecological terms can be called primary productivity. Algae, mosses, and floating and rooted plants along the shores of lakes and wetland areas produce the majority of organic material that fuels the aquatic food chain wherever there are sufficient direct sunlight and nutrients to support good growth of the plants. However, there is another major source of plant material to support the aquatic food chain and that is the terrestrial vegetation. In a study conducted on Bear Brook, a small New England stream, it was found that only 1% of the total organic matter in the stream was produced by upstream plants (3). The rest came from terrestrial sources: 44% from litter and throughfall from the adjacent forest, and the other 55% carried in by surface and subsurface flows. The majority, 66%, of this input washed downstream to other areas while the remaining 34% was used by consumers in the study reach. Clearly the input of organics from the surrounding land is critical to the productivity of these small streams which on the basis of production to surface area are much more productive than the larger bodies of freshwater.

Well-developed terrestrial vegetation establishes nutrient cycles which are very efficient at ensuring there is little loss through leaching processes. This control of dissolved nutrients by the vegetation is an important factor in the growth of instream plants. Disruption of the vegetation results in less developed cycles, as happens in forest clearcutting or farm land clearing, and produces an increased input of nutrients to the aquatic environment.

THE RIPARIAN ZONE VIEW

As one moves closer to the watercourse the influence of the terrestrial vegetation becomes more pronounced. In most cases the detrimental impacts of vegetation removal elsewhere in the watershed can be mitigated to a point where they are within a tolerable range. The one exception to this is the loss of infiltration capacity which reduces runoff volume and the recharging of the groundwater. Vegetation along

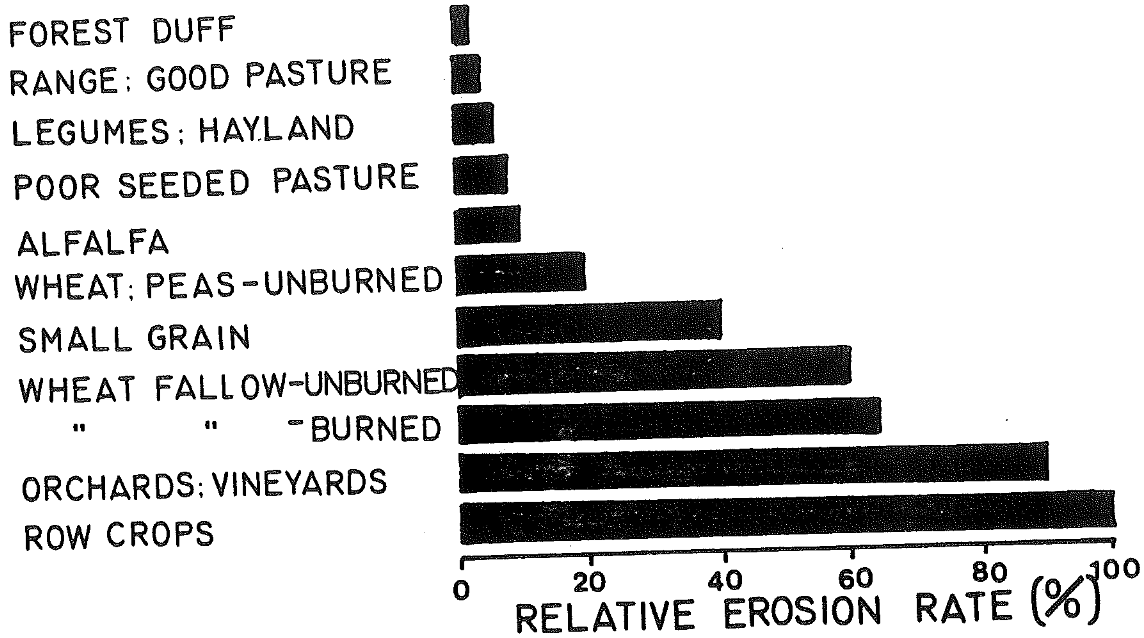

Figure 2. Relative erosion rates under different streamside vegetation covers.

watercourses also has some direct influences on the aquatic environment.

We are all familiar with the fact that it is cooler in the shade because the direct rays of the sun are blocked. Actually plants moderate the temperature changes of things underneath them, keeping them cooler by day and warmer at night as well as slowing the rate of temperature change. The effect on watercourses is dramatic and keeps water temperatures within optimum growing conditions for salmonids. This is particularly critical during times of warm weather and low flows. In winter this same moderating influence reduces the chance of stream bottom freezing and damage to overwintering habitat and incubation areas.

Organic nutrient energy flow comes largely from the immediate area of the stream. In the Bear Brook study mentioned earlier, 44% of the organics entering the stream came from throughfall and litter (twigs, leaves, and needles). Much of the remainder was introduced through surface runoff washing in materials from the forest floor and dissolved organics from the riparian areas.

Plants along the banks provide habitats for insects which fall into the water to become the major food source for fish during certain periods of the year.

Trees, shrubs, and grasses along the banks of streams hold the soil with their roots and reduce velocities over mineral soils with their leaves and branches. The erosion control this provides helps control stream siltation and builds stable banks, which in turn promote stream flow conditions that create fish habitat. Large well-rooted vegetation will form a stabilized root mass on the surface allowing the flows to cut out material from beneath them. These under cut banks and overhanging vegetation close to the water surface provide excellent cover for fish. Where banks have been broken down or the river has become wider than it should be, the establishment of the proper vegetation will restore both the bank height, by trapping moving material from the stream, and in turn reestablish a proper stream width. With stable banks built up to the flood plain level, a stream width is eventually established which gives a cross section able to carry the 1 in 2 year storm. Velocities at this bank during full flow are the ones that will develop the bedforms (pools, riffles, and runs) needed for excellent fish habitat. So bank vegetation works with the running water to create fish habitat. Most watercourses in the maritimes have bottom materials of gravel, cobble and rock in the right proportions to form the stable bedforms under the flows the channel has to carry in all but low frequency flood conditions. Most but not all. Some watercourses have bottom material which is too small to provide stable bedforms under the local stream gradient conditions and as a result form wider than normal channels with a featureless run for a bottom. Terrestrial vegetation has a role to play here too. Under natural conditions climax forests along the banks provide a slow but continual input of large organic debris as windfalls and branches. This material becomes incorporated in the stream bed by the water flow. This produces a stream bottom which resembles steps as the flow excavates pools and piles washed gravel against the logs to form spawning and rearing areas. Large organic debris is important in other watercourses as well to provide overhead cover for fish and shelter from high velocities. Forest harvesting practices in the past have resulted in younger, more even-aged stands along the streams or the removal of mature trees before they can fall. This, in combination with stream clearance programs, where this material was cut up and winched out to improve flows and fish passage have allowed some stream habitats to degrade.

In winter the stable channel, consistently shaded along its length, will help to ensure a slow even ice break up reducing the likelihood of ice jams that cause flooding.

Well established vegetation on a flood plain prevents erosion of the very sensitive saturated soil. In addition, if the vegetation is shrubs or trees, it will slow the velocity of flood waters reducing the erosion potential and actually causing the materials carried by the flows to drop out. Debris carried by the flows will be filtered out before it causes damage in fields or at stream crossings.

RIPARIAN AREAS: HOW DO YOU MANAGE THEM?

Riparian zones are identified by the presence of vegetation that requires free or unbound water or conditions which are more moist than normal. Since available water is the basis of all life, the easier access to it in these areas leads to more diversity in plant life and the development of critical habitats for fish and wildlife.

If riparian vegetation is so intimately connected to fish and wildlife habitats then how do we manage it to optimize the production of all the resources using these areas? This question has been answered in many ways in the past, including the following:

- 30 m to 45 m exclusion zones along all watercourses leading to the natural development of forest growth.
- Variable width exclusion zones depending on bank slope.
- Formula for the calculation of width based on such things as angling success, scenic values, and river width.
- 75 m selective cutting up to 40% of the basal area in the outer 50 m and no cutting in the other 25 m.
- A permit could be required to modify vegetation within 30 m of a watercourse. The amount and method would be specified.
- A 20 m zone along all watercourses on the forest resource base maps and a 10 m zone along the others.
- Finally a most promising proposal is to base land use guidelines on measures of land sensitivity to environmental disruption.

These suggestions all contribute to habitat protection in their own way, but none are perfect. Currently it is clear that there is a need for a workable policy and set of regulations defining the proper management of riparian areas to protect and enhance water quality, fish and wildlife habitats, and recreational values in Nova Scotia. At the present time the land owner, developer, planner and contractor have to decide how best to protect these resources so that they do not break fisheries or environmental laws.

It is this Department's policy to help you with these decisions through integrated resource planning on a regional, sector or watershed basis.

In summary, the fish habitat connection to terrestrial vegetation needs to be taken into consideration when working around watercourses. Terrestrial vegetation has the following influences:

(1) Provides shade to regulate water temperature.

(2) Stabilizes the banks reducing erosion, or actually building banks which in running water contribute to the development of fish habitat.

(3) Is a major source of primary productivity to fuel the food chain.

(4) Stabilizes flood plains and soils throughout the watershed reducing erosion.

(5) Regulates watershed runoff, reducing peak flows and slowing snow melt.

(6) Influences water chemistry, providing desirable characteristics.

(7) Riparian areas provide the conditions for more diversity in plant and animal species, which is important to the ecological stability of the area.

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Impacts of Silt on Fish and Their Habitat

David L. Morantz

ABSTRACT

Siltation is the most common and, overall, the most destructive aquatic pollutant in Nova Scotia's rivers. Human activities including urban development, forestry, mining, road construction and agriculture often result in erosion and subsequent stream siltation far exceeding that which can occur naturally. Trout and salmon are coldwater species which depend upon clean, well oxygenated water and a silt-free gravel substrate for spawning, egg incubation and juvenile rearing. As adults, they are tolerant of relatively high silt levels for short time periods, but such tolerance is very limited in the egg, larva, and juvenile life stages. Silt affects fish and other aquatic organisms both directly and indirectly, in settled and suspended forms by: reducing primary production; reducing aquatic insect production or causing a shift to undesirable species; clogging and abrasion of gills; smothering fish and invertebrate eggs and larvae; entombing swim-up fry; obliterating gravel substrate habitats; inducing behavioural modifications, including avoidance of silted habitats; affecting prey capture due to reduced visibility, and increasing the susceptibility of fish to disease, predators and reduced oxygen levels. In Nova Scotia streams, siltation due to forest road construction can continue to have negative impacts on salmonid populations for at least a decade after construction. Studies have shown up to 85% mortality of salmonid eggs with only moderate silt deposition. Survival of emergent fry is inversely correlated with the percentage of fines in the substrate. Siltation due to most streamside and instream disturbances can be avoided if environmental construction practice guidelines are followed. Examples of appropriate mitigation methods are provided.

INTRODUCTION

Sediment is found in all brooks, streams, rivers and lakes. It is inorganic, particulate material originating from the weathering of rocks and soils in a watershed or the erosion of unprotected streambanks and floodplains by flowing water. In small amounts, sediment is harmless to aquatic organisms; in large concentrations it is a serious pollutant, threatening the productivity of the freshwater environment.

Erosion and subsequent stream sedimentation have been exacerbated by numerous land use practices which expose soils to precipitation, runoff and wind. This process is insidious, since it is often unspectacular and goes relatively unnoticed. In fact, sedimentation of our rivers has continued for so long, it is often considered completely natural that streams appear brown and turbid when it rains. However, damage to fish populations from the acceleration of the erosion and sedimentation process is often widespread and permanent (1).

Sediment is composed of particulate clay (less than 0.004 mm), silt (0.004-0.06 mm) and sand (0.06-2.0 mm) (2). All three size fractions are either carried by flowing water in suspension or settle (at variable rates) to the stream bottom where water velocities are reduced. Where silt (the word "silt" is often used to describe all fine inorganic material) becomes deposited on a gravel substrate, it fills interstitial spaces and in large amounts, completely blankets the stream bottom.

Brook trout (*Salvelinus fontinalis*) and Atlantic salmon (*Salmo salar*) are species whose freshwater life stages are highly sensitive to the direct and indirect impacts of silt. While their steady population decline in Nova Scotia can be attributed to several factors, the effects of silt described in this paper and the widespread siltation of streams throughout the province (3) suggests that this pollutant has been a major contributing factor. Because salmon and trout are both prized sportfish having aesthetic, social and economic importance, they are used in this paper as indicators of the impacts which can result from excessive siltation.

Life Cycle and Freshwater Habitat Requirements

During autumn, adult female trout and salmon deposit their eggs in depressions or **redds** dug in clean stream gravel, generally in the mid to upper portion of a watershed. These eggs develop over the winter and spring buried in the substrate. There they depend on the continuous replenishment of oxygen brought by water flowing through the gravel. The sac-fry or alevins which hatch in late spring remain within the protective cover of the gravel, emerging only when their yolk sacs have been completely absorbed. As they grow and their swimming ability improves, these predatory fish begin to feed actively on aquatic invertebrates and terrestrial insects which fall into the stream. Juvenile salmon, now called **parr**, remain dependent on the gravel and cobble substrate in riffles and runs for shelter from predators and excessive water velocities, for overwintering cover, and because such areas tend to be rich in aquatic invertebrates favoured by these fish (4). Similar habitats are selected by young trout except that they prefer somewhat quieter stream reaches adjacent to pools.

After two years (normally) in fresh water, salmon parr (now called **smolts**) turn silver in colour and swim downstream to the sea. There they grow rapidly due to the abundance of available food. Brook trout can be subdivided into two categories; those that reside permanently in fresh water and those that spend their adult lives in salt water. The cycle is completed when adult fish ascend river systems in search of suitable habitat to spawn.

SEDIMENT EFFECTS

The fresh water stages of both salmon and trout are inextricably linked to clear, well oxygenated water and a stable, clean gravel substrate. Sediment damage to this habitat directly and indirectly impacts upon individual fish and the productive capacity of affected streams.

Direct Effects on Fish

Suspended sediment in high concentrations can be directly lethal to fish by damaging their gills (5, 6). Silt particles cause abrasions on sensitive gill tissues as the fish breathes, causing the production of increased amounts of protective mucus. If silt levels are high and are prolonged over a long period, sediment particles stick to the mucus in such large quantities that the gill no longer serves as a respiratory surface and the fish suffocates (5).

The literature contains conflicting evidence on the lethality to fish of suspended sediment (1). In an experiment involving 16 warmwater species, Wallen (7) could not detect any behavioural effects on fish until suspended sediment concentrations exceeded at least 20,000 mg l^{-1}. Further, mortalities did not occur until suspended sediment concentrations reached 175,000 mg l^{-1}. Conversely, Phillips (6) reports significant mortalities in rainbow trout fingerlings exposed to silt concentrations of only 1,000 to 2,500 mg l^{-1}. Similarly, Herbett and Merkens (8) found that 270-810 mg l^{-1} of suspended sediment for ten days was lethal to rainbow trout. It is apparent that there is wide variation in the tolerance of fish to suspended sediment. Warmwater species generally inhabit waters with naturally high levels of silt and are therefore adapted for survival in such conditions. Coldwater species, such as salmon and trout, typically are found in rivers with little turbidity. These fish are sensitive to elevated levels of silt and are adversely affected by it, particularly if high turbidity persists for several days.

It is also true that large fish are more tolerant of suspended sediment than juvenile fish of the same species. This is evident from the life history of the Atlantic salmon inhabiting the Bay of Fundy area. Adult fish will readily swim through highly silted waters in the Bay in their spawning migrations. Similar silt concentrations would be lethal to juvenile salmon.

It is not possible to predict what level of suspended sediment will kill fish. This is dependent on a variety of factors including species, age, temperature, health of the individual, duration of exposure and the nature of the sediment. Angular silt particles are more abrasive to gill tissues and result in mortalities at lower levels than more rounded particles. However, it is likely that suspended sediment concentrations must exceed 200-300 mg l^{-1} for several days before direct mortality results (6).

Effects on Eggs and Alevins

The destructive potential of sediment which settles to the stream bottom has been well documented. Silt which fills the gravel interstices in a spawning bed reduces the exchange of oxygen rich surface water with oxygen deficient water within the gravel bed (6). Salmon and trout eggs are dependent upon this exchange to provide them with the oxygen they require for survival. This interstitial flow of water is also necessary for the removal of potentially toxic metabolic wastes such as carbon dioxide which accumulate outside the egg (1, 5). The smothering of a spawning bed by settled silt also prevents the emergence of fry from the gravel. Normally, these small fish have no difficulty in swimming up through gravel spaces. However, when these spaces are clogged with fines, the fry's movement is impeded or made impossible. Mortality then results due to suffocation or starvation.

McNeil and Ahnell (9) demonstrated that a small increase in the composition of fines in the gravel significantly reduces permeability and egg survival. While a 5% composition of silt and sand in the gravel had no apparent effects, a 10% composition of these fines reduced survival of eggs by half. Similarly, Shelton and Pollock (10) found that chinook salmon eggs in a spawning channel suffered up to 85% mortality when 15-30% of the gravel interstices were filled with sediment.

Substrates containing more than 20% silt and sand show slower rates of emergence of brook trout fry from the gravel and a decreased percentage of surviving fry (11). Delayed emergence can affect later survival since such fish are in a weakened condition and are susceptible to disease, predation, and starvation due to their reduced ability to compete for food. Heavy siltation of the stream bottom resulted in reductions of 50% in survival to emergence in an experiment involving steelhead trout and coho salmon eggs (12). The time of siltation has also been shown to be critical in determining egg and alevin survival. Silt added to a coho salmon spawning area during the initial stages of egg incubation resulted in very low fry yields averaging only about 1% (12). Addition of silt after hatching also reduced yield, but to a lesser extent.

Productive salmon and trout spawning beds should not contain more than 5% silt. Further, the presence of more than 30% silt constitutes a non-productive area for these fish (12). The impacts due to settled silt are subtle. Since the eggs and alevins are stages in the life cycle of salmon and trout invisible to the streamside observer, their loss due to the effects of silt cannot readily be detected.

Effects on Food Chain

Suspended and settled sediment have indirect impacts on trout and salmon individuals and populations by reducing overall stream productivity. Juvenile salmon and trout feed extensively on aquatic insect larvae, many of which are in turn dependent for food on green plant material. In streams, these plants or primary producers, are represented by algae which are attached to the substrate. It is therefore evident that damage to any part of this food chain can lead to a reduction in fish populations.

Primary production in streams is dependent on light transmission through the water. Suspended sediment scatters and absorbs solar radiation and causes the greatest loss of light in the water column (13). The presence of elevated suspended sediment levels for several days can result in a significant reduction or even elimination of plant material (5, 12). These effects are exacerbated by the direct physical impacts of both suspended and settled silt on algae. Silt particles flowing in water or in shifting bed material remove algae by grinding and dislodgement (12).

Aquatic insect populations are affected by silt indirectly, through reductions in primary productivity, and directly, through smothering, abrasion of respiratory organs, clogging of their filter feeding apparatus and displacement. Young salmon and trout prefer the larvae of such insects as caddisflies, mayflies, stoneflies, and blackflies. These invertebrates inhabit gravel interstices and so are dependent on the percolation of water through these spaces to provide them with oxygen, food and remove body wastes. This interstitial flow is reduced or prevented when gravel spaces become filled with sediment. Several insect species live in exposed locations on the upper surface of rocks. Larger sediment particles can dislodge such animals from their substrate attachments and move them downstream as drift where they may be preyed upon in excessive numbers.

Invertebrate populations have shown losses of as much as 70% due to siltation in some situations (14). The replacement of a clean gravel bottom by a blanket of sediment can result in an invertebrate population dominated by chironomids and tubificids, but these cannot replace the clean water species in the salmonid food chain. In most situations, insect populations rebound within several months after accumulated sediments are flushed out. However, prolonged reductions in this food supply can lead to fish starvation, displacement, and adverse indirect effects on weakened fish from disease and predation.

Effects on Salmonid Habitat and Populations

Heavily silted gravel and cobble substrates cannot provide protective cover to juvenile salmon and trout. Unable to find shelter within gravel spaces, these fish are readily swept downstream by strong currents where they often face heavy predation, unsuitable habitats or severe competition. Even adult trout can be affected when their preferred habitats are disrupted. These fish are commonly found under the shelter of undercut banks, particularly where these border on pools. Saunders and Smith (15) found significant depressions in trout population densities in a Prince Edward Island stream where such undercuts were filled with silt.

Salmon and trout are sight feeders. In turbid waters, their ability to see and therefore capture food is dramatically impaired (6). This is illustrated by declining fishing success in silted waters, a situation well known and unappreciated by many anglers. When suspended sediment levels remain high for a prolonged period, mortality can result from starvation or reduced resistance to disease.

Salmonids avoid spawning beds with poor intragravel permeability (16, 17). This was documented by Saunders and Smith (15) who found an absence of fry in a silted Prince Edward Island stream reach previously known to support trout spawning. Cordone and Kelley (1) relate instances where trout will attempt the construction of a redd but cease when subsurface silt is encountered. To the casual observer, salmon and trout spawning and rearing grounds may appear silt-free when in fact, they are heavily sedimented just below the gravel surface. This is because surface silt is often quickly removed by strong water currents. However, just below the top layer of gravel, water velocities are not sufficient to flush out deposited silt. For this reason it often takes a great deal of time, perhaps decades, to clean a gravel bed of accumulated sediment.

Siltation can result in long term adverse impacts on salmon and trout populations. Evidence to support this statement is abundant in a comprehensive literature survey prepared by Cordone and Kelley (1). It is apparent that many rivers in North America have suffered dramatic decreases in salmonid populations or even the elimination of these populations due to the combined effects of suspended and settled silt. Cordone and Kelley (1) report that the disappearance of Atlantic salmon from many streams around Lake Ontario can be blamed on erosion and sediment. In Nova Scotia, siltation due to logging road construction has been found to depress salmon populations for at least nine years (18). The confounding effects of overfishing, acid rain and water quality degradation make it difficult to determine the overall contribution of erosion and sedimentation to declining Atlantic salmon and trout stocks in Nova Scotia. However, because erosion and the subsequent release of silt is common to such widespread activities as agriculture, forestry, road construction, urban development, bridge and culvert installation and channelization, it can be concluded that overall, **silt is probably the most destructive aquatic pollutant in Nova Scotia rivers.**

Erosion and Sedimentation Prevention

Procedures and techniques are readily available to prevent erosion and subsequent stream siltation from most soil disturbance activities. Manuals have been prepared by agencies responsible for both forestry (19) and agriculture (20, 21) to curb practices that are harmful to aquatic and wildlife resources. In addition, the Department of Fisheries and Oceans, in cooperation with the Nova Scotia Departments of the Environment and Transportation have assembled specifications designed to prevent aquatic sedimentation due to a variety of construction activities (22).

Erosion is a predictable consequence of soil disturbance. It is usually preventable by incorporating environmental safeguards in the pre-construction planning stage and by the application of common sense. Consideration of sediment control measures usually results in long term economic advantages. This is because initial erosion control and site stabilization reduce maintenance requirements and prolong the life of roads, culverts and bridges. Within the agricultural context, erosion control has long been considered essential for the preservation of precious topsoil.

Specific examples of appropriate mitigation methods serve to illustrate how simply erosion and sediment transport can be curtailed:

(1) Sediment control barriers. These fabric filter fences can be installed around work sites to prevent the downslope flow of silt following precipitation events.

(2) Ditch cutoffs. Where feasible, road ditches should periodically be turned away from the road into a forested area where suspended sediment can be filtered by vegetation and forest floor litter.

(3) Water bars. Along steep ditches, these barriers (generally made of wood, gravel or straw) serve to pond flowing water, causing silt to drop out of suspension.

(4) Cofferdams. These barriers are used during the installation of bridge abutments or piers to separate the working area from the flowing portion of the stream.

(5) Site stabilization. Wherever soil has been disturbed, it is important that it be capped soon after construction. Capping may involve any material or vegetation which serves to protect the soil from erosion due to precipitation or runoff. Usually, rapid revegetation is preferred using hydroseeding to enhance the environmental and aesthetic qualities of the site.

SUMMARY

The evidence is mounting that siltation, more than any other cause, has been responsible for limiting the natural reproduction of trout and salmon (23). It affects all components of the food chain and therefore results in damage to fish and their habitat both directly and indirectly. Settled sediment affects salmon and trout more severely than suspended sediment. This is because free swimming fish are relatively resistant to periodic bursts of silt while the egg and sac-fry stages cannot escape the entombing effects of heavy sediment deposits. The damage to fish and their habitats is insidious. Siltation is common in small headwater streams that are, in fact, the productive components of a river system. The loss of eggs, alevins and juveniles generally goes unnoticed. The impacts of such damage are typically only detected years later when fishing success declines.

The amount of sediment that can be safely added to streams is not known. Because this pollutant often accumulates in the aquatic environment, even small amounts added over a prolonged period can be harmful to fish productivity. Damage from siltation is usually unnecessary. It can be prevented with available knowledge and techniques, often at little additional expense. Most important is the development of a philosophy which incorporates consideration of all resources into land use, development and construction activities. "Man must acquire a responsibility to future generations that matches the power he has gained through the development of heavy machinery" (1). In Nova Scotia, it has become apparent that only such a change in attitude will prevent the continued loss of salmon and trout habitat.

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QUESTIONS

Is there any evidence for the effects of suspended sediments on fresh water filter feeders?

Morantz: Yes, there is a fair amount of information that shows the impact of silt on invertebrate filter feeders. In one study 70 percent of the invertebrates, which were predominantly filter feeders, were killed off after a fairly heavy sedimentation event.

Water, The Liveliest Molecule

J. Gordon Ogden III

ABSTRACT

Although 75% of the earth's surface is covered with water, less than 3% is fresh, and of that less than 0.5% is liquid and possibly potable in lakes, streams, and accessible groundwater. The 0.035% that is present as vapour in the atmosphere is responsible for all of the energy exchanges we know as weather, and over time and broad regions as climate.

The unique and remarkable physical and chemical properties of water make it the most active and important biological and geochemical substance known. The hydrologic cycle of precipitation and evaporation makes water our most renewable natural resource. Urban and industrial utilization often interrupts and interferes with the water cycle and affects critically important water quality parameters. Release of organic-rich domestic or industrial waste waters may overwhelm oxygenation capacity due to the limited solubility of Oxygen in water (ca. 10 parts per million) compared to air (20% = 200,000 parts per million). This difference drastically limits the numbers and kinds of microorganisms capable of attacking the volume and variety of substances we wish to dispose of by flushing them away.

Other processes threaten water quality and fish habitat by acidification and consequent loss of alkalinity, as well as the mobilization of potentially toxic heavy metals. Construction and development activities frequently expose minerals with high acid generating capacities. As global energy requirements continue to increase, fossil fuel combustion increases the atmospheric burden of sulphur and nitrogen oxides as well as aromatic hydrocarbons and other volatile materials. Even with stricter emission controls, inevitable atmospheric contamination makes site-specific ameliorative technology an increasingly imperative priority.

Continuing population growth and urbanization, together with changing life styles contribute to increasing nutrient burdens in lakes, streams, and coastal waters.

A non-trivial solution to many water quality and fish habitat problems would be a requirement that municipalities and industries install their water intakes downstream of their outfalls.

WATER, THE LIVELIEST MOLECULE

It is difficult to be comprehensive about a complex topic in a brief review. Simplification invites triviality, yet attempts to be scholarly will inevitably be drowned out by the click of hearing aids being turned off.

At the risk of oversimplification, I take here a brief look at four critical water quality parameters which impact directly on fish habitat and are adversely affected by alteration or manipulation as a result of domestic, municipal, or industrial management decisions. The top four in my list include:

(1) Dissolved Oxygen
(2) Alkalinity
(3) Nutrients
(4) Toxic substances

Before considering these parameters in some detail, I would like to digress to remind us all of some of the basic facts about this remarkable substance which I call the "liveliest molecule."

The chemical and physical properties of water make it absolutely unique. What other substance is less dense as a solid than as a liquid? If, like most other chemical substances, water attained maximum density as a solid, it would sink and the biology of temperate and arctic lakes subject to ice cover would be very different, if there was any life at all.

Water warms and cools more slowly than most other substances, including the land around a lake or stream. It is the closest thing to a perfect solvent that we know. We consider glass to be virtually insoluble, yet if you wish to demonstrate that Boron is an essential element in plant nutrition (it is), you cannot conduct your experiments in borosilicate glass vessels nor will you live long enough to leach all the Boron from the glass.

Because of its high specific heat and volatility, water is the most "renewable" natural resource on the planet. We are all familiar with the basic water, or hydrologic cycle (see Figure 1, page 44): precipitation falls as rain, snow, sleet, dew (etc.) and runs off land surfaces or percolates through the ground to lakes, streams, or wells, gets stuffed into pipes, and appears at our taps as clear (usually) Department of Public Health approved tap juice. After use, what goes down the drain is bad, but it goes somewhere and something happens, and it eventually reappears at your tap in an approved form.

For each of the critical properties in the following discussion, we will look at some of the interactions that make them important in fish habitat suitability, and then consider some case histories where severe dislocations have occurred.

1. DISSOLVED OXYGEN

For the most part, we are used to getting our oxygen dissolved in air, at a concentration of about 20% (= 200,000 parts per million). Fish, on the other hand, along with most other aquatic organisms live in a soup that rarely exceeds 10 ppm (parts per million = mg/L), and the solubility of oxygen decreases at water temperatures greater than 14°C. Even at 0°C, oxygen concentrations do not exceed 15 ppm. Interestingly, however, Martin Thomas of the Fisheries Station at St. Andrews has shown that in plunge pools at the base of falls, supersaturation of dissolved oxygen to values of 30-50 ppm can be measured. It would seem that salmon and other anadromous fish hyperventilate before intense physical activity much as basketball players and swimmers do.

This limitation of dissolved O_2 has a number of important biological consequences. Not only are there very few organisms that can exist in both atmospheric and aquatic environments, but the abundance and variety of a very important group of organisms, the Decomposers, is severely limited.

There is an absolute biological requirement for oxygen, either molecular as O_2, or attached to other molecules. There are a limited number of microorganisms that are capable of extracting metabolic oxygen from sulphates (SO_4), nitrates (NO_3), or even carbon dioxide (CO_2). The products of anaerobic metabolism include potentially explosive methane (CH_4), the rotten egg smell of hydrogen sulphide (H_2S), and ammonia (NH_3).

It is the decomposers who clean up the mess we make, and to assist them in far too few instances, we install expensive aeration equipment to supply additional oxygen and keep the system aerobic. Unfortunately, the organisms which are the best at handling the job of decomposition are forest floor microorganisms, such as the actinomycetes and fungi. In addition there is a bewildering assortment of bacteria capable of degrading almost any carbon-containing molecule, including polyethylene. Polymer chemists around the world continue to search for a coating that will completely resist microbial and/or solar ultraviolet radiation. A dead tree or animal in the forest is soon recycled to become part of other living systems. The fact that trees can be preserved for hundreds and even thousands of years in aquatic environments should provide a clue to the limitations imposed by low oxygen availability.

The metabolic pressure that wastes place on the environment has traditionally been described by B.O.D.$_5$, or 5-day Biochemical Oxygen Demand. The method, now in world-wide use, was developed in the late 1800's by a British sanitary engineer and was based on the fact that no river in Great Britain takes longer than five days to reach the sea. Life was simpler then, and so were the wastes that had to be disposed of.

Surely, the length of British rivers is a dubious criterion for assessing the impact of late 20th century North American domestic, municipal, or industrial waste which contains carbon-containing substances and other materials never dreamed of in the 1800's.

Among the alternatives, a variety of oxidative reactions are employed to determine C.O.D., or Chemical Oxygen Demand. Without going into great detail, they have the advantage of relative ease and rapidity of measurement (instantaneous rather than 5 days), and are readily automated in analytic streams. A disadvantage is that they may measure Oxygen Demand in excess of the ability of microorganisms to metabolize. In other words, substances may be biologically inert, while still retaining appreciable C.O.D. A more appropriate measure would be an Oxygen Demand Index (O.D.I.), which can be defined as the maximum amount of chemical, physical, and biological oxidation pressure that can be brought to bear on a particular waste prior to release into a particular environment. Such a measure would therefore be both site and process specific. Unfortunately, very little research has been supported in this area and O.D.I. measurements are conspicuously lacking in treatment system specifications.

2. ALKALINITY

Most of you have probably noticed that I did not include pH as a major parameter. As a card-carrying geochemical limnologist, I regard pH as an indicator, but with all the stability of a flag whipping in the wind. It is, however, a quick, convenient, and usually mismeasured and misunderstood value. Beware of the phrase "mean" or "average" pH. The arithmetic mean of a logarithm is nonsense to several decimal places.

The term alkalinity itself is a misnomer, since we measure it conventionally by titration with standard sulfuric acid to various acidic end points ranging from 3.7 to 5.2 to describe the carbonate-bicarbonate buffering system. The presence of other buffering systems, for example, dissolved organic matter (for which water colour is a surrogate), provides additional buffering capacity (the ability of a body of water to resist change in pH with added acid or base). The presence of these systems is partially recognized in "Gran titrations," the details of which I will save for another occasion.

All of this leads to a sweeping generalization that "Acid rain only stings, but loss of alkalinity kills." It is the loss of alkalinity and subsequent acidification of rivers along the southern and eastern shore of Nova Scotia. Figure 1 shows that Nova Scotian precipitation is substantially less acidic than continental areas to the west due to the buffering effect of marine aerosols as low pressure systems cross the Gulf of Maine and Bay of Fundy. The data shown in this figure are averages from a series of 5 storms that were sampled individually at collection stations in the U.S.A. and Nova Scotia. Elevated values of marine ions (esp. sodium, magnesium, chloride) in the Nova Scotian data reflect the consumption of oceanic bicarbonate and consequent reduction in hydrogen ions compared with the continental data.

The resistant and insoluble rocks of southern and eastern Nova Scotia provide little natural alkalinity to fresh water systems.

3. NUTRIENTS

It is possibly trite to observe that anything added to a process or a system enriches it, thereby satisfying a definition of eutrophication. Experience from agriculture and our own front lawns teaches us that if you add nutrients (fertilizer) you increase growth and production. Unfortunately, there is a cost associated with increased productivity. As you increase growth and production, you also and concomitantly increase metabolic oxygen demand.

All natural systems utilize resources for survival, growth, and reproduction. However, all natural systems are productive only to the limit of some critical resource. This generalization has been formalized as the "Law of Limiting Factors," which is universally true, frequently misunderstood, and usually misapplied. Because I feel that the concept is critically important, I offer an operational definition:

> "A limiting factor is anything added to a reaction or process which increases rate or the product of that reaction or process...."

Most freshwater aquatic systems are limited by the

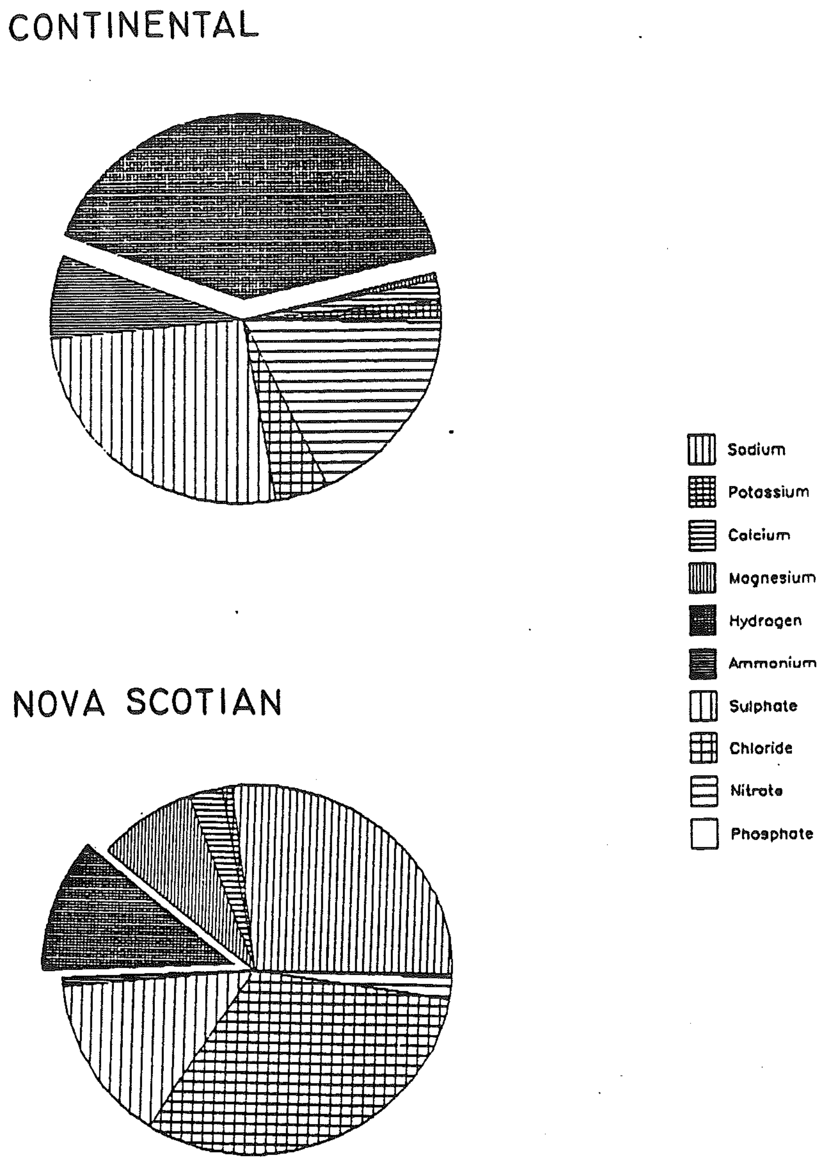

Figure 1. Chemical properties of rainfall in Nova Scotia compared with continental average.

amount and availability of phosphorus, only rarely by nitrogen, and almost never by carbon. Marine systems, on the other hand, are usually limited by nitrogen availability, occasionally by phosphorus, and almost never by carbon.

Table I contrasts the nutrient content of marine, nutrient-poor (oligotrophic) Bluff Lake, N.S., nutrient-rich (eutrophic) Cranberry Lake, N.S., a sewer outfall draining into Cranberry Lake and average domestic sewage.

It can be noted that domestic wastes are extremely high in ammonia-nitrogen, which is rapidly oxidized to nitrate-N (cf. Cranberry Lake). Similarly, N:P ratios are low (<4.0) in sewage, eutrophic lakes, and the ocean but range from 10 to >30 in oligotrophic lakes.

As waste waters are added to natural systems, limiting factors change dramatically. Organic-rich wastes from domestic and municipal sources, food or fibre processing industries are usually Carbon-rich, but the industrial effluents are usually deficient in N and/or P.

In both cases, however, the limiting factor usually becomes the oxygenation capacity of the receiving waters. Recall that as growth and productivity increase, so too does metabolic oxygen requirement. Increased algal growth does provide additional oxygen by photosynthesis, but only during daylight hours,

Table 1. Ionic Composition of Marine and Freshwaters in Relation to Sewage Effluents

Substance	Average domestic sewage	Cranberry L., N.S. Sewer Outfall	Cranberry L., N.S. Lake Centre	Bluff Lake	Average Ocean
Sodium	125	15.9	17.9	4.3	10543
Potassium	10	5	3.2	.33	380
Calcium	25	22	12.1	1.6	400
Magnesium	5	3.2	2.3	1.7	1272
Iron	5	.4	.04	.48	.05
Ammonia-N	20	14.3	.33	.32	.03
Bicarbonate	200	132.6	96.4	3.8	140
Sulfate	50	46	20	4.1	2465
Chloride	50	27.5	31.1	10	18980
Phosphate	5	8.2	.07	.03	.03
Nitrate-N	—	1.9	11.2	.026	.015
Nitrite-N	—	.24	.007	.003	.002
O.D.I.	—	36.5	7.5	1.7	—
N:P	4	1.9	4.4	11	1.6

and to depths determined by light attenuation from increased shading and light absorption. In any event, at night and due to increased zooplankton activity, oxygen consumption rates increase, and the limited solubility of oxygen in water becomes a limiting factor.

Even extended aeration may not resolve the problem because many of the microorganisms best able to do the job cannot survive in an aquatic environment.

Parenthetically, because salt marshes are among the most productive ecosystems on the planet, it is tempting to use salt marshes to maximize oxidation of domestic and industrial wastes. It should be recalled that these systems are already operating at, or near their oxygenation capacity, and that their role as nurseries for offshore fish stocks and in geochemical cycling of N and S can be threatened by injudicious management. The concept that marshes are 'undiscovered waste disposal sites' requires careful reexamination.

4. TOXIC SUBSTANCES

Beginning in 1918, the then Chemical Rubber Company published a "Handbook of Chemistry and Physics." Since that time, it has gone through more than 60 editions and from one comprehensive pocket-sized volume to a mega-page multi-volume hernia-inducing treatise that 'abridges' the state of the art.

Many organic, and some inorganic compounds have sufficiently high vapour pressure to be broadly distributed throughout the atmosphere. In addition, many new compounds are produced by fractional distillation in tall smokestacks. An increasingly eutrophic atmosphere invites photochemical reactions that constitute a brand-new alchemy.

In the face of increasingly overwhelming chemical diversity, a few simplistic observations may offer some guidelines, but certainly, no solutions:

(a) Because the atmosphere is becoming increasingly acidic, due largely to fossil fuel combustion; and,

(b) Because increasingly powerful development technology continually exposes unweathered bedrock;

it follows that because streams, lakes, and rivers are biogeochemical sinks, rather than sources, aquatic resources, and therefore, fish habitats are at increasing risk.

Acid Rain and Reproduction in Atlantic Salmon: Effects and Mitigation

J.F. Uthe, H.C. Freeman, G.B. Sangalang, K. Haya and L.S. Sperry

ABSTRACT

The primary goal of the Department of Fisheries and Oceans (DFO) is to manage, conserve, protect and allocate fisheries resources. Toxicology deals with the effects of chemicals on aquatic biota, ranging from individuals through populations and communities to complete ecosystems. Between 1979 and 1986, the Toxicology and Organic Contaminants Section of the Marine Chemistry Division, located at St. Andrews, New Brunswick, has developed and applied a number of biochemical parameters as indicators of the health of aquatic animals. All studies on Atlantic salmon indicated that a response in fish to sublethal concentrations of chemicals is increased **gluconeogenesis**, and decreased food intake, resulting in decreased growth.

Research carried out within the Marine Chemistry Division at the Halifax Fisheries Research Laboratory, in Halifax, Nova Scotia, on wild male Atlantic salmon (*Salmo salar*) returning to spawn in the Westfield and Medway Rivers, Nova Scotia, showed that salmon captured in the acidified Westfield River had low or undetectible levels of testosterone and 11-ketotestosterone, the two hormones required for testicular development and maturation. Later studies on caged fish identified impaired growth, altered sex and stress (corticosteroid) hormonal metabolic patterns, in sexually maturing salmon of both sexes held in the Westfield River (pH 4.8-5.1) compared to the more normal Medway River (pH 5.3-6.0). High mortalities occurred in post-spawned fish in the untreated acidic water and moribund fish survived when transferred to the Medway River. Limed Westfield River water improved fish performance substantially but did not result in performance levels equivalent to control salmon and abnormalities in ripening times were noted.

These results show that simply restoring water pH levels to apparently acceptable levels with limestone did not result in maintenance of normal health and reproductive capacity in salmon. We hypothesize that acidic deposition is removing toxic materials from the watershed to the stream and such materials are still capable of exerting their toxic effects even when water containing them is restored to normal pH by liming. We investigated this in 1987 by addition of calcium, disodium EDTA to complex toxic metals such as aluminum. Improved fish performance was found but neither the fish nor the eggs were normal.

INTRODUCTION

The primary objective of the Department of Fisheries and Oceans (DFO) is to manage, conserve, protect and allocate fisheries resources. The quality of the aquatic habitat (ecosystem) determines the productivity of economic and other species and the marketability of fishery products. The broad objective of the Toxicology and Contaminants Science Program may be stated as follows:

> To control chemical contamination of aquatic ecosystems in order to protect, restore, maintain and enhance freshwater and marine fisheries, the ecosystems that support those fisheries, and the wholesomeness of fisheries products.

Toxicology deals with the effects of chemicals on aquatic biota, ranging from individuals through populations and communities to ecosystems. Chemicals and mixtures of chemicals are tested for acute and chronic toxicity. Sub-lethal (early warning) effects are investigated for utility in detecting impending significant toxicological events. The coupling of these effects with chemical structure (chemometrics) enables prediction of effects of a large number of chemicals by testing representative members of chemical classes.

BIOCHEMICAL SUBLETHAL EFFECTS

Stress (e.g., from chemical contamination) inflicted on an organism's mechanism for maintaining a healthy physiological state may cause changes in histological properties (structures of cells and tissues) and behavioral, physiological and biochemical processes. A series of diagnostic tests is needed to assess the health of aquatic communities and populations and as an early warning signal of impending pollution. Biochemical responses of aquatic animals upon exposure to chemicals can vary with species, organ or tissue studied, and with many other normal physiological variables, (e.g., reproduction, environmental temperature, etc.). Other environmental stressors, (e.g., hypoxia, salinity, etc.), also affect biochemical responses. The current research is aimed at determining baseline biochemical and physiological information in order that the effects of chemical "stressors" can be separated from other "stressors." Between 1979 and 1986, the Toxicology and Organic Contaminants Section of the Marine Chemistry Division, located at St. Andrews, New Brunswick, has developed and applied a number of biochemical parameters as indicators of the health of aquatic animals (Table 1). Each of the tests will not be considered in depth here. The table shows that there is no single test which is applicable to all chemicals in all species in all situations although the "glucose and gycogen" test (column d in the table) shows wide applicability. For example, all studies on Atlantic salmon indicated that a response in fish to sublethal concentrations of chemicals is increased **gluconeogenesis**, (i.e., synthesis of glucose, the major "food" in the blood for the nervous system), and decreased food intake, resulting in decreased growth. In other words, the animal shows signs of starving in spite of the availability of food. One can predict that starvation would affect not only the long-term survival of the animal but also its reproduction, since fish need large body reserves of nutrients for reproduction, and also that production within the fisheries itself would be affected since starved fish would not yield normal amounts of fishery products, (i.e., muscle or "meat").

EFFECTS OF ACID RAIN ON REPRODUCTION IN SALMON

Southwestern Nova Scotia is historically noted for its high salmon productivity. The river systems are generally brown water ones with low **buffering capacity** (ability to absorb acid) . The area is a primary receptor for deposition of aerial contaminants discharged by major north-eastern North American industrial and population centers. Thirteen rivers are "dead"—no longer having spawning salmon populations—while the stocks in many others are severely endangered. The Westfield and Medway Rivers in southern Nova Scotia are two such rivers, the Westfield being more so and flowing into the Medway.

Our studies on salmon ascending these two rivers began in 1981. That work showed that blood levels of the androgenic hormones needed for successful reproduction in male salmon were significantly lower (often undetectible) in salmon from the Westfield River compared to those from the Medway. The pH in the Westfield averaged about one-half unit below that of the Medway, which has a pH of about 5.5, i.e., the Westfield is about three times more acidic than the Medway.

Caged fish studies began in 1982. Salmon were held in cages in both rivers over the period of sexual maturation, generally mid-summer to late fall. The fish were fed and tended daily. The research questions concerned:

(1) Blood levels of sex hormones in maturing male and female salmon.

(2) Weight, length and condition index (total weight of animal divided by its length) changes in both sexes.

(3) Fecundity of female salmon, i.e., number of eggs produced by the fish divided by its length.

(4) Egg viability and hatchability in the hatchery following fertilization in the field.

(5) Manufacture of steroid hormones in reproductive organs and interrenal gland (adrenal gland equivalent in fish).

(6) Survival of fish in acidic water after spawning.

In addition to these questions, investigators who had developed other techniques for determining the effects of acid rain on fish were invited to participate in the experiment. The large degree of participation by

Table 1. Potential of biochemical tests studied between 1979-1986 as indicators of the health of aquatic animals.

Project	Animal	Chemical[1]	Tissue[2]	Potential as Indicator[3] Biochemical Parameter[4] a	b	c	d	e	f	g	h	i
Chemicals												
Belledune	lobster	Cd^{++}	1,2,3	1	1							
Laboratory	lobster	Zn^{++}	1,2,3	2	1							
	lobster	Cu^{++}	1,3	1	1			1				
	Neries	OC Pest	5		2	2	4	5				
	salmon	OC Pest	1,2	4	2	2	5	4				
	salmon	OP Pest	1,2,4	4	2	2	5	4			5	
	salmon	phenols	1,2	4	2	2	5	4				
	salmon	fenvalerate	1,3,4		2	2	5					1
Acid Rain												
Laboratory	salmon eggs	pH 4.5	5						5			
	salmon	pH 4.5	1,2,3		2	2	5	4				
	salmon adult	pH 4.5	1,2,3	2	2	2	5	4				
Mersey Hatchery	salmon	pH 4.7	2		2	2	5	4				
Baseline												
Seasonal Variation	clams		5		4							
	mussels		5		4							
	flounder		1,2,3,4		3					3		
	ocean pout		4							3		
Moulting	lobster		1,2,3	1	1			3				
Starvation	salmon		2,3		2	2	5	2				1
Physical Stress	salmon		3	1	1	1	1	2				5

Footnotes:

[1]Chemicals OC Pest-organochlorine pesticides; OP Pest-organophosphate and carbamate pesticides.

[2]Tissues 1 = gill; 2 = liver or digestive gland; 3 = muscle; 4 = blood; 5 = whole body.

[3]Potential 1 = no observed effect, no potential; 2 = variable effects observed, low potential; 3 = baseline studies, not evaluated yet; 4 = variable effects, has potential; 5 = definite effect, high potential.

[4]Biochemical Parameter a = Na^+, K^+-ATPase activity; b = adenylate energy charge; c = phosphorylation potential; d = glucose and glycogen; e = arginine or creatine phosphate; f = chorionase activity; g = antifreeze proteins; h = acetyl cholinesterase; i = lactate.

other scientists has added substantially to our information on acid rain-induced effects. Their results will not be discussed here.

Salmon held in the more acidic Westfield River grew less than controls (fish held in the Medway River), produced fewer and smaller eggs, demonstrated abnormal metabolism of sex hormones (testosterone and 17-alpha, 20-beta-dihydroxy-4-pregnen-3-one) and showed interrenal hormonal metabolism characteristic of severely stressed fish (Table 2). Fecundity (eggs produced/cm length of fish) was reduced and 90.9% of the eggs from Westfield fish died compared to 59.3% for the Medway eggs.

Blood hormone concentrations of testosterone and 17-alpha-20-beta-dihydroxy-4-pregnen-3-one, the hormone involved in the final release of reproductive products (eggs and sperm) in the fish were determined every 2-3 weeks over the course of the holding. In normal fish hormonal levels increase in the blood, bringing about ripening of the fish, followed by increased levels of those hormones, resulting in spawning. Following spawning, blood levels of all hormones decrease rapidly to levels prior to initiation of sexual maturation. Obviously it is important that male and female salmon, in substantial numbers, are ready for spawning at the same time. Changes in the normal time of ripening would result in significant changes in reproduction, if not of decreased numbers of fertilized, viable eggs, at least in alterations of the gene frequencies within the population. Significant alterations in blood hormonal levels were found in fish held in the acidic Westfield River compared to those of fish held in the Medway. Also there was a significant shift in the percentages of males and females that were ripe at the same time, the percentage of such fish being reduced in the Westfield River. Additional studies of hormone metabolism in the interrenal tissue of the fish showed that the Westfield River fish were undergoing severe stress.

Fish were held in their cages after spawning to investigate survival in the presence of acidic water. Many of the fish held in the Westfield River died during the period of the first, cold rain originating from the southwest. Transfer of dying fish from the Westfield to the cage in the Medway River resulted in survival of all fish over the winter.

Earlier research had shown that addition of limestone to restore pH to more normal levels reversed many of the acid-induced effects. In 1986 the effect of liming on reproduction in salmon was investigated by holding salmon in Westfield water which had been allowed to flow through sufficient marble chips to restore the pH to that of the Medway. It is possible that acidic groundwater could leach a variety of other toxic

Table 2. Spawning data on the effects of limestone treatment and EDTA treatment of the acidic Westfield River on the Atlantic salmon, *Salmo salar* (1987 experiment).

River (group)	Ratio, no. of spawned females to total no. of surviving females	Ratio, no. of spawning males to total no. of surviving males	Fecundity (no. eggs/g body weight)	Egg mortality[a]
Medway (control)	11/21	23/24	2.30	70%
Westfield				
(untreated)	3/23	22/22	2.02	86%
(limestone)	2/21	21/21	3.47	90%
(EDTA)	5/24	18/20	2.65	100%

[a]Egg mortality to the hatch stage for eggs from fish that were spawned before November 25, 1987.

materials from the earth whose effects on the fish would not necessarily be reversed simply by liming the stream water. The results indicated that liming resulted in a marked improvement in the condition of the fish and improved hatchability although neither was as good as the Medway fish (Table 3). The fish still demonstrated severe stress (interrenal metabolism), blood abnormalities, calcium loss from vertebrae and irregularities in the times of ripening of male and female fish so that smaller percentages of both sexes are ready to spawn at the same time (Table 4). Work continues to define the agents responsible for these effects and ways of compensating for them. The intention is to create 'refuge areas' by treatment to ensure survival of the unique genetic pools associated with different salmon runs in the affected watersheds.

Since we had hypothesized that the acid rain could have leached toxic materials out of the watershed into the river we investigated the effect of adding very small concentrations of calcium disodium ethylenediamine tetraacetate (EDTA), a known food additive which binds and detoxifies a number of toxic metals including aluminum to Westfield River water. EDTA was effective in improving fish performance, survival, and egg production, but did not improve egg hatchability nor eliminate the severe stress imposed on the fish in the Westfield River water (Tables 3 and 4). Efforts to discover better agents for countering the effects of acid rain will continue in the future.

Table 3. Weight changes in Atlantic salmon maintained in the Westfield and Medway Rivers from early September to spawning in November 1987.

River (Group)	Weight Change Range (- loss; + gain) (Mean)	
	Males	Females
Medway (Control)	-150 to +350 (n=24) (+37)	-95 to +325 (n=21) (-7)
Westfield (untreated)	-225 to +350 (n=20) (0)	-100 to +375 (n=22) (-36)
Westfield (limestone)	-125 to +365 (n=23) (+9)	-95 to +375 (n=18) (0)
Westfield (EDTA)	-150 to +475 (n=27) (+13)	-250 to +75 (n=20) (-68)

Table 4. Blood peak levels (ng/mL plasma ± sd) of steroid hormones in Atlantic salmon held in the Medway and Westfield Rivers from early September until early December 1987.

Steroid/River (group)	Male	Female
	17-alpha, 20-beta-dihydroxy-4-pregnen-3-one	
Medway (control)	40.3±26.0 (n=18)	128.4±57.9 (n=8)
Westfield (untreated)	41.3±26.7 (n=24)	52.7±16.7 (n=3)

Table 4. Blood peak levels (ng/mL plasma ± sd) of steroid hormones in Atlantic salmon held in the Medway and Westfield Rivers from early September until early December 1987.

Steroid/River (group)	Male	Female
	17-alpha, 20-beta-dihydroxy-4-pregnen-3-one	
Westfield (limestone)	51.4±26.7 (n=19)	113.5±99.7 (n=5)
Westfield (EDTA)	61.7±18.2 (n=23)	134.2±84.0 (n=5)
	testosterone	
Medway (control)	69.7±18.2 (n=23)	62.1±19.3 (n=14)
Westfield (untreated)	64.0±17.3 (n=24)	33.0±22.0 (n=13)
Westfield (limestone)	79.1±21.4 (n=22)	59.7±5.5 (n=5)
Westfield (EDTA)	56.7±17.5 (n=18)	54.1±26.4 (n=18)

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QUESTIONS

There was no mention made of the effects of highway salt infiltrating freshwater bodies. Would someone like to comment on that?

Uthe: I am not aware of any work that is been done around here but I know there has been work done on the prairies by the Fresh Water Institute.

Ogden: We have looked at the effects of salt in and around Halifax area lakes. Prior to 1977 Chocolate Lake and waters got extremely high values of salt. By and large the levels of salt that have appeared in most of the lakes in and around the Halifax area (up to 200 to 300 parts per million) do not seem to have had a demonstrable detrimental effect on the fish in the lake.

Characteristics of Estuarine and Coastal Waters

Ken H. Mann

ABSTRACT

Estuarine and coastal waters are more productive at all levels of the food web than the open sea because a variety of physical factors associated with the coastal location combine to stimulate upwelling of nutrients, which leads to enhanced production. As a result, estuarine and coastal waters are to be regarded as especially valuable fish habitat. At the same time, these waters are particularly vulnerable to man-made disturbance because estuaries and the rivers draining into them are prime centres of human settlement.

In all coastal waters, the plant and animal remains which sink to the bottom break down to release substances which act as fertilizing nutrients for the plant life. Hence, waters near the bottom tend to be nutrient-rich while surface waters, in which the microscopic plants are actively growing, tend to be depleted in nutrients. As a result, any process which causes deep water to upwell to the surface stimulates the plant production and increases productivity at all levels.

In an estuary the flow of the fresh water from the river over the top of the salt water layer causes an "estuarine circulation" in which nutrient-rich bottom water is drawn into the estuary and upwelled to the surface. This makes estuaries particularly productive of phytoplankton. The ebb and flow of the tides assists this process, making the estuaries even more productive. In addition, estuaries are sites of the precipitation of muddy deposits which make fertile soil for the development of salt marshes, whose plants add further to estuarine productivity.

Many animals adapt to the estuarine circulation, timing their life histories to make use of the strong pulse of freshwater which occurs at snowmelt. Damming of rivers or estuaries can modify the traditional pattern of runoff and disrupt the life cycles of finfish, molluscs and crustaceans. Many species of fish and crustacean spend their early life histories in the estuaries, making maximum use of the highly productive habitat. Contamination of estuarine waters may adversely affect these species by causing oxygen depletion of the water, or by introducing pathogenic organisms or toxic substances into the habitat.

In coastal waters production is enhanced by the effect of winds which drive surface waters away from shore. Nutrient-rich waters are drawn up from depth along the coastline to take their place. In addition, in places where the water is shallow and the tidal currents are strong, movement of water over the bottom sets up turbulence which may carry nutrient-rich water up to the surface, again stimulating production at all levels of the food web. The area off southwest Nova Scotia is such a tidally mixed area. It is noted for its high productivity of herring larvae, lobsters and kelp. It has recently been shown that even the young cod and haddock spawned on Brown's Bank migrate into the coastal waters off SW Nova Scotia and exploit the high productivity.

INTRODUCTION

A very large percentage of the population of industrialized countries lives close to estuaries or to a river which flows into an estuary. We have only to think of New York on the Hudson Estuary, London on the Thames Estuary, the population of the Great Lakes area which drains into the St. Lawrence Estuary, and so on. In our own province the greatest population concentration is in the Halifax-Dartmouth area, and Halifax Harbour is an estuary of sorts, with the Sackville River flowing into the head of Bedford Basin.

I hope to show in what follows that estuaries are very special places, characterized by a variety of mechanisms that lead to high biological productivity, so it is important to preserve them as habitat for fish and shellfish. Yet, because of their attractiveness as places for human settlement they are particularly vulnerable to human modification.

THE HIGH PRODUCTIVITY OF ESTUARIES AND COASTAL WATERS

Many estuaries have extensive muddy deposits between tide marks, and this leads to the growth of salt marsh plants. A well-developed saltmarsh has about the same amount of plant production as a good hay-field or a wheat crop yet nobody has to till the ground or provide fertilizer. It is fertilized by the rise and fall of the tidal waters with their contained nutrients. This is one of the reasons why an estuary is so productive.

Another factor in the high productivity is the pattern of water circulation, which will be discussed in detail later. The combination of river outflow and the rise and fall of the tide leads to ideal conditions for the growth of phytoplankton, and many estuaries have levels of phytoplankton production much higher than the coastal waters outside the estuary.

One result of this high productivity is that many species of shellfish and finfish feed in the estuaries, particularly during the young stages of the life history. Juvenile herring make extensive use of estuaries, as do flounders, eels and the anadromous fish such as salmon. Estuaries are often ideal sites for the growth of oysters and mussels.

Even the cod and haddock from the offshore banks come inshore as juveniles. Recent work by Frank and his group at DFO's Bedford Institute of Oceanography has shown that the cod and haddock that are spawned on Brown's Bank are carried by the prevailing currents towards coastal waters and large numbers of juveniles are found feeding and growing in the nearshore waters of SW Nova Scotia. A map of the distribution of juvenile herring stocks around the maritimes (Figure 1) shows that they too become concentrated in coastal waters (1).

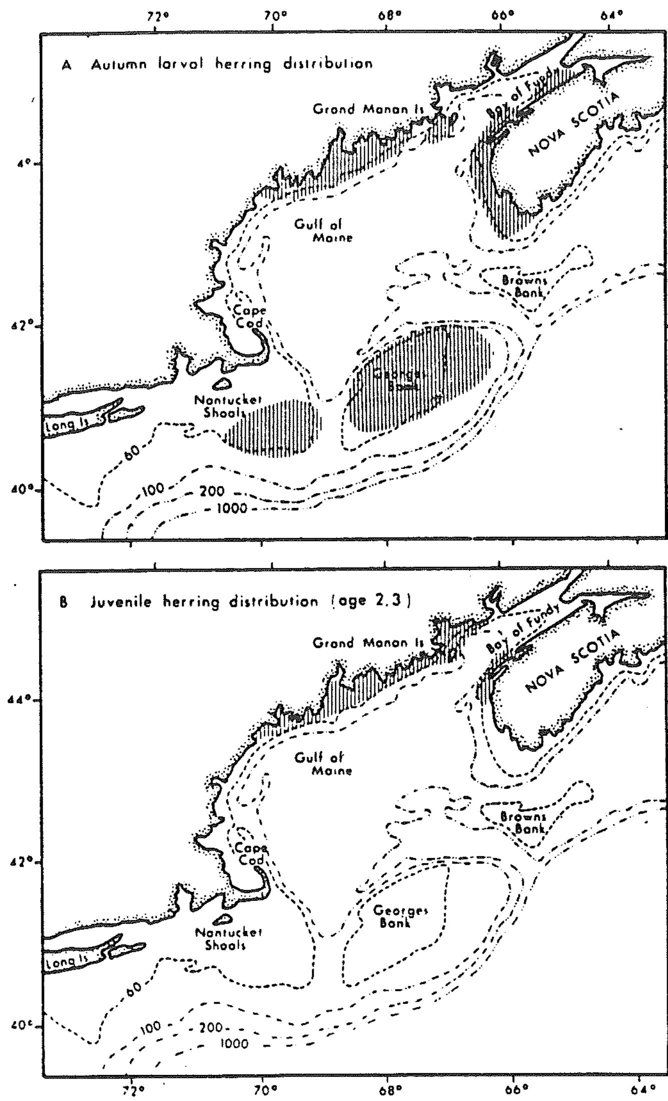

Figure 1. Distributions of larval and juvenile herring.

HOW AN ESTUARY WORKS

Water Circulation

One way to understand what is going on in an estuary is to think of it as one large mechanism geared to the production of plants and animals. This is the systems approach (2). Figure 2 shows sections through various types of estuaries with the fresh water coming in on the right, and the mouth of the estuary to the left. In a quiet inlet with little tidal current freshwater flows in passively, floats over the top of the salt water, since it is lighter, and forms a layer that becomes thinner as it gets further from the river mouth (Figure 2a). This is called a **salt-wedge estuary**.

In most situations, however, there is a twice-daily rise and fall of the tide, so that salt water enters and leaves the estuary, creating tidal currents, especially on the bottom. As these tidal currents move over the bottom they cause upward mixing of the water by turbulence. This breaks down the sharp division between fresh and salt water and we get what is known as a **partially mixed estuary** (Figure 2b).

If the freshwater flow is small but the tidal rise and fall is strong, the whole estuary can be mixed from top to bottom and we refer to it as a **vertically mixed estuary** (Figure 2c). Everything depends on the

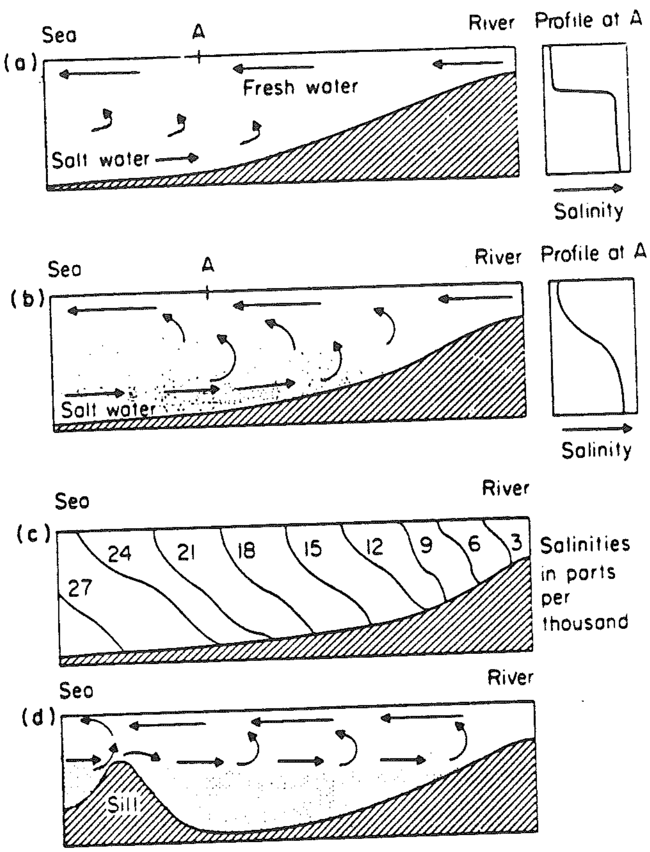

Figure 2. Vertical structures of estuaries. a - Salt-wedge estuary; b - Partially-mixed estuary; c - Vertically-mixed estuary; d - fjord.

relative strengths of the tide and the river flow, whether an estuary is a salt wedge estuary, a vertically mixed estuary, or something in between. The partially mixed condition is the most common, and this is the type we will discuss further.

As the fresh water flows seaward over the salt, the friction between the two layers causes mixing and some of the salt water joins the seaward flowing freshwater layer. By the time it gets to the mouth of the estuary the freshwater layer has entrained a large volume of salt water, typically about 20 times its own volume. The curved arrows in Figure 2 show this. Since there is this large amount of salt water moving out to sea, there must be a compensating landward flow of salt water in the lower layer. Thus, in a typical estuarine circulation, there is a landward flow on the bottom and a seaward flow at the surface.

Biological Production

The next thing we need to understand is that production by the floating microscopic plants, the phytoplankton, takes place near the surface in the sunlight, so that plant nutrients like nitrates tend to be used up in the surface waters, slowing down the growth of the phytoplankton. The plants may be eaten by animals, the zooplankton, or they may become senescent and sink from the surface waters. Similarly, the zooplankton may be eaten by fish, or they may live to breed and die. Meanwhile they are producing droppings which sink to the bottom. The net result of all this is that the plants and the animals and their droppings eventually sink to the bottom, where they decompose and release their nutrients. Hence, the water entering an estuary near the bottom is rich in the nutrients that plants need. When these waters get carried up to the surface by entrainment or by tidal mixing they have the effect of fertilizing the plant growth. This is why estuaries are places of high phytoplankton productivity.

Sedimentation

Another characteristic of estuaries is that the inflowing rivers, especially at times of spate, often carry heavy loads of suspended silt. When the freshwater meets the salt water a physico-chemical change occurs which causes this silt to be deposited. This leads to the formation of extensive mud banks. In many places they quickly become colonized by salt marsh grasses, which as we have seen, can be very productive.

An aerial view of a salt marsh shows it to be dissected by a network of creeks in which the tide rises and falls in a regular rhythm, a kind of inhaling and exhaling of seawater. It is this tidal ebb and flow that carries the fertilizing salts to the plants. Those plants closest to the edges of the creeks are the ones that grow tallest. It has been shown (3) that the productivity of a salt marsh is proportional to the amplitude of the rise and fall of the tide (Figure 3).

The Fate of Salt Marsh Production

There has been much debate in scientific circles about whether the plant material produced on a salt mash just dies and decays there, or whether it is exported on the tides and is used to feed fish and

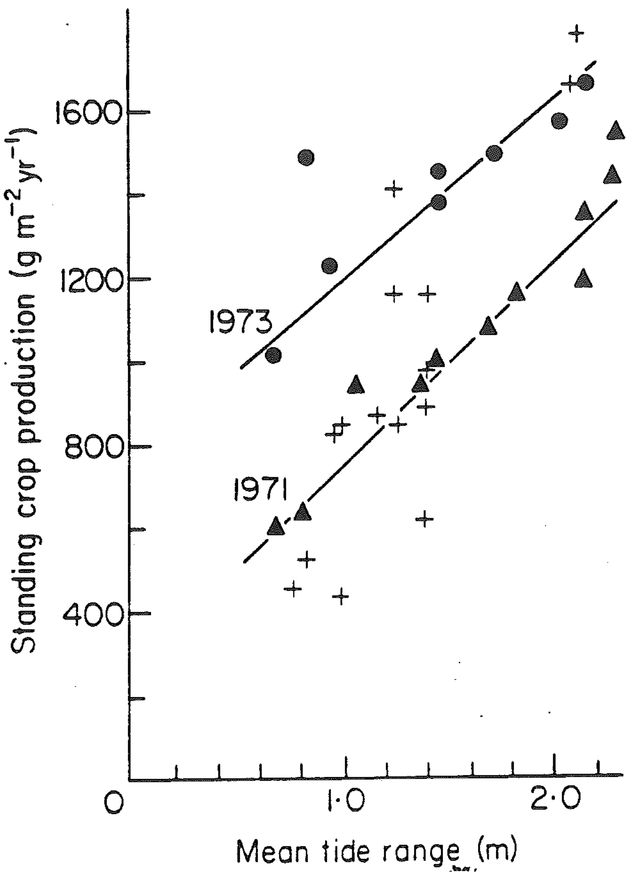

Figure 3. Relationship between tidal range and salt marsh production.

shellfish in coastal waters. In Georgia, where the salt marshes are tens of km in diameter, it had been claimed that they were the main support of the fisheries along the coast. It was suggested that huge volumes of partially decomposed salt marsh grass were carried out to sea with the ebbing tides and used in the coastal food web. E.P. Odum of the University of Georgia referred to it as the '**outwelling**' of organic matter to feed the coastal fish and shellfish.

Then the pendulum swung in the other direction and it was suggested that most of the production of salt marshes simply decayed on the marsh. Therefore, it was argued, salt marshes were relatively useless and could be filled or dredged. The truth is somewhere between these two extreme positions. In the Maritimes the ecological value of salt marshes has been clearly demonstrated. We can safely say that the salt marshes around the Bay of Fundy do support the fish and birds to a considerable extent. Shad eat a swimming shrimp called *Mysis* which in turn eats fine particles of salt marsh grass in large quantities. Migrating wading birds eat a burrowing shrimp called *Corophium* by the million, and it depends on salt marsh detritus. In summer it feeds mainly on microscopic algae that grow on the mud surface, but in fall and winter when these do not grow, it turns to the particles of plant material derived from the nearby salt marshes (4).

Thus we can see that there are two main mechanisms leading to high productivity in estuaries: the estuarine circulation which makes possible high productivity of the phytoplankton, and deposition of sediment which makes possible the development of salt marshes.

FJORDS

The bottom picture in Figure 2 shows a slightly different type of estuary, known as a fjord. Many fjords originated as channels cut by glaciers. Where the glacier stopped, it dropped a load of sediment, so that there is a shallow sill at the mouth of the estuary. This has the effect of holding pack a pool of salty water on the bottom for long periods, while the normal estuarine circulation goes on above it. Bedford Basin is an example. One of the problems with fjords is that if there is too much biological productivity in the water above, the decaying remains which sink to the bottom use up all the oxygen and we have a layer of oxygen-depleted water in which many bottom living organisms are killed. This has been shown to occur in Bedford Basin (5), and in years gone by was used as an argument against siting a major sewage treatment plant in Fairview Cove.

ESTUARIES AS HABITAT FOR FISH AND SHELLFISH

Many of the animals found in an estuary have evolved migration patterns which enable them to make best use of the habitat. For example, in the Sheepscot Estuary in Maine it was clearly shown that young herring, after leaving the spawning beds, stayed in the landward-flowing bottom water until they were near the head of the estuary, then rose to the surface and spent many days feeding in the rich plankton as they slowly moved back towards the mouth of the estuary.

Fortier and Legget studied herring in the St. Lawrence Estuary. Here too, the herring larvae moved upstream from the spawning beds until they came to a particularly favourable spot in the estuary. They then began to make periodic vertical migrations and alternated between riding upstream in the bottom water and downstream in the surface waters, while they fed on the plankton.

Flounders are particularly tolerant of lowered salinities so are frequently found in estuaries, and are often abundant both as adults and as juveniles. An intensive study of their behaviour showed that young flounders buried themselves in the bottom mud when the tide was ebbing but came up a little way off the bottom on the rising tide, thus getting carried up towards the head of the estuary. When they reached it, they moved up into surface waters on the rising tide and were carried into the small creeks of the salt marsh, where suitable food was particularly abundant.

Similar results were found with oyster larvae. These microscopic organisms are totally incapable of swimming against a current, but they maintain their position in an estuary by sinking to the bottom when the tide is ebbing, and rising to the surface to feed on the rising tide.

Shrimps are similarly adapted to the estuarine circulation. One species hatches its young near the mouths of estuaries. They travel up the estuary in the bottom water, rise to the surface near the head of the estuary, complete their larval life in the surface waters, then settle to the bottom after they have been carried out to sea. In this way they exploit the rich estuarine plankton to the full.

HOW MAN MAY INTERFERE WITH THE SYSTEM

Control of Runoff

Under natural conditions there is a seasonal variation in river runoff. For example, in Canada there is normally a peak at the time of snow melt. Over evolutionary time animals may have adapted to the seasonal pattern of runoff and to the monthly and yearly changes in tidal flow. Any major disruption of this pattern is likely to be detrimental to the organisms. For example, they may time their breeding to coincide with high spring runoff and correspondingly strong bottom currents to carry the young stages up the estuary. Now suppose that a major tidal barrage is built, and instead of allowing the meltwater to run off naturally, it is held back and used to generate power over several months. The expected conditions of strong circulation in spring will not occur and the animal may have its breeding cycle interrupted. There are many ways, too numerous to mention, in which disruption of the seasonal pattern of river runoff can be expected to adversely affect fish habitat in estuaries.

Isolation of Salt Marshes

Consider a situation in which a road bed is built along the edge of a salt marsh, blocking the ebb and flow of the tide. The marsh is now cut off from its regular supply of nutrients in the twice-daily inflow of sea water, and the plants become less and less productive and may eventually die. Not only that, but we have seen that there are many fish and invertebrates that migrate in and out of the salt marshes and use their organic production. Construction of a barrier to this migration makes that kind of interaction impossible, and the fish production is that much reduced.

Eutrophication

Eutrophication is the term we give to any perturbation that greatly increases productivity in a localized area. A common cause of eutrophication is the release of treated or untreated sewage into an estuary. This leads to a big increase in the supply of plant nutrients and as a consequence the phytoplankton becomes extremely abundant. For some purposes, increased phytoplankton production may be a good thing, but in parts of Chesapeake Bay, for example, the phytoplankton has become so abundant that the water in places is green and turbid, and the larger rooted plants that have grown there for many years have died out for lack of light. The process is hastened by dense growths of small seaweeds all over the surfaces of the rooted plants, tending to smother them. The rooted plants are important as traps for silt, and as habitat for various species. The changes are associated with serious deterioration in the production of a number of species of commercial importance.

Another consequence of eutrophication is that microscopic organisms feeding and growing on the added nutrients may become so abundant that they use up all the oxygen in the water and there are massive kills of fish and shellfish. In the 1960's the Thames estuary contained zero oxygen for 50 km below London Bridge as a result of the discharge of London's sewage into the estuary. Needless to say, it was fishless. Over the next two decades, clean up of the discharge (6) resulted in a return, first of the common estuarine fish and finally of the salmon that had not been able to get up the Thames for hundreds of years. Here in eastern Canada we do not have the population density to produce such a spectacular effect, but the effluent from pulp mills has the potential to produce similar consequences.

Contamination with sewage, even at a more modest level, also brings with it the danger that shellfish, which live by filtering fine particles from the water, may accumulate organisms which cause sickness in humans, so that the shellfish beds have to be closed.

The runoff from cities often contains substances other than sewage that may be toxic to the organisms or cause the organisms to be toxic to man. Heavy metals are an example. Often these wastes are carried in the sewers and even if the sewage is treated to reduce the biological oxygen demand, or even to remove plant nutrients, it is not practicable to remove contaminants like heavy metals. The best solution would be to control the discharge of heavy metals at their source.

Finally we come to a topic that is very much in the news at present. Under conditions of particularly high nutrient concentrations and with the appropriate set of physical oceanographic conditions, we find explosive growths of microscopic plants called dinoflagellates which have the characteristic of secreting toxic substances that kill fish and shellfish. One well-known type makes the water appear blood-red, so, the term "red tide" is often used to describe any of these toxic blooms. It appears that they are becoming more frequent than they used to be, especially on the eastern seaboard of the USA, and it has been suggested that the problem is a chronic long term eutrophication of coastal waters. Proponents of this idea suggest that the cumulative effect of increasing sewage pollution, runoff of fertilizers from agriculture and nutrients from air pollution are enough to create conditions where red tides are more likely to occur. This serves to remind us that fish habitat can be degraded slowly and almost invisibly by small changes in a number of factors, each of which, by itself, appears not to be important.

COASTAL WATERS

In coastal waters outside the estuaries, in summer, it is usual for the water column to be divided into two layers. The upper layer is lighter because it is warmed by the sun. The lower layer is colder and heavier. As discussed earlier, the plants in the upper layer use up the nutrients and their growth is then slowed. The lower layer contains abundant nutrients. Any mechanism to bring the nutrients to the surface is likely to stimulate plant production.

One such mechanism is the wind (Figure 4). If it causes the surface layer of water to move away from the shore, there must be an upwelling of deeper, nutrient rich water close to the shore. This is one of the reasons why coastal waters are more productive than the open ocean, and why we must protect them.

Another mechanism is tidal mixing. As in the estuaries, the daily rhythm of the tides causes water to flow rapidly across the bottom, and this generates turbulence in the water above. If the tidal current is strong enough and the water shallow enough, the water will be mixed from top to bottom. In areas that are tidally mixed in this way, all the nutrients contained in the deep waters are carried to the surface and there is more phytoplankton production. One such area is the coastal water off southwest Nova Scotia (Figure 5). The tidal mixing probably accounts for this being one of the most productive areas for lobster and kelp, and for it being a major breeding ground for herring.

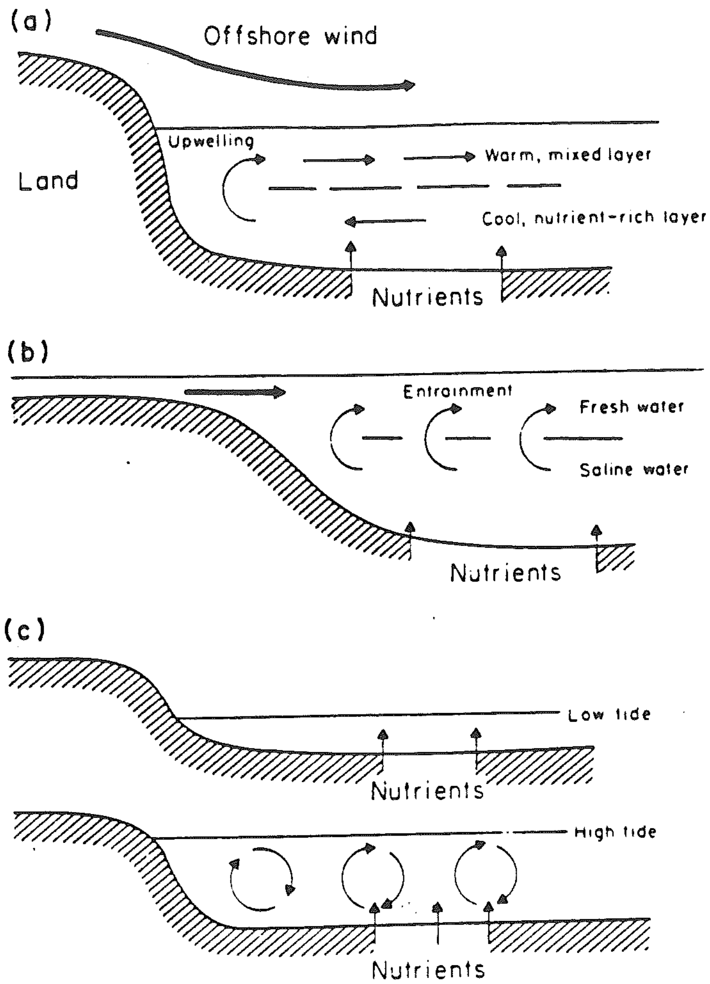

Figure 4. Causes of vertical mixing in coastal waters. a - wind; b - river runoff; c - tidal mixing.

If we consider an inlet like St. Margaret's Bay, and we see that some small rivers run into it at the head of the bay, we may ask whether it is an estuary. The answer is that since it forms in summer the two layers that I have just described as characteristic of the open coast, it is more like coastal waters than estuarine waters. Nevertheless, calculations show that the runoff of the rivers has the effect of causing upwelling of nutrients near their mouths, and these cause the bay to be more productive than it would be otherwise.

Sutcliffe had the idea that the Gulf of St. Lawrence could be likened to an enlarged version of St. Margaret's Bay. In the upper reaches is an estuarine part, with its two-layered circulation driven by river runoff, and out in the Gulf proper we have water that stratifies in summer like ordinary coastal water. Near the mouth of the estuary there is a region where the flow of freshwater brings nutrients to the surface, and these are carried throughout the Gulf and stimulate the plant production. Sutcliffe argued that in years of strong spring runoff the productivity of the Gulf should be higher than in years of low runoff. Looking for some long-term records of productivity in the Gulf, Sutcliffe picked the records of landings of Quebec lobsters (7). When these were plotted above the records of the river runoff, (Figure 6) it was clear that they varied in parallel. This was clear evidence of a connection between the river runoff and the shellfish production. Sutcliffe found that there was a nine-year lag between the peak of river runoff and the peak of lobster landings, and he explained it by saying that it is the larvae that survive better in a year of good runoff, but it takes them nine years to grow up and be caught. In fact, the time taken is more like five years, so Sutcliffe's story is not yet complete.

THE IMPORTANCE OF KELP BEDS

On the open coast, where the full force of the waves is received, much of the shoreline is rocky. On this coastline the important large plants are seaweeds rather than salt marsh grasses. Of particular importance are the large seaweeds known as kelps. They are extremely productive, even more so than the salt marsh grasses. They grow rapidly at the base and at the tips are constantly eroding to release particles of plant material into the water. These particles are readily used by shellfish such as mussels. Studies in several parts of the world have shown that mussels living in kelp beds make use of the seaweed particles, and that lobsters living in those same kelp beds feed on the mussels.

Kelp beds are very dense along the rocky shores on the open Atlantic side of Nova Scotia. We now know that they are important as habitat for lobsters. In the 1970's large areas of kelp beds were destroyed by a massive outbreak of sea urchins, and as the kelp beds declined so the lobster catches declined (8) (Figure 7). In the years 1980-83 the sea urchins were decimated by a disease, and as soon as the urchins were gone the kelp came back. At about the same time the lobster catches went up. A study by Miller (9) showed that the lobsters in the kelp beds were already several years old (Figure 8), when the kelp beds were newly regener-

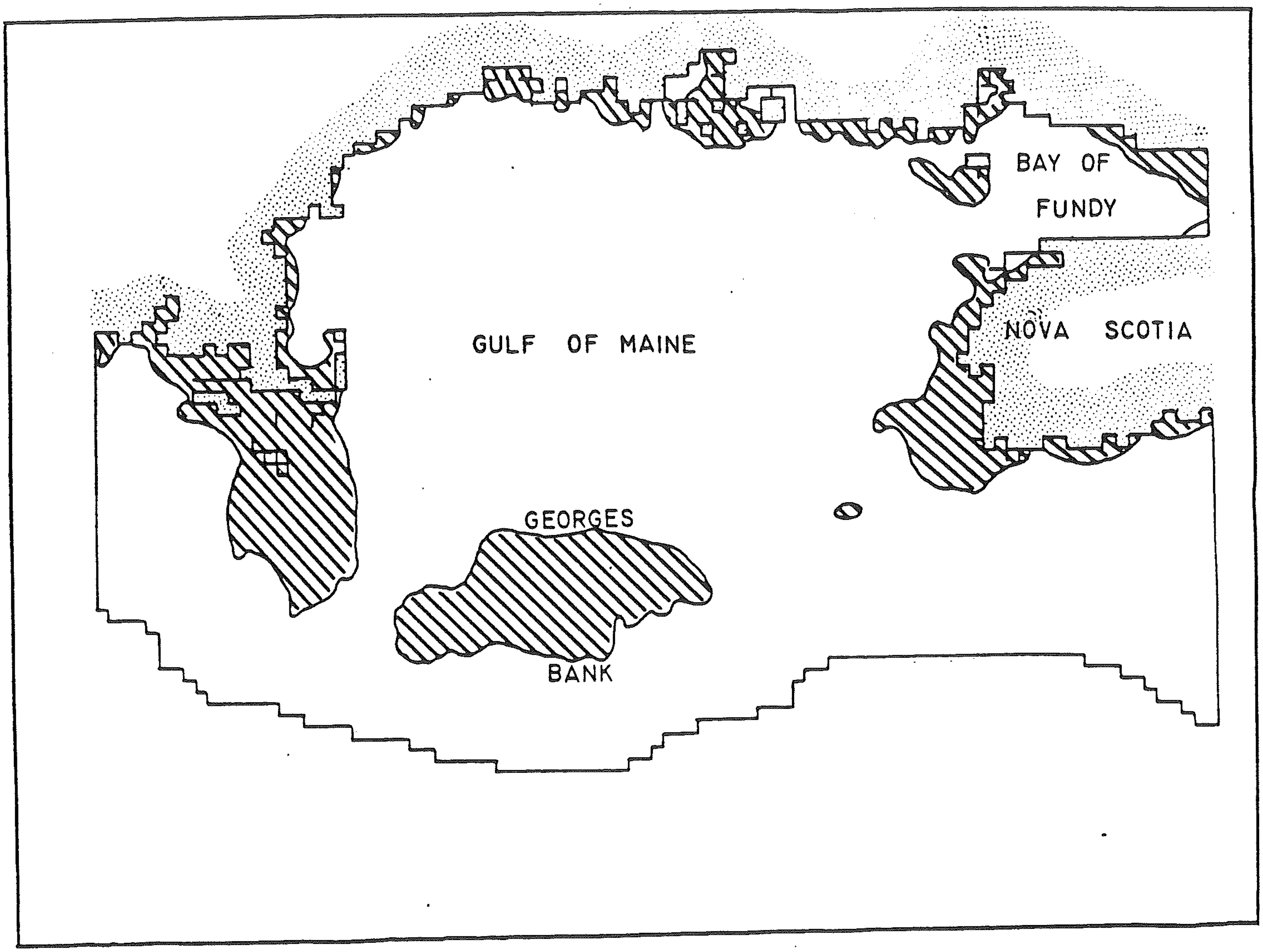

Figure 5. Tidally-mixed areas of the Bay of Fundy-Gulf of Maine-Georges Bank region.

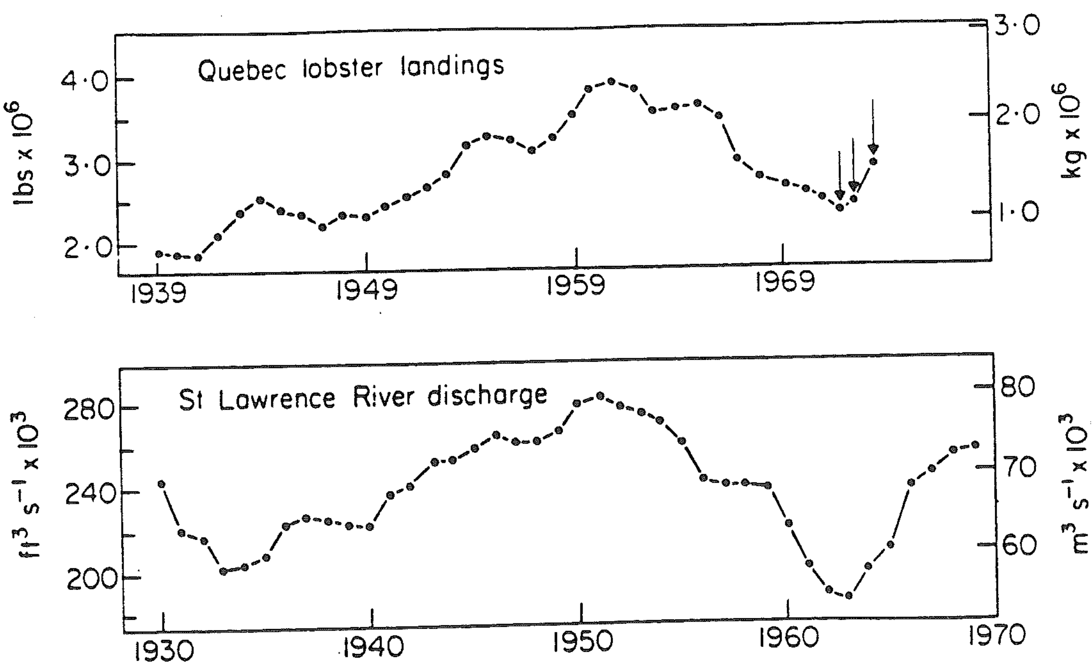

Figure 6. Relationship between river runoff and lobster landings. Arrows indicate predictions of landings based on correlation of previous years.

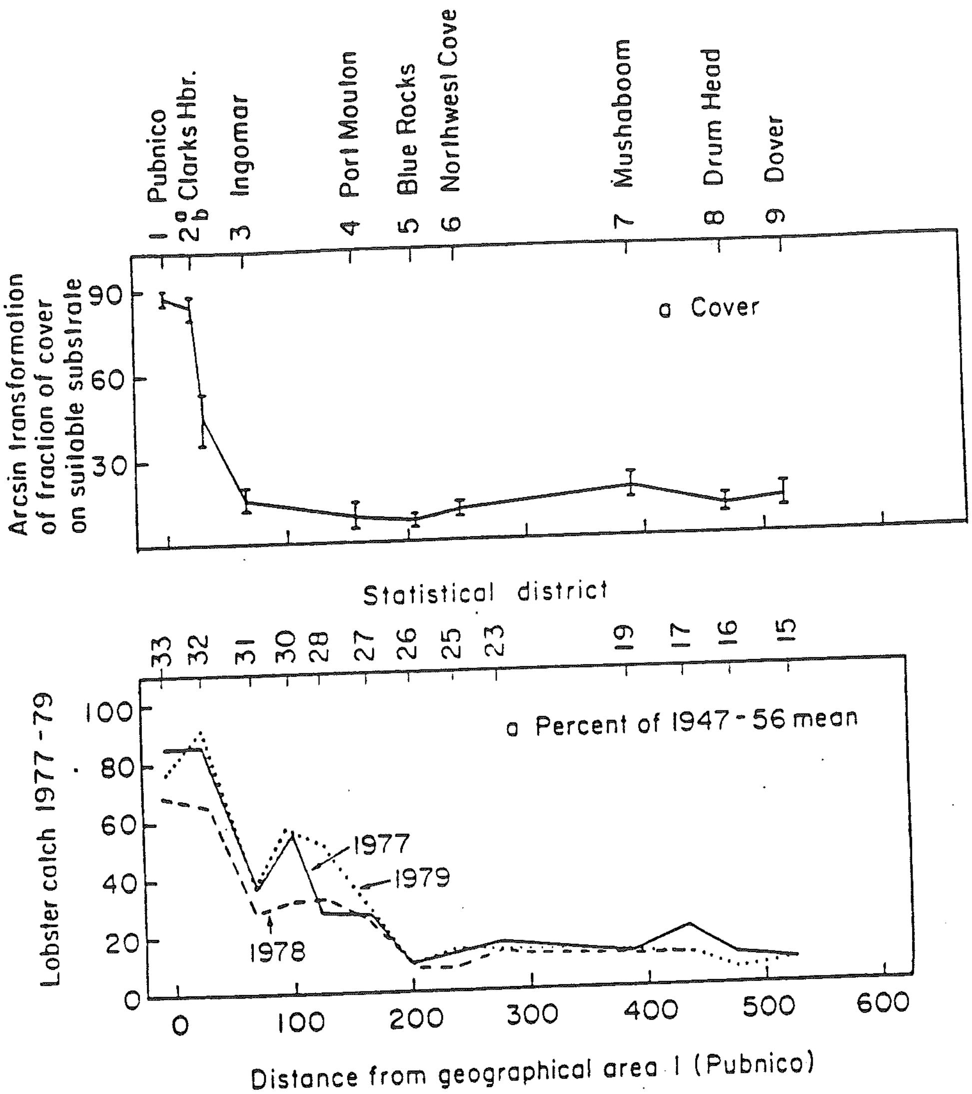

Figure 7. Relationship between kelp abundance and lobster landings in different locations on the Atlantic coast of Nova Scotia.

ated. It seems probable that the lobster population had increased by immigration into the kelp beds from elsewhere, showing that the kelp beds are preferred habitat.

The purpose of explaining these relationships is to show that kelp beds are not independent entities that can be harvested without any particular consequences for the other resources in the system. Kelp is a valuable crop, but it plays a role both in sustaining other organisms which use the fine particles it produces, and also as a habitat for lobsters and other species. There is a tradeoff between the utilization of the kelp as a resource and the probable effects on other species of equal or greater value.

SUMMARY

In this short review of a very large topic I have tried to emphasize those aspects of estuarine and coastal habitat that are basic to maintaining the high productivity of resources that we all desire.

The basic principle running through it all is that plant production goes on near the surface of the water, where the light is strongest, but the reservoir of fertilizing nutrients that the plants need are in deep waters, near the bottom. Any mechanism that brings the nutrients to the surface, that is to say any mechanism for upwelling, will increase productivity. Three main mechanisms are at work:

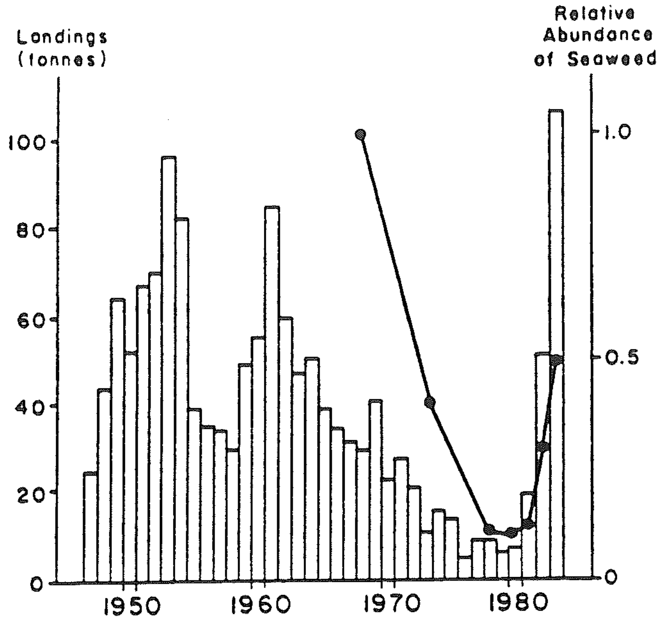

Figure 8. Relationship between kelp abundance and lobster landings.

(1) The runoff of a river into an estuary sets up an "estuarine circulation" in which nutrient-rich water is drawn into the estuary, then brought to the surface. For this reason, estuaries are especially productive. Modification of river flow will change the functioning of an estuary.

(2) Tidal mixing. The ebb and flow of the tides sets up tidal currents which, as they move over rough bottom, set up turbulence in the water above. Tidal mixing interacts with freshwater flow in an estuary to enhance production still further. Some areas of coastal water such as off SW Nova Scotia, are tidally mixed most of the time and are therefore more productive than other waters.

(3) Wind-driven currents may carry surface water away from the coast. When this happens, deep water upwells along the coast to take the place of the water that has been carried away. This upwelled water is rich in nutrients and is another factor causing coastal waters to be more productive than the open sea.

In addition to these mechanisms for increasing phytoplankton and zooplankton production, we have seen that large marine plants, especially salt marsh grasses and seaweeds, grow at the edge of the sea and make major contributions to the productivity of coastal waters.

I have concentrated on showing what are the mechanisms that stimulate plant production. Once that production is in place, the invertebrate animals are able to exploit it and the fish are able to feed on the invertebrate populations. It is clear that estuaries and the coastal zone are regions of especially high production and are therefore high quality fish habitat.

Since the river basins, the estuaries and the coastal zone are sites of high density human populations, particular care is needed to protect them from the deleterious effects of human activity.

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QUESTIONS

What brought about the bloom of sea urchins that destroyed the kelp? Is it a cyclic phenomenon?

Mann: All we know is that they have gone from being scarce to being abundant and back to being scarce again, but that in itself does not constitute a cyclical pattern. Before that we only have evidence from fishermen who remember years when there were lots of urchin shells on the beach. The question of why they became so abundant remains unanswered. We originally suggested that the lobsters are the natural predators of the urchin, and because we have been fishing lobsters heavily that allowed the sea urchin to become very abundant. But we have not been able to prove that and others have felt that it was not a very good idea. Another idea is that normally the recruitment of sea urchins is very dependant on the currents. They spend many weeks as plankton, floating passively around and if they all get carried out to sea that will be a bad year for sea urchins. It may be that there was one year in which the oceanographic conditions were extremely favourable for urchins and then they were so abundant that the natural predators couldn't keep up with eating them. They then became so abundant that they destroyed all the kelp beds. However, we must say that we honestly don't know.

Do you feel that the construction of the Canso Causeway has affected lobster recruitment?

Mann: That is another theory that has been put forward. It sounds like a good theory but we haven't been able to collect evidence either for or against it. The theory was that when theStrait of Canso was constructed this blocked Chedabucto Bay, which gets its larvae from the Gulf of Saint Lawrence through the Strait. This resulted in the absence of lobster larvae, so after a few years its lobster population collapsed. When that population collapsed, it used to feed its larvae on the prevailing currents to locations down the Eastern shore, so in turn they collapsed and so on down the coast. Its an interesting theory but I am not sure how you would decide whether it is the causative factor in the stock decline. Since the lobster populations have recovered and the Canso Causeway is still there it makes you wonder.

Is the mixing of the nutrients to stimulate growth a year round type of mixing?

Mann: The only time that it is important is in spring to fall during the growing season of the plankton.

Effects on Fish Habitat of Physical Modifications in Estuaries

Graham R. Daborn

ABSTRACT

Estuaries have played a supremely important, but often unrecognised role in the development of human civilisations throughout the world. Probably a quarter or more of the world's population lives on estuaries, or in conurbations that have grown up around estuarine systems. Many of the rest have indirect effects on estuaries through their influence upon upstream watersheds. Relentless modification of estuarine morphology has transformed the role(s) played by most estuaries, because the physical characteristics of an estuary determine the nature and extent of its biological productivity.

Urban and industrial development in estuaries and their watersheds has led to extensive modification of estuary morphology. Bulkheads, wharves and pilings installed to reduce erosion convert interactive, energy-absorbing shorelines into channels, resulting in conservation of tidal and river flow energy, and hence affecting mixing characteristics of the estuary. Bridges and causeways variously diminish the cross-sectional area of the channel, increasing current velocities (and hence the probability of erosion) in some locations. Causeways, in particular, diminish tidal flushing, favouring stratification and decreasing estuarine circulation. Land "reclamation" schemes for residential, industrial or agricultural development remove tidal marshes as productive units contributing to the estuary, and also lead to further channelisation in order to protect land of elevated human value.

The impact of these changes on fish habitat are extensive and mostly detrimental. Removal or destruction of spawning or feeding grounds, for both commercially important fish and forage fish, has been extensive. Changes to the mixing characteristics of the estuary modify food webs. While estuaries are resilient, adjusting to changed patterns of mixing, erosion and sedimentation, the time involved is considerable. A new equilibrium may take decades to establish, by which time new pressures for change are developing. Even small local modifications may not be innocuous: the cumulative effect of many small changes has commonly been underestimated.

Estuaries also interact strongly with all systems to which they are connected—the watershed upstream, the nearby coastal zone, and even very distant waters—through tidal and biological effects. These points will be illustrated with reference to eastern Canada.

INTRODUCTION

The interface between freshwater and marine habitats is one of Canada's most poorly known environments (1). Estuaries are obviously the recipients of a multitude of abuses occurring upstream, and act as important buffers between the land and coastal seas. They are also strongly influenced by a wide range of oceanic events, from rhythmic tides to dramatic storm surges. But the greatest influences upon estuary condition and function during the last few hundred years have undoubtedly been man's activities.

Historically, estuaries have played a supremely important role in the development of most human societies. They provide food, transportation, waste treatment, recreation, land (through "reclamation"), sites for urban and industrial development, cooling waters for thermal power stations, mechanical and electrical power, and so on. For centuries we have freely modified estuaries by construction of sea-walls, dykes, bridges, wharves, piers, harbours, canals and causeways. Within the last century our capacity to modify coastal systems has increased dramatically, and as a consequence many estuaries have suffered severe degradation. Even modest changes in physical parameters appear to have profound ecological consequences. Furthermore, estuaries are characterised by being in a state of continual change due to natural processes of erosion, sedimentation, and changing sea level. The complexity of these interactive processes is forbidding. In general, our ability to change these systems far exceeds our ability to predict the consequences of those changes.

To a great extent, the degradation of estuaries can be attributed to changes in their physical characteristics—particularly modifications of water flow patterns and velocities. Understanding the effects of structures that affect water flow is a key to knowing what must be done to preserve our rapidly diminishing fish habitat.

EROSION CONTROL

A high value has traditionally been placed upon coastal property for both aesthetic and practical reasons. This is in obvious and direct conflict with the inexorable process of erosion seen along almost all shorelines. Although the rate varies considerably from place to place, the combination of rising sea level and geologically 'soft' coastal margins results in the loss *on average* of 1.5 m per year over much of the eastern seaboard of North America (2). Consequently, much effort has been expended to counteract the loss of land through beach replenishment programmes, and construction of groynes, bulkheads, tombolas, sea walls and breakwaters of various kinds. Although much imagination has been shown in engineering design, the failures of these structures to perform their function have been frequent and often spectacular. Causes of failure can be traced to two fundamental underestimations: the sheer power of waves and coastal currents, and the long distance interconnections between one portion of the shoreline and others. Frequently, construction of a breakwater or groyne induces beach stability or replenishment at the site, but increases erosion along stretches of shoreline downcurrent of the construction.

A classic example of accelerated erosion resulting from construction of a breakwater is illustrated in Figure 1. From 1927-28 a detached breakwater was installed almost parallel to the shore at Santa Barbara (California) to protect the harbour from strong wave action. Although it had been anticipated that the natural drift would pass sand through the gap between the shore and breakwater and thus keep the harbour clear, immediately after construction sedimentation began to occur in the sheltered lee of the breakwater. In 1930, therefore, the breakwater was attached to the shore. This induced extensive deposition of sand on the western, updrift side, and within seven years the shoreline had accreted to the end of the breakwater and

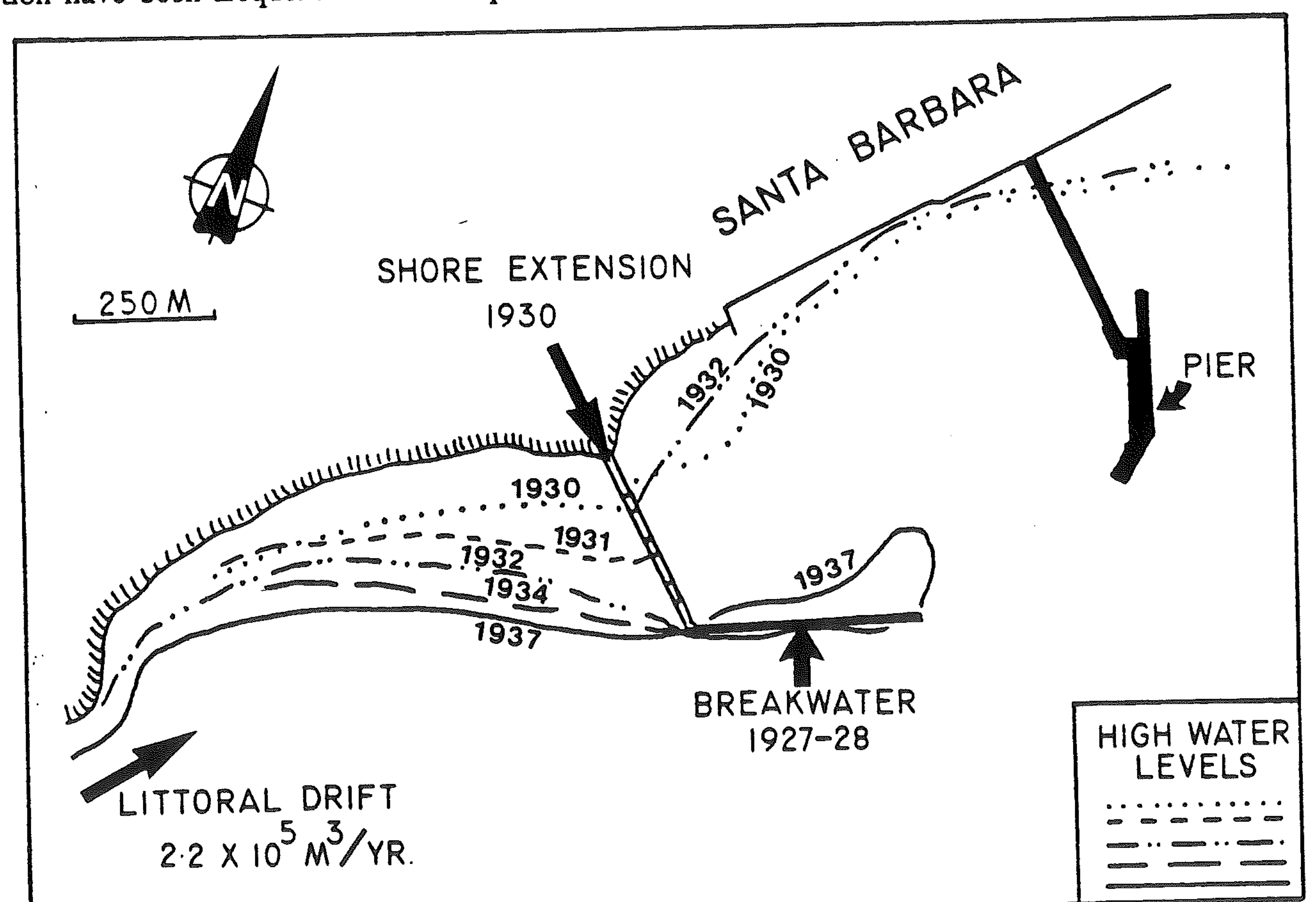

Figure 1. Effects of breakwater construction on erosion and deposition of sediments. (After Komar, 1983)

began to form a spit that would eventually have closed the harbour. The solution has been to dredge the harbour continuously ever since. Of equal significance to the threatened closure of the harbour, however, and of greater importance to the issue of fish habitat, is that the shore-attached breakwater induced extensive shoreline erosion on the down-drift side, that could be detected for almost 40 km.

In other situations, structures for erosion control or stabilisation of estuarine margins can have quite different effects. In most cities built upon estuaries or the lower reaches of rivers, urban and dock development commonly results in construction of vertical walls or embankments to prevent spring tide or storm surge flooding of the settlement. Such smooth, uniform surfaces significantly decrease friction, conserving the energy of water movement. The effects of this in terms of estuarine mixing processes, which determine the characteristics of the estuary as a fish habitat, are probably too subtle in most cases to be detectable. They can, however, be of considerable significance. The largest tidal bore in the world occurs in the Tsientang Kiang River of China, where a wall of water some 5 m high surges upstream for many kilometres. For centuries the Chinese constructed earth and stone embankments to constrain the bore and prevent devastating flooding of peripheral land, only to find that the bore progressed ever further upstream. Eventually, recognising the need to dissipate the kinetic energy of the bore, engineers incorporated stone buttresses on the river side, against which the wave could break.

Encouragement of sandy beach formation is commonly done for two purposes: to reduce erosion of soft shorelines, and for aesthetic reasons. Well-designed and constructed groyne fields have certainly been effective in many instances. From a biological point of view, however, sandy beaches are relatively unproductive, supporting few fish species compared with either rocky or muddy shores. Consequently, many such modifications of the shoreline in or near estuaries must be seen as exchanging existing or potential fish habitat for industrial, residential or recreational benefits. It is also essential to recognise that the benefits desired may be of relatively short duration: the continued rise of sea level will require persistent upgrading and redesign of most man-made shoreline structures.

TRANSPORTATION

Most of the world's harbours are or were estuaries. Progressive development in size, accommodation of greater and greater quantities of shipping, and particularly the adjustments made to accommodate larger and larger vessels, have generally resulted in wholesale elimination of such estuaries as fish habitat. The natural soft margins of the estuary are removed in favour of docks and wharves; productive marshes and tidal flats disappear under asphalt and concrete. In most harbours, recreational fishing is now the prerogative only of children whose interest lies in the catching of a fish regardless of its species or edibility. Since most harbours are associated with urban regions, the removal of productive habitat is compounded by the noxious materials added to the estuary, leading to widespread anaerobic conditions and toxic water and sediments.

As indicated in the previous paper, the natural estuarine circulation typically causes an upstream migration of sediments, which tend to accumulate near the head of the salt intrusion. As urban centres around ports grow, construction activities dramatically increase the quantities of sediment contributed to the estuary: erosion associated with construction produces 10 to 100 times the volume of sediment yielded by mining or agriculture. In North America it has been estimated that an increase of 1,000 people in a city population results in 600 to 1600 tonnes of sediment being mobilized during the first five years (3). Much of this ends up in the estuary.

Attempts to deepen the harbour to allow vessels of greater draft to enter the port also cause an increase in the upstream flow of bottom water, inducing even more rapid deposition of sediments than before. Dredging of estuarine harbours thus becomes a permanent requirement with a positive feedback feature: the more one removes sediments from a region of natural deposition, the more rapidly those deposits are replaced. Logic should therefore suggest an alternative strategy.

The environmental implications of harbour dredging are widespread, and relate both to the nature of the sediments (e.g., particle size, density) and the associated chemical loading. These are discussed in the following paper.

The requirements of transportation systems have resulted in contruction of large numbers of bridges and causeways across estuaries at convenient points. In general, bridges cause little loss of fish habitat except where extensive access roads are involved, and where dredging of intertidal sediments is necessary for footings or scour protection. Bridge stanchions do decrease the cross-sectional area of the river or estuary, resulting in local increases in current velocity, but these are usually minor effects that are readily overcome by appropriate design.

Estuarine causeways, however, are a very different problem. Generally constructed of rock-fill and/or concrete, causeways provide a relatively inexpensive means of traversing a shallow estuary, particularly in regard to ongoing maintenance costs. The environmental costs, on the other hand, are usually extremely high and often underestimated. In Atlantic Canada many estuaries have been extensively modified by causeway construction in recent decades. Three of these provide very useful examples of the extent to which a causeway modifies important natural estuarine processes.

In 1958-60 the Maritime Marshland Rehabilitation Administration (MMRA) constructed the Annapolis River Dam across the narrows of the Annapolis River near Annapolis Royal, N.S. (4). The objective was to replace a failing highway bridge and to protect some 1740 ha of "reclaimed" agricultural marshland from flooding during high river runoff and high tide events. The dam incorporated sluice gates for decreasing the river level in anticipation of extreme runoff, and a fishway to permit passage of migratory species that spawned in the Annapolis Estuary and River. The effect of the dam was to convert a vertically homogeneous estuary with up to 9 m tidal range into a stratified, salt wedge estuary (5) (Figure 2). With stratification, bottom deposits up to 30 km upstream became covered with fine silt because of the lack of tidal turbulence. Benthic communities, which remained diverse and productive below the dam, were impoverished upstream. Direct effects on fisheries are difficult to determine because there had been no environmental studies of consequence prior to construction of the dam. The river continues to harbour a variety of species, some of which spawn in the river, but no firm information indicates whether stocks have decreased in size since the construction. In 1980-84 the estuary was further modified by installation of a tidal power station, which has had a variety of environmental effects. Operation of the turbine requires the sluicing of large quantities of water into the headpond on the rising tide, with a consequent increase in vertical mixing above the dam. In some ways, therefore, the development of the station may be seen as reversing some of the negative effects of building the original causeway. In other respects, however, particularly with regard to movements of mature and juvenile fish, the establishment of the station has compounded the problems (6, 7).

From 1968-70, a 1050 m causeway containing five sluice gates and a fishway was constructed across the Petitcodiac River near Moncton, N.B., about 21 km below the previous head of tide, and 34 km above the mouth of the estuary. As with the Annapolis dam, the objective was to prevent flooding of reclaimed marshland, and to provide a highway crossing (8). Tidal range averaged about 6.1 m, and a conspicuous tidal bore occurred on spring tides. Tidal resuspension of fine silt and clay particles from surrounding mudflats maintained a very high turbidity in the water column, with suspended loads of 10 to 25 g/L near Moncton. Within two years of closure of the causeway a massive mudflat some 20 km in length had formed on the seaward side, which increased in height at 1.5 to 2 m per year in some places. In addition, the permanently open fishway allows passage of almost 400 tonnes of sediment upstream on each tide, most of which is retained above the dam. The consequence of this construction has been elimination of large areas of feeding grounds for migratory fish, and increased erosion in the headpond above the causeway.

A similar sequence of events accompanied construction of a 900 m rock-filled dam across the Avon

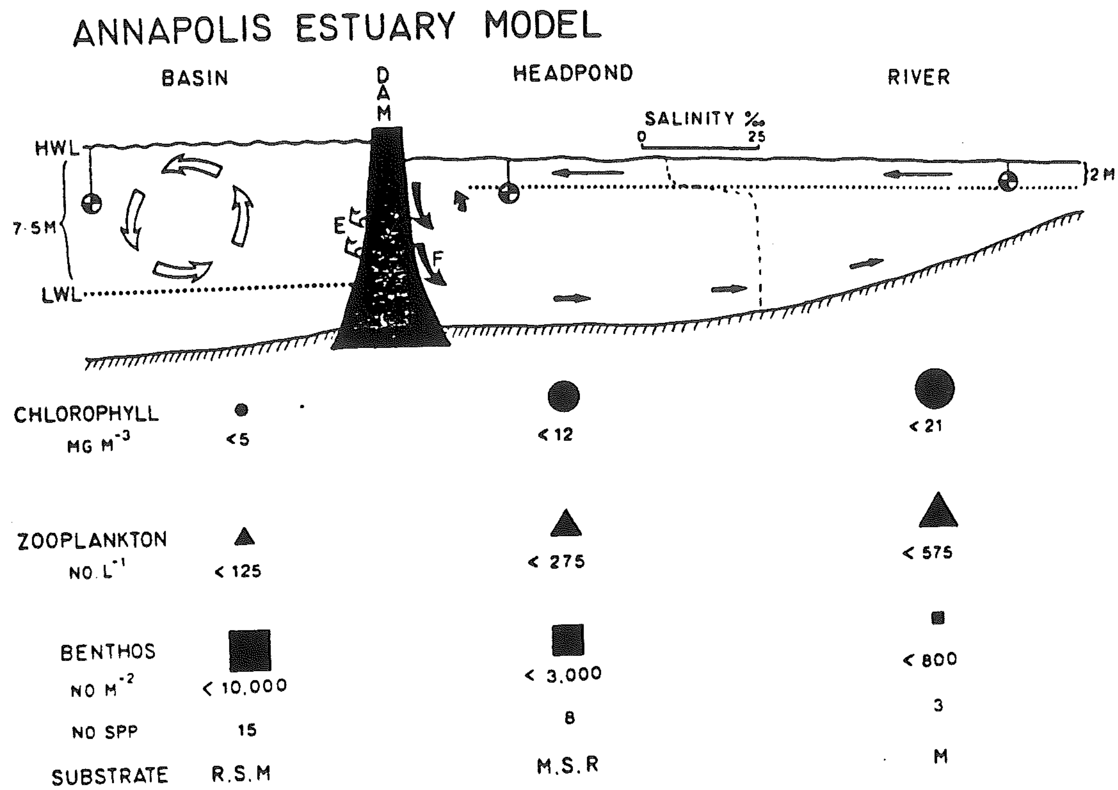

Figure 2. Effects of the Annapolis Tidal Dam on structure of the Annapolis Estuary.

River near Windsor, N.S. in 1969. Within 6 years a mudflat 750 by 600 m had formed on the seaward side of the dam, with rates of accumulation exceeding 15 cm per month. At the present time it appears that the mudflat is continuing to extend subtidally down the estuary. The continuing shallowing of the estuary is seen as a serious threat to shipping operations at Hantsport about 8 km away.

Studies of the emerging mudflat at Windsor have demonstrated the long time sequence involved in adjustment of the estuary to the changed conditions. At first the rates of sedimentation are so rapid that they are biologically barren: water content is very high, so that the muds remain too fluid for colonisation by benthic organisms. The area becomes of no use as spawning or feeding habitat for fish or shorebirds that depend upon benthic crustaceans, worms or molluscs, until the mudflat has consolidated sufficiently. Recent observations of both shorebirds and fish-eating birds (herons, cormorants) foraging on the edges and surface of the mudflat indicate that the benthic community is now becoming re-established, more than a decade and a half after the dam was built. Patches of saltmarsh grasses have also appeared on the mudflat in recent years, suggesting that consolidation of the mud is sufficiently advanced that the natural process of marsh succession is now under way.

These examples illustrate some consequences of the construction of causeways across estuaries, but there are many others. Decreasing the tidal flushing in an estuary encourages accumulation of nutrients and sediments derived from the rivers above, which may lead to eutrophication. As with lakes, eutrophic conditions are generally unfavourable for higher quality fish species that Man generally prefers. High surface production by phytoplankton, if allowed to settle below the freshwater-saltwater interface into the poorly-circulated salt wedge, will lead to anoxic conditions, with destruction of benthic animals and degradation of fish habitat. Many current examples of this are to be found in Prince Edward Island, where a programme of removing causeways and replacing them with bridges has recently been initiated.

Elimination of well-flushed intertidal and tidal flats reduces the productivity of those elements that often make estuaries favourable nursery and feeding areas for fish. Given time, the stratified portions of the estuary may develop productive pelagic communities, and in some circumstances might be utilised profitably by mariculture operations that can benefit from increased phytoplankton and pelagic production. Often, however, pollution may prevent this.

LAND "RECLAMATION"

Tidal marshes have been exploited by Man for centuries, usually for some economic benefit. They constitute a significant, often preeminent, component unit of estuaries, particularly in temperate regions (9). Because of urban and industrial sprawl, many marshes in both North America and Europe have been eliminated for housing, factories, or landfill sites. An older and apparently more justifiable activity has been "reclamation" of marshlands for agricultural purposes.

In the Maritime provinces, dykeing and draining of saltmarshes to create fertile agricultural land began with the Acadians in the early 17th century. It has been estimated that within a century of the establishment of the Habitation at Port Royal, N.S. (in 1605), most of the 35,700 ha of saltmarshes surrounding the Bay of Fundy had been "reclaimed" from the sea, and were producing large quantities of wheat, hay and vegetables. Today, perhaps only 16% of the primeval saltmarsh remains, some of which has become 'out to sea' as a result of storms destroying dykes that have not been repaired. Assessing the consequences of this removal of natural saltmarshes in regard to fish habitat requires a sound understanding of the natural role of the marsh.

Tidal marshes occur where sediments accumulate in shallow estuarine or coastal shorelines. They are typically dominated by erect grasses, particularly the Saltmarsh cordgrass, *Spartina alterniflora*, at the lower end of the intertidal zone, and the Marsh or Saltmeadow hay, *Spartina patens*, toward the high water mark. As tidal waters flood over the marsh, the baffling effect of the grass stems induces sediments to accumulate, together with their associated nutrients, to create a fertile soil. Consequently, tidal marshes are recognised as places of high biological productivity. Ecologically, the marsh community is a pioneering one, colonising and stabilising a relatively new habitat. It therefore consists of relatively few species (i.e., has low diversity), some of which are both abundant and productive. Typically, a successional cycle of events can be seen in the development of the marsh (Figure 3), whereby the early pioneering species, *S. alterniflora*, colonises exposed mudflat, causing further sediment to accumulate, and producing a peat deposit that grows progressively upward towards the higher tide levels. Eventually the *S. alterniflora* marsh reaches the highest level of the local neap tides, where conditions are less suitable for that species, and it begins to decline, to be replaced by *S. patens* and other more tolerant plants. The process of upward growth of the marsh continues, until the level of high spring tides is reached, when *S. patens* gives way to terrestrial shrubs.

During this sequence, the productivity of the marsh changes considerably: on an annual basis, the lower *S. alterniflora* marsh is far more productive than the higher marsh grasses. In our region, much of the above-ground growth of the *S. alterniflora* zone is lost in the form of leaf detritus to the flooding waters, where it forms the basis of food chains leading through crustaceans to fish (Figure 4). Recent studies suggest that present day marshes contribute 25 to 30% of the total production of the inner regions of the Bay of Fundy. This is an ecosystem that provides important feeding grounds for more than 50 species of fish (including stocks that migrate from many parts of the eastern seaboard of North America), and also for millions of shorebirds that migrate there from the Arctic and the Caribbean to feed (5). If the natural sequence is allowed to continue, most of the marshlands would end up as high marsh which is infrequently flooded, and is less productive than the lower marsh. Under natural circumstances, however, periodic storms or changes in river courses result in a removal or destruction of the high marsh, setting the successional process back to the earlier, colonizing phase, with its higher productivity. Rising sea level has a similar effect.

It is this higher marsh, with its fertile soils accumulated over centuries, that has been the primary target of "reclamation" programmes aimed at increasing agricultural land. In this sense, the removal of the less

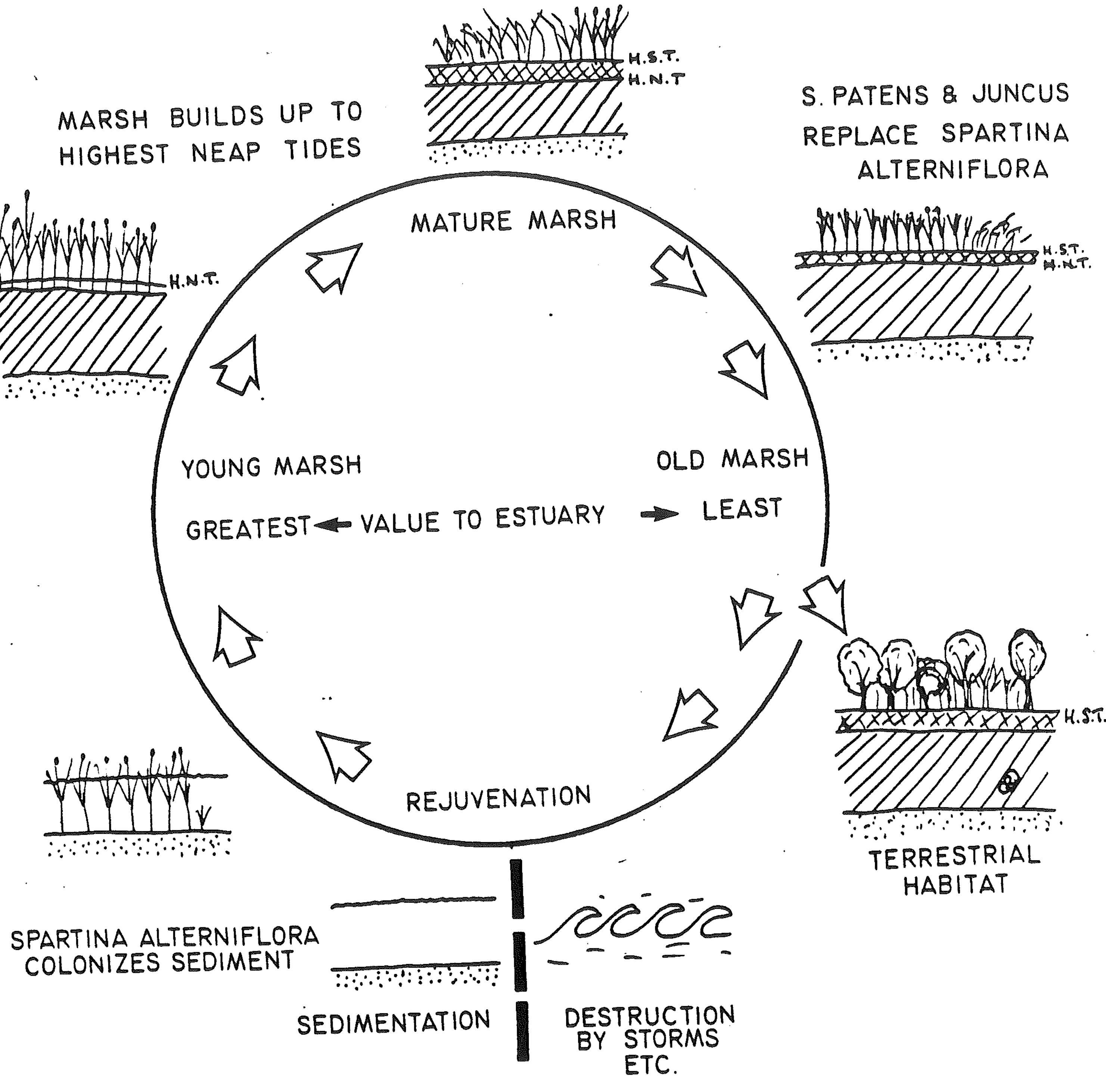

Figure 3. The saltmarsh cycle. (Modified after Godfrey and Godfrey, 1975)

productive high marsh, which contributes little directly to estuarine food chains, may be seen as an unimportant loss to fish habitat. On the other hand, such marshes are periodically destroyed by natural events and, as described above, replaced by much more productive low marsh. Consequently, breaking this cycle by converting high marsh into land for agricultural or landfill purposes, etc., represents an important loss to estuarine and coastal fishery resources.

The progressive conversion of the marsh into farmland of higher human evaluation, is coupled with protective dykes that also place a strict limit upon the seaward development of the lower saltmarsh.

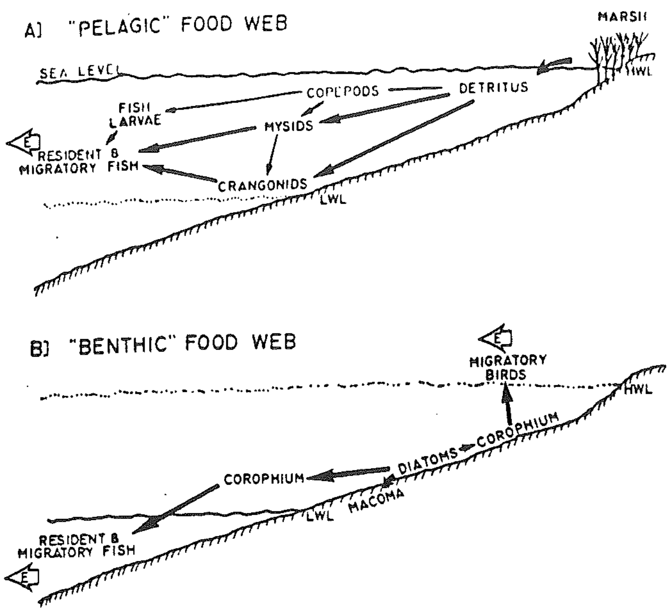

Figure 4. Food chains of the Bay of Fundy.

Some of the most extreme examples of land reclamation are to be seen in the Netherlands. Almost half of the 32,600 km² area of the country is below sea level, traditionally protected by dykes built around the seaward edges of marshes and dunes. Major reclamation schemes can be traced back at least to the 17th century, and minor schemes for many centuries before that. All reclaimed land, however, once settled, assumes a higher value in human estimation, and thus must be protected against natural events. A major disaster occurred in 1953, when a 3 m storm surge breached many dykes, flooded 1,365 km² of land, and killed 1,835 people. Immediately afterward, a government decision was made to close off all estuaries between the Western Scheldt and the European Canal using concrete and rockfill dams. Closure of the estuaries led to stagnation of impounded waters, the destruction of major estuary-based fisheries, pollution of drinking water, and elimination of important recreational assets. Finally, public outcry over the consequences of dam construction on such a massive scale caused planners to revise proposals for closure of the last major estuary, the Eastern Scheldt. A much more expensive storm surge barrier was used rather than a dam, in order to preserve what remained of estuarine fish habitat in the Delta area.

POWER GENERATION

Estuaries are commonly sites of power generation using nuclear or thermal stations, because of the need for cooling water. Large quantities of water are removed from the river or estuary, to be returned at considerably higher temperature. In the cool climate of eastern Canada, thermal pollution is not usually a major problem, although it becomes one in the warmer climates further south. In such circumstances, elevated summer temperatures not infrequently exceed the tolerance of larval fish, causing direct mortality, or indirect effects through depletion of oxygen and food resources. Direct mortality is also caused on screens used to protect power station intakes.

Where tidal range is sufficiently high, mechanical or electrical power can also be generated directly from the tidal movement of estuarine waters. Tidal power is an old technology: tidal mills yielding mechanical power were in operation in 11th century Europe, and could still be found in North America within the last hundred years. Modern proposals for tidal power development, however, are of relatively large scale and produce electricity. Tidal power stations ranging from 0.4 to 240 MW currently exist, and proposals for much larger stations are being seriously considered. The design for all is essentially the same: a rockfill or concrete dam is thrown across a macrotidal inlet (> 5 m tidal range) to create a headpond that can be filled by the flooding tide. The dam contains sluices for controlling water flow, and generators for electricity production. Power is usually generated on the ebb tide, although both flood and ebb may be used.

The physical effects of such structures are associated both with the dam itself and with the operation of the station. Construction of tidal barriers necessarily involves major changes in patterns of water flow throughout the estuary and the coastal waters with which the estuary is connected. Macrotidal estuaries are vertically well-mixed because of strong tidal currents. After construction of the dam, as shown in the case of the Annapolis Tidal Dam described above, tidal mixing upstream of the dam is so restricted that the impounded headpond tends to stratify. One casualty of this effect is the benthic community, which no longer receives continuous flushing or replenishment of food sources. Operation of a tidal power station may decrease stratification to some extent, depending on the amount of water sluiced into the headpond during filling. Nonetheless, the net result is likely to be a decrease in fish habitat for those species that previously spawned or fed in the well-mixed tidal reaches that existed before. Because of a decrease in turbidity of the water following stratification, light penetration in the headpond may increase, giving rise to greater primary productivity in surface waters. While this may not be transferred to the benthos because of the stratification, it could yield favourable conditions for pelagic species.

Experience with the Annapolis Tidal Power Station, which began operating in 1985, has reinforced the ideas outlined above with regard to the impact of the causeway on the ecological condition of the estuary. Sluicing operations required to fill the headpond on the rising tide have caused greater vertical mixing in the water column for some distance above the dam. Light penetration is greater than when the headpond was stratified (because the Annapolis River water is naturally stained a deep brown), and consequently primary production extends to greater depth than before the station was opened. The results suggest more favourable conditions for benthic animals in the region near the causeway, and consequently, more favourable habitat for fish foraging above the dam. Other effects, however, remain to be evaluated. In particular, claims that erosion of river banks has increased upstream, and that the sediments have passed through the dam to be deposited on intertidal areas below the dam, have not yet been verified. Observations within the headpond suggest that sedimentation above the dam has not permitted the expected increase in benthic populations except near the causeway itself. It is probable that several years will be required before conditions stabilise sufficiently.

Restriction of water flow to the turbine passages during generation poses significant threats to fish populations that are migrating seaward, or moving past the dam on feeding forays. Mortality rates at the Annapolis Tidal Power Station were found to be higher than expected for all stages of the life cycle (6, 7). It is possible that fish may be deterred from passing through the turbine, but obviously adequate passage downstream is an absolute requirement for preservation of natural stocks.

Dam construction in macrotidal estuaries, however, may have environmental effects that extend far beyond the limits of the estuary itself. Macrotidal estuaries derive their characteristic high tides from the fact that the natural period of oscillation of the water in the estuary is almost the same as, or a simple multiple of, the 12.4-hour natural period of the tides. As a result, each incoming tide is reinforced by the reflected wave of preceding tides - a phenomenon known as resonance—so that each is amplified. The natural period of the Bay of Fundy - Gulf of Maine - Georges Bank (FMG) System is approximately 13 1/3 h: shortening the Bay by construction of a barrage at its head will tend to bring the natural period even closer to the forcing period of the tide, and therefore increase the amplification (10). Consequently, it is predicted that construction of a barrage across Minas Basin will increase the tidal range in the Gulf of Maine by 20-30 cm, representing 10-15% of the present range.

The ecological consequences of such a change could be profound, and have special significance for fish habitat in the whole of the FMG system. Increases in tidal range will cause greater vertical mixing in shallow areas of the Gulf; this in turn will decrease the sea surface temperature fractionally, but increase the rate of return of nutrients from deeper water, which should stimulate primary production by phytoplankton in the surface waters. These changes should be beneficial for some of the major commercial fish stocks of the Gulf and Georges Bank (11). Negative effects associated with enhanced tidal range include increases in coastal fog, flooding, and possibly drainage problems.

Large scale tidal power development thus represents a very mixed bag of environmental effects. These proposals have shown that estuaries are closely tied by both physical and biological connections (through migratory fish and birds) to coastal waters that are great distances away. In the case of the Bay of Fundy, the biological connections through fish extend to the whole of the eastern seaboard of North America. Migratory birds link the Bay to the eastern arctic and South America. These proposals also show clearly that each estuary is to some extent unique, so that information gained by study of one estuary may be applied to another only with the greatest caution. The Annapolis Estuary, for example, is not a very good paradigm for other estuaries in the Fundy system because physical conditions are not exactly the same elsewhere.

A final issue related to physical modifications of estuaries and their effects on fish habitat is the effect of changes upstream of the estuary itself. The manner in which river and ocean waters mix in the estuary depends upon the shape of the estuary, the local tidal range, and the river runoff. As described in this and the previous paper, the pattern of mixing is critical in determining the nature of the productivity, and aspects of fish habitat in the estuary. Consequently, changes in river outflow are important. Conventional hydro-power developments in the watershed may extensively modify the seasonal pattern of river flow, and hence the degree of stratification or mixing downstream. For the same tidal range, higher river flow tends to favour stratification in the estuary, and enhances estuarine circulation. In the Atlantic region, hydro storage schemes tend to conserve the high runoff events of spring and and early summer, reducing the input to the estuary at those times, but increasing the input during winter. The effects on fish habitat in estuarine and coastal waters depend upon the natural seasonal cycle of the fish (whether they are spring, summer or fall spawners), and their relative reliance on pelagic or benthic food resources.

The cumulative effects of several different hydro schemes within the same watershed cannot be underestimated, although commonly each scheme would have been assessed on its own. An excellent example of the interaction of several projects is to be seen in the Gulf of St. Lawrence. During the last three decades dozens of storage reservoirs for hydro development have been constructed in the watershed of the St. Lawrence. While most of these have been relatively small, one of them - Manic 5 in the Manicouagan watershed, Quebec - holds 140 km^3 of water, or approximately the equivalent of 200 days' total discharge of the St. Lawrence at Montreal. The accumulated control of surface runoff to the river achieved by these structures not only smooths out the seasonal variation in river flow, but also permits damping of the year-to-year fluctuations of the whole river output. It has been shown that the rate of river output is correlated with catches of commercially important species in the Gulf of St. Lawrence (see the previous paper). It has also been suggested (12) that regulation of the St. Lawrence output may affect the ecology, and hence the fish habitat over the entire coastal system of north eastern North America, at least to Cape Cod.

CONCLUSIONS

Estuaries and coastal waters are extremely important fish habitat. They provide favourable conditions for spawning, growth and feeding for many fish species in Atlantic Canada, including all of those that are commercially important, and many others deserving consideration for conservation or aesthetic reasons. The critical properties that give rise to the high productivity of our estuaries and coastal waters are determined by the physical features of the land, the relationships between water depth and flow patterns, tidal movements and waves, and the output of rivers. All of these are subject to change by human activities in the coastal zone itself, in estuaries, and in the river basins feeding those estuaries.

This very brief review of Man's modifications to estuaries and coastal waters yields three inescapable conclusions:

(1) Physical modifications to estuaries and coastlines induced by Man always have the potential for causing significant changes to critical processes that affect the fish habitat of the region;

(2) The effects induced by human modifications have been far more extensive in time and space than anticipated;

(3) The consequences have generally been negative in regard to fish habitat.

These conclusions in turn lead to another: if we are to continue to enjoy the benefits of some of the most productive, valuable and aesthetically pleasing of natural systems, which represent critically important fish habitat, then we must not only reassess the extent to which we are prepared to modify existing watersheds, estuaries and coastal shorelines, but also make greater efforts to rehabilitate those systems that have already suffered severe degradation as a result of past and present practices. Responsibility for this rests with all whose activities impinge upon natural water courses.

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Water and Sediment Quality Related to Fish Habitat in the Estuarine and Coastal Environment

S. MacKnight

ABSTRACT

The "quality" of both the water column and bottom sediment are integral components in the definition of fish habitat. "Quality" can be related to a variety of concerns ranging from the general concept of environmental protection through to impact on human health, from concern over dead fish in our waterways to the economic impact of a depleted or tainted fishery. The concern for the maintenance of fish habitat quality has been expressed internationally through several conventions (e.g., the London Dumping Convention) and nationally through the Fisheries Act and the Ocean Dumping Control Act.

Early efforts in the control of habitat quality centered on water quality. This reflected our ability to observe deterioration in water quality and to observe how simple engineering solutions could improve the quality. It was often assumed that many of the man-made chemicals were hydrophobic, were readily sorbed by the sediments and thus made essentially non-bioavailable.

More recent studies have shown that a chemical equilibrium is set up between sediments, the pore water within the sediments and the overlying waters. Changes (especially "improvements") in the quality of overlying waters, can alter the chemical equilibria leading to the release of chemicals from the sediments; thus sediments can act as both "sinks" and "reservoirs."

Unlike freshwater systems, there are no published water quality or sediment quality objectives for estuarine or marine systems, There are broad guidelines under such Acts as the Ocean Dumping Control Act and the Montreal Guidelines for Wastes from Land, however, the schedules of substances of concern are relatively limited and rarely specify concentrations.

Sediment and water quality objectives are closely linked to such industrial activities as disposal of dredged material and ocean mining. Economically, open-water disposal of dredged materials is preferred, as it is about one-quarter the cost of placing the material in a confined disposal facility. Yet, the presence of various contaminants (with the actual list of contaminants to be monitored, growing daily), in such sediments can raise legitimate concerns for the impact on marine environmental quality.

It is present policy to determine the total or bulk concentration of various contaminants in sediments to be dredged without taking into account the variations in the bioavailability of contaminants. The concept of developing sediment quality objectives will be discussed in terms of Atlantic Canadian examples.

INTRODUCTION

Under the Fisheries Act, "fish habitats" are defined as those parts of the environment on which fish depend directly or indirectly, where "fish" is taken to include "fish, shellfish, crustaceans, marine animals and marine plants." Restrictions and regulations under the Act serve to control alteration or disruption by chemical, physical, or biological means (1). This gives a very wide definition to processes which can occur within the estuarine and coastal environment.

Much of our initial concerns with fish habitat were based on the "quality" of the water in which fish live, since such effects as increased suspended solids (turbidity), decreased oxygen levels, increased temperatures, or visual changes in water quality (e.g., oil slicks, phytoplankton "blooms") were easily related to fish mortality and significant reductions in fish populations. Increasingly sophisticated analytical techniques showed that very small concentrations of various man-made chemicals (e.g., pesticides) could also drastically affect the water quality, but under conditions that were much more difficult for the average person to discern. From this data base have been developed freshwater quality objectives. These have been primarily developed for the Great Lakes, but considerations for changes in hydroelectric project headpond water quality and general river/estuary quality are leading to a more wide-spread use of such objectives (2, 3).

Water quality objectives can also be closely related to human health considerations. Although it may be possible for some type of fish to live in non-potable waters, most people will recognize that good drinking water also means good fish habitat. This is more difficult to apply to marine environments, but the general concepts can still be accepted by most people. It is also relatively easy to set freshwater quality objectives as the analytical chemistry of contaminants in freshwater is fairly well established.

But fish habitat is not just trout in a babbling brook. "Fish" includes shellfish, bottom-feeding fish and crustaceans; in short, "habitat" includes sediment and suspended solids or particulate matter. That is, "habitat" is a multi-phase system and any regulation of habitat quality must take into consideration how changes in one phase can lead to changes in another phase.

But why consider sediments? Many authors have stated that sediments in estuaries are "sinks" to chemicals. The partition coefficients and chemical properties of many chemical compounds lead to preferential distribution into the sedimentary (or suspended solids) phase.

Anecdotal information, however, indicates that it is too simplistic to assume that contaminants end up preferentially in sediments. Bottom-feeding fish in several areas containing high concentrations of polynuclear aromatic hydrocarbons (PAH) have been found to contain abnormally high incidences of lesions, organ cancers and other histopathological disorders (4). Lobsters in the harbour of Sydney, N.S. (5) have been found to contain very high concentrations of PAH in the tomalie gland, and lobsters in the harbour of Belledune, N.B. have been found to contain very high concentrations of cadmium and other metals (6). Since contaminants in the sediments may exchange readily with the water column, the pathway of uptake by fish is unclear. A strong case can, however, be made to consider quality objectives that apply to the whole ecosystem.

SEDIMENT QUALITY OBJECTIVES

Sediment quality objectives (SQO) are parallel to water quality objectives in that they are a set of guidelines against which the "quality" of sediment in a particular location can be measured. The end objectives are:

(1) to provide a means of defining the nature of the existing habitat;
(2) to provide a benchmark to determine the degree of effort necessary to bring the sediments up to specifications;
(3) to provide a component of the definition of marine environmental quality.

In terms of earlier programs, this would be akin to requiring a reduction in suspended solids in a stream due to stream alteration. In the estuarine or coastal environments, the issue is much more complex. Designing SQO's will require consideration of the end use. For dredged material disposal, it will require consideration of whether the contaminants in the disposed sediments will be "rapidly rendered harmless"; for existing sediments in harbours, it will influence long-term planning of water quality improvements.

There are various ways of defining SQO's:

- Comparison to background levels,
- Extension of water quality criteria,
- Equilibrium Partitioning,
- Biological Responses.

Each method has advantages and disadvantages.

Comparison to background levels requires the identification and definition of what constitutes "background" and consequently the need to locate relatively "pristine" environments. For man-made substances it may be relatively easy to state that a zero content is the only acceptable level. This does not take into account the virtually ubiquitous nature of many of these substances (e.g., PCB's). The use of background levels implies that the level is acceptable. But what of the cases where natural levels in one location are much in excess of natural levels in other locations; which is the more acceptable?

Extension of water quality criteria does have the advantage of using existing criteria, acknowledging that the actual criteria have only been established for a few chemical compounds in the freshwater environment and even fewer in the marine environment. Existing water quality criteria are applied to concentrations measured in pore or interstitial waters. The drawbacks of the method are:

(1) The assumption that sediment-biota transfers of contaminants are negligible;

(2) The assumption that viable and true measurements of interstitial water concentrations can be made;

(3) The assumption that the geochemical regimes used to define water quality objectives in overlying waters are the same as in the interstitial waters.

Equilibrium partitioning can refer to sediment-water partitioning, sediment-biota partitioning (e.g., bioconcentration factors) or accumulation relative to sediment concentrations (ARS factor). A simple model is used to describe the partitioning of a contaminant between sediment (primarily the sedimentary organic matter) and the interstitial water. Knowing the partitioning constant between the two phases and knowing the water quality objective contaminant concentration in the interstitial water, it is possible to calculate a sediment quality objective. As it has been shown for most hydrophobic organic compounds that the sedimentary organic matter controls the distribution between sediments and interstitial water, then the partitioning coefficient is a function of the organic matter partitioning coefficient or more commonly the octanol-water partitioning coefficient. The disadvantages of the approach include determining how to account for compounds that partially react with the aqueous phase (i.e., ionizable compounds), the presence of dissolved organic material in the interstitial waters (e.g., in interstitial waters in estuaries strongly affected by pulp and paper wastes), and the effect of the solid to liquid phase ratio.

A parallel approach is the use of the equilibrium between sediment and biota where the governing factor is the food/health acceptable concentrations in biota and the relationship to sediment concentrations. However, a great deal of difficulty has been encountered in this approach due to the lack of data for health limits in non-human food (e.g., polychaetes) and the difficulty in assessing true bioconcentration factors where the chemical compound may not be accumulated, but may be metabolized and therefore chemically altered.

The biological responses approach can be divided into three sub-types:

Field Bioassay. This approach treats sediment toxicity as a "black box" in that the total effect of all contaminants present, whether measured or not, is considered. It is a useful method for identifying problem sediments, but cannot by itself be used to set SQO's.

Screening Levels. The presence of a given benthic species is related to sediment contaminant concentrations to determine the minimum concentration of a given compound that was not exceeded in 90% of the samples. The process is carried out for numerous species and the screening level is estimated as that contaminant concentration above which less than 95% of the total enumerated species of infauna are present. The drawbacks to the technique are the need to accumulate a large volume of data and the inability to discern interactive effects of various contaminants.

Apparent Threshold Effects. Sediment contaminant concentrations are classified according to the absence or presence of associated biological effects to determine the concentrations above which statistically significant effects would always occur. The disadvantages in the method occur due to the need for extensive field data sets for various chemicals, with the strong likelihood of also needing extensive bioassay testing. The uncertainty is further increased by the likelihood of interactive effects of various contaminants, but this effect can be decreased by the use of data sets from different areas with different contaminant levels.

To summarize the techniques for establishing SQO's would lead anyone to state that the difficulties are not worth the effort. Yet, we will soon arrive at the case where very large efforts are being expended to improve or meet water quality objectives and where the underlying reservoir of contaminants in the sediments will apply a limiting floor below which no WQO can be achieved. Further, it must be recognized that the habitat is a complete ecosystem involving a complex biological set within a complex chemical regime.

CASE EXAMPLES OF REQUIREMENT FOR SQO'S IN THE ATLANTIC REGION

There are over 3000 harbour facilities in the Atlantic region of which some 500 harbours/channels have required dredging over the past twelve years. The data have been derived from the permits for open-water disposal of dredged sediments as issued under the regulations of the Ocean Dumping Control Act. Review of these data (9-12) shows that about 10% of the harbours could be considered to be problem harbours in that sediment concentrations can be directly linked to observed effects on the resident biota, where the most common measure is the accumulation of a particular contaminant.

Table 1 lists some of these identified harbours, with group 1 having sediments with multi-contaminant problems; group 2 having PCB contamination; group 3 having cadmium (and usually also lead and zinc) contamination. Group 1 harbours are typically very commercialized and have a watershed containing a significant residential/industrial base. The other two groupings are more a reflection of one-industry effluents or naturally high background concentrations.

Analyses of sediments in the harbours of Fortune, Petit-de-Grat and Canso show high concentrations of PCB in the sediments (11,12). Ernst *et al.* (13) calculated that the PCB in Petit-de-Grat harbour could be attributed to the accumulated sediments generated by the solids in the fish processing plant effluents. Various studies have shown that PCB can be bioaccumulated in benthic animals (e.g., *Nereis virens* - 14). The benthos in these harbours is not being exposed to PCB from a chemical manufacturer (primary entry), spills or leaks from disposed equipment or liquid (secondary entry), but rather to effluents containing bioaccumulated PCB (tertiary entry-15).

Table 1: "Problem Harbours" in the Atlantic Region

I. Multicontaminant Problems	III. Cadmium Problems
Halifax	Newellton
Sydney	Bear Pt.
St. John's	Shag Harbour
Dalhousie	Clark's Harbour
Bathurst	
Belledune	
Lunenburg	
II. PCB Problems	
Fortune	
Canso	
Petit-de-Grat	
Old Perlican	
Liverpool	
Clark's Harbour	

Cadmium is another contaminant of significant concern. It has been placed on the Schedule I list of the London Dumping Convention and the Canadian Ocean Dumping Control Act. Studies in Belledune harbour (16) have shown a strong bioaccumulation in both fish and the benthos. In contrast, benthic organisms in Dalhousie harbour exposed to similar concentrations of cadmium have not been found to bioaccumulate the metal (17-19).

Present policy in the evaluation of sediments for open-water disposal is to compare the bulk or total chemical concentrations to specified limits of acceptability. For cadmium this is 0.6 mg/kg; for PCB, 0.1 mg/kg (dry weight). This method is relatively easy to use in a regulatory sense, but does not take into account differences in the bioavailability of the contaminant in question. It also does not take into account the differences in the physical-chemical regime that exists in each particular set of sediments.

In order to relate the contaminant concentrations to the present policy of no net loss of habitat and yet still permit the economical dredging of harbours and channels, there is a need to develop SQO's for Canadian marine sediments.

USE OF ATLANTIC CANADA DATA FOR SQO DEVELOPMENT

The identification of the "problem" harbours and the ensuing difficulty faced by the program managers in having to deal with requests for Ocean Disposal Permits, suggests that SQO development would prove useful in both this practical example and in the longer-term development of marine environmental quality.

The U.S. Army Corps of Engineers has applied the Apparent Effects Threshold concept (8) to the definition of sediment quality objectives for Puget Sound. By collecting a large volume of data, mostly drawn from existing data bases, they were able to establish AET values for many organic and inorganic contaminants of interest. Figure 1 provides an illustration of their technique. By determining the concentrations for no observed sediment toxicity and no observed benthic depressions, they established four concentration values: maximum observed concentration, apparent toxicity threshold, apparent benthic effect threshold, and potential effect threshold.

The State of Washington Department of Ecology then developed these factors further. They established a "screening level" as 10% of the highest apparent effects threshold concentration, where that value was based on a number of biological indicators (J. Thorton, personal communication). These screening values are used to evaluate not only the nature of sediments being proposed for open-water disposal, but also to evaluate other sediment areas that might be considered "contaminated." Table 2 compares some of these values to "typical" concentrations of various contaminants in Atlantic Canadian harbours (12-15).

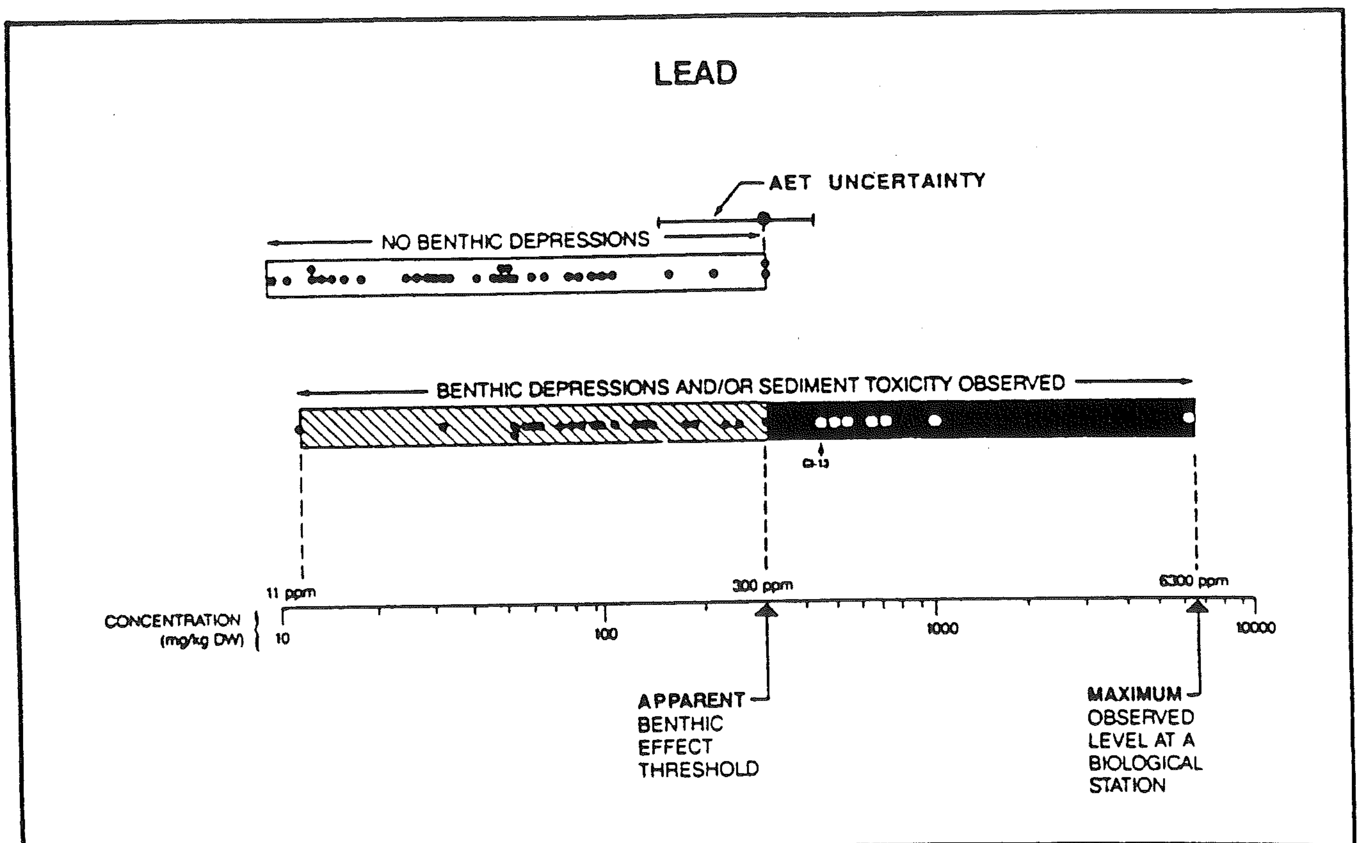

Figure 1. Apparent Effects Threshold concept. Concentration values for a contaminant are compared for samples in which no environmental effect was found (upper bar) with samples where depression of benthic populations was detected (lower bar).

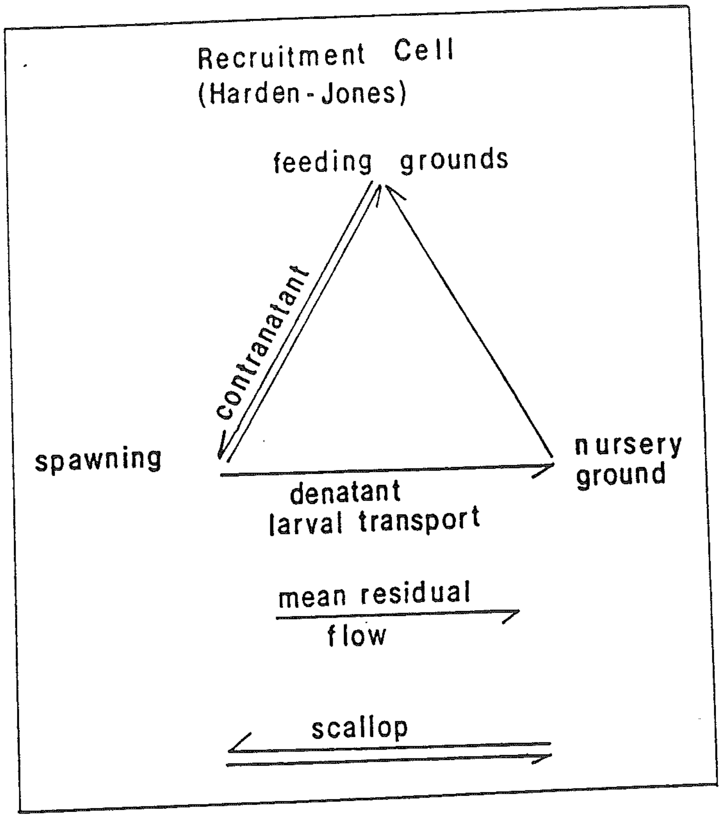

Figure 1. A recruitment cell for a fish population. (After Harden-Jones, 1968)

After reaching a size large enough to commence migratory behavior juveniles join the feeding migrations of the adults or migrate by themselves. At maturity a migration back to the spawning grounds occurs to complete the cycle. Migration is usually upstream in a particular current regime and is termed the **contranatant phase**. Depending on the species this may occur once in the life cycle or a number times.

It is important to realize that each of these phases requires a specific habitat and an unimpeded migratory route. Fish which have adapted to spawning at a particular site or in a certain river cannot change overnight. For this reason spawning grounds, nursery areas and migration routes are termed critical habitat. Without any one of these critical habitats a fish population may cease to exist.

CASE HISTORIES

Atlantic Sturgeon

Sturgeon are large, bottom-feeding fishes. There are two species in the Maritimes, the Atlantic sturgeon, *Acipenser oxyrynchus*, and the shortnose sturgeon, *Acipenser brevirostrum*.

Atlantic sturgeon spawn during spring in the lower reaches of large rivers. The eggs are adhesive and attach to the substrate for a few days before hatching. Soon after hatching the larvae drift downstream to the estuary. Juveniles spend 2-4 years in the estuary where they grown to 80-100 cm and 3-10 kg. They then migrate to sea where they spend 6-10 years growing to maturity before returning to a river to spawn. Adult Atlantic sturgeon are 150-250 cm long and weigh 100-300 kg. Each year while at sea Atlantic sturgeon migrate along the east coast of North America wintering off the Carolinas and spending the summer around the Maritimes (Figure 2).

Sturgeon are rather secretive and they live in a habitat that is difficult to exploit. They are not often seen except by commercial fishermen and are thought to be rare. They are, however, relatively abundant and Atlantic sturgeon occur in most larger Maritime rivers. The largest population is in the Saint John River, New Brunswick. They are common in the ocean in the upper Bay of Fundy and on the Scotian Shelf.

Populations of Atlantic sturgeon in the United States have diminished because of estuary and river pollution, which affects the juvenile nursery grounds or because of dam construction which prevents access to spawning grounds. Overexploitation of stocks during the late 1800's also reduced many populations to levels from which they have never recovered. Overexploitation of the Saint John River population during the late 1880's reduced that stock and it has never recovered to its former levels, if commercial catches are indicative of abundance. Sturgeon in Maritime Rivers have not been adversely effected by habitat alteration although the recent development of tidal power in the Annapolis River is affecting that population. Because of their large size sturgeon cannot easily pass through hydroelectric turbines without being struck and numerous adults have been killed by the turbine blades at Annapolis (5). Whether this habitat alteration will adversely affect the population remains to be seen.

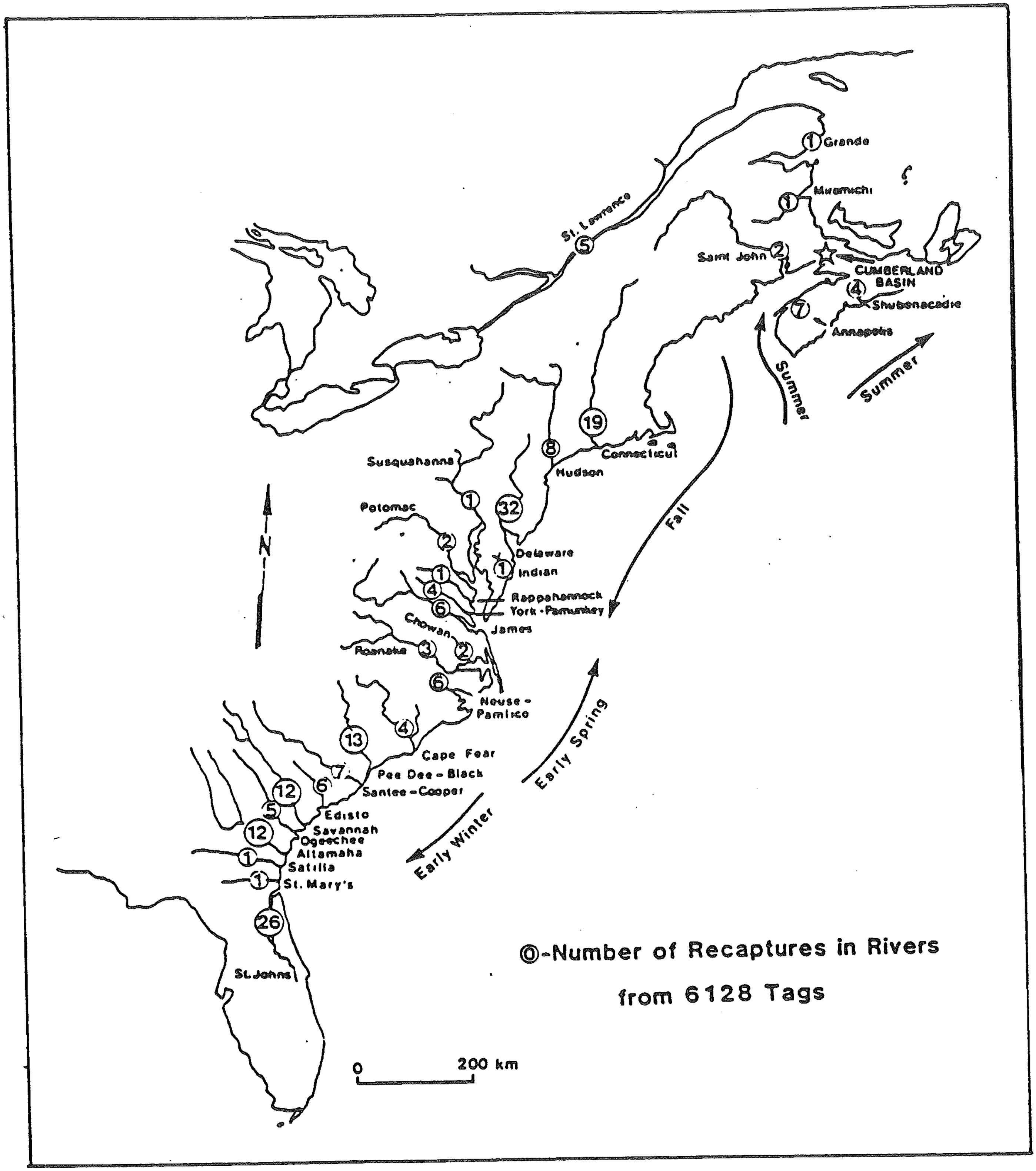

Figure 2. Generalized annual migration routes of Atlantic sturgeon and Striped bass along the east coast of North America.

Striped bass, *Morone saxatilis*, is a large sea bass which supports both important commercial and recreational fisheries from North Carolina to the Maritimes. They spawn during the spring in the lower reaches of rivers, usually just above the head of the tide. Eggs drift downstream and hatch in the upper tidal reaches of the estuary. Juveniles grow rapidly and migrate to sea at the end of their first summer. Bass reach maturity after five years of age at a size of 30-50 cm and 2-5 kg, when they return to their natal river to spawn. They live 15-25 years and can reach a size of 120 cm and 35 kg. While in the sea they migrate north and south along the east coast of North America each year in a manner similar to the sturgeon (Table 1).

The major concentration of bass is from Chesapeake Bay to the Hudson River but there are large populations in Maritime Rivers (Annapolis, Saint John, Miramichi). A phenomenon of striped bass populations is their cyclic abundance. Populations virtually disappear for a number of years, then suddenly become superabundant. The Saint John River population exhibits population peaks at periods of 10-15 years.

Bass habitat in the Maritimes has been affected by the construction of causeways across estuaries and the dyking of salt marshes in the upper Bay of Fundy but in general is little impacted. The large estuaries they frequent are relatively unaltered. The situation in the United States, however, is poor. The huge bass populations of Chesapeake Bay are so reduced that there is a moratorium on commercial and recreational fisheries in the bordering states. Pollution from land drainage and acid rain are being blamed for the poor bass year classes since 1970. The bass decline in the United States is affecting the Maritime catches since large numbers of these bass no longer migrate north each summer (2).

Atlantic salmon, *Salmo salar*, is one of the most esteemed commercial and recreational fish from the Maritimes. Salmon spawn in the fall, generally a long way inland in the upper reaches of shallow, riffle-filled streams. The eggs are buried in the gravel, where they overwinter and hatch in the spring. The young parr remain in the gravel a few weeks before moving into the shallow riffle areas of the streams where they occupy individual territories. After 2-4 years' growth in the stream they migrate seaward as silvery smolts. All North American salmon migrate northward in the sea during summer to Greenland and the Davis Strait (Figure 3). After 1-2 years at sea they return to their home rivers to spawn. Some survive to spawn 2-4 times. First-run salmon are 4-8 kg in weight and adults may reach 20 kg.

Salmon need access to cool, clean streams and alteration of this habitat can severely impact a population. One of the best documented salmon populations in the Maritimes is the Saint John River. During the late 1800's the Saint John, like most Maritime rivers, was recovering from sawdust and timber blockage. Landings since then until 1950 fluctuated but were generally maintained at a level of about 300,000 lbs/year. Starting in 1950, however, habitat alterations and pollution impacts began. By 1970 salmon landings were severely reduced, resulting in closure of the commercial fishery. Although the commercial fishery was blamed for the reduced salmon population this argument makes little sense since the population had maintained itself at a high level for 60 years under

Table 1. Sites and dates of tagging and recapture for migrant striped bass associated with the Bay of Fundy

Tagging Site	Date	Recapture	Date	Days at Large	Source
Potomac R., MD	Feb/59	Walton, Minas Basin, NS	Sept/59	159	Nichols and Miller, 1967
" "	Apr/60	Bear R., NS	Jul/60	99	" " "
" "	Apr/61	Annapolis Royal, NS	Jul/61	127	" " "
Annapolis R., NS	14 Jul/75	Potomac R., VA	25 Mar/76	255	Underwater Naturalist, 1976
" "	29 Aug/66	Rockingham, NC	24 Jun/67	308	Moss, 1971
Cheboque R., NS	13 Jul/69	Long Beach Is., NJ	22 Apr/70	283	" "
" "	13 Jul/69	Sakonnet R., RI	10 Jun/70	342	" "
" "	4 Sept/66	Indian R., DE	13 Mar/67	178	" "
" "	12 Aug/66	Patcong Ck., NJ	15 Jul/67	337	" "
Nanticoke R., MD	14 Apr/73	Reversing Falls, NB	25 Oct/76	1279	Boone, MD Fish & Game
Darlings Lake, NB	5 Jun/69	Montauk, NY	19 Nov/69	167	Underwater Naturalist
Westfield, NB	12 Sept/72	Blackstone R., RI	23 Oct/72	36	Williamson, 1974
Reversing Falls, NB	7 Aug/73	Southampton, NY	Nov/73	90?	Dadswell, 1976
Annapolis R., NS	17 May/82	Shubenacadie R., NS	12 May/83	360	Dadswell, unpub. data
" "	20 May/82	" "	31 May/83	376	" "

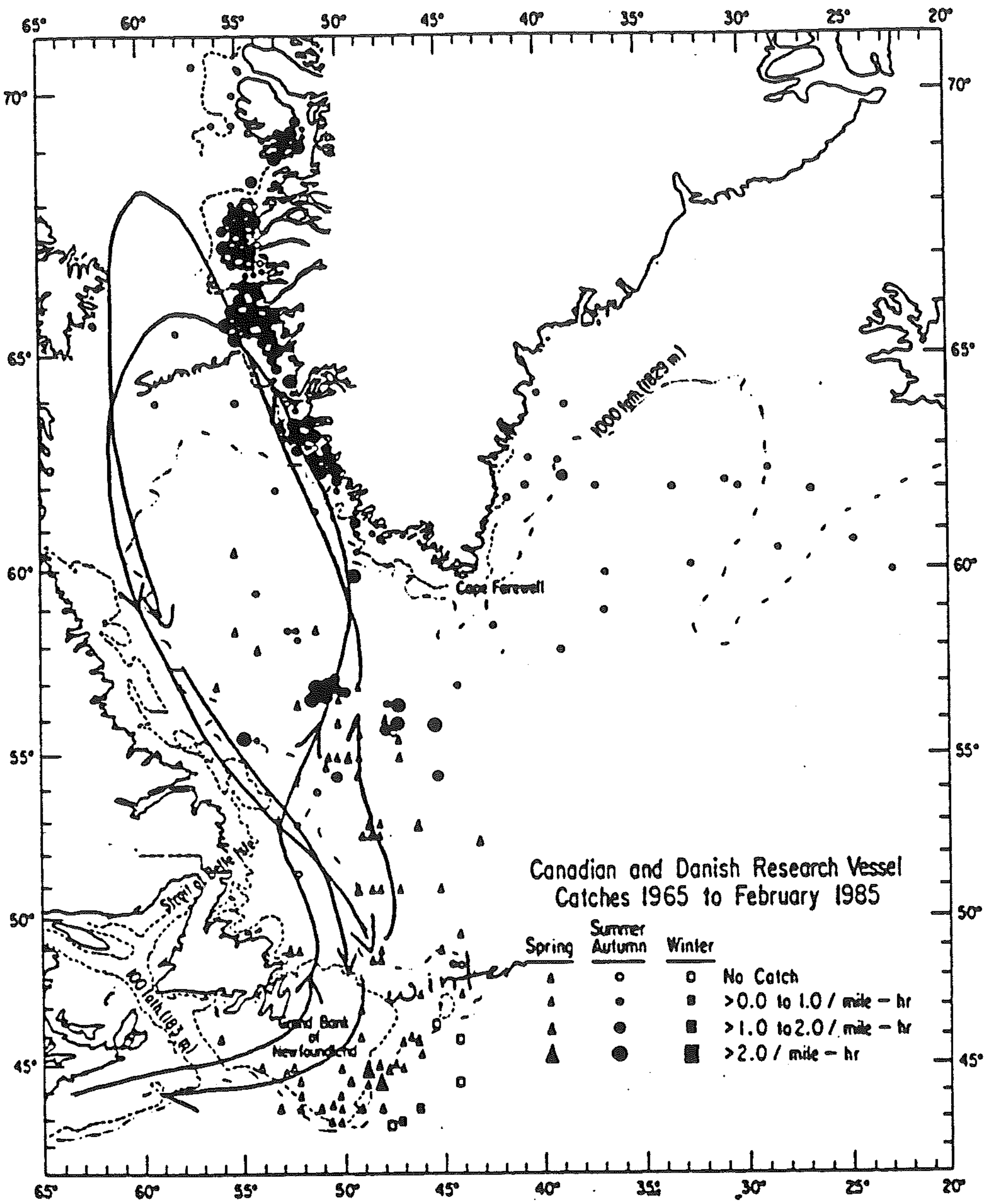

Figure 3. Migration path of North American Atlantic salmon at sea.

similar commercial pressure. A more likely reason for the population decline was the alteration of habitat by the widespread damming of the river.

The American shad, *Alosa sapidissima*, is a large-herring type fish. This species supports a large commercial and sport fishery from Florida to Quebec. Adults spawn in large rivers from tidewater to the headwaters. Eggs drift downstream for 2-3 days then hatch. Juveniles stay in the river for their first summer of life and migrate to sea in fall. They then spend 4-5 years migrating north in summer and south in winter along the east coast of North America (Figure 4). At maturity they reenter their natal rivers to spawn.

There are large spawning populations of shad in the Maritimes particularly in the Saint John, the Annapolis (7) and the Miramichi Rivers; however, the largest concentrations occur when shad from the entire east coast collect in the upper Bay of Fundy during summer (3). Shad habitat in the Maritimes has been impacted by dams (6), and the recent development of tidal power. Some of the greatest habitat impacts on shad occurred in the large east coast United States rivers at the turn of the century. Damming of the Susquehanna, Merrimack and Connecticut Rivers and pollution in the Delaware and Hudson Rivers reduced their populations to low levels. These reductions in turn severely reduced landings in the upper Bay of

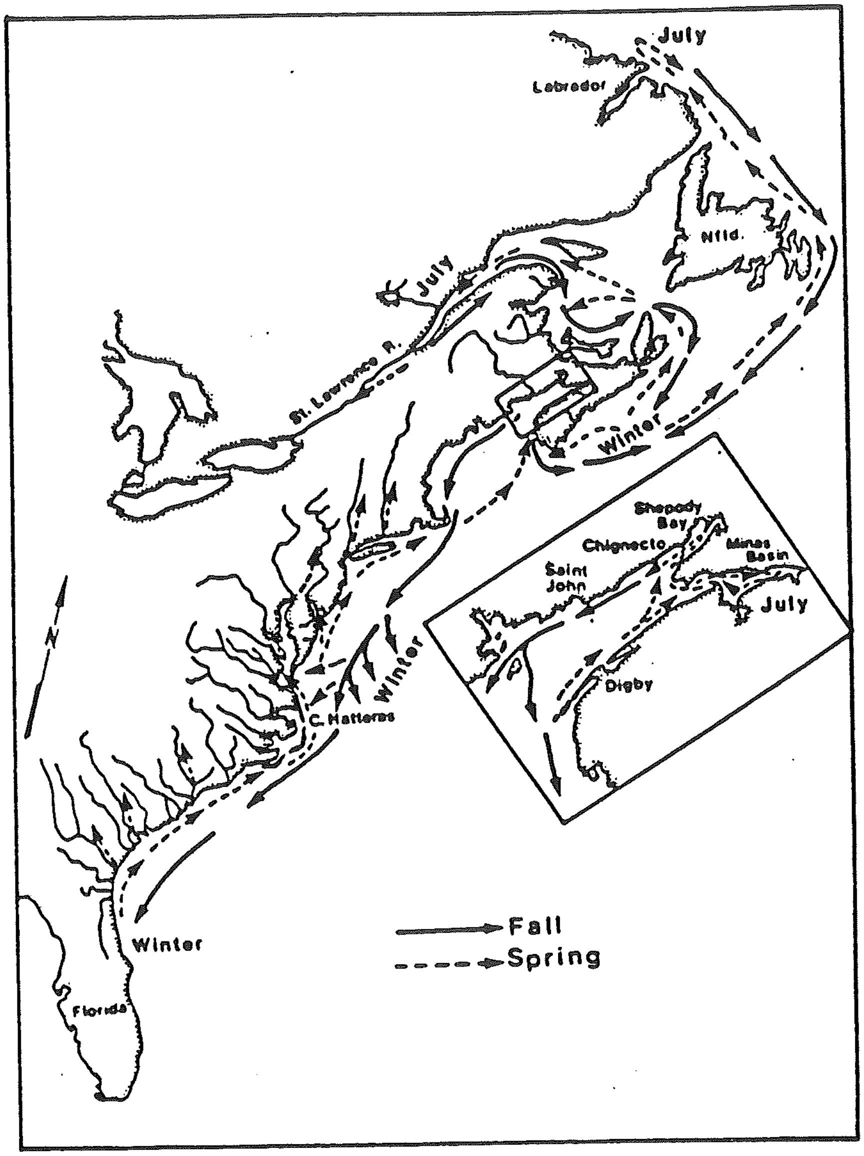

Figure 4. General migration pattern of American shad on the east coast of North America.

Fundy--then the site of extremely valuable fisheries.

Reproductive, feeding and migratory aspects of fish habitat are of critical importance to the wellbeing of fish populations. Reductions of habitat or denial of access causes population decline and often extinction of stocks. The protection of habitat is essential for the health of valuable fisheries resources.

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Mariculture and Potential Multiple-Use Resource Conflicts in Atlantic Canada

D.J. Wildish

ABSTRACT

Mariculture is a relative newcomer to the many uses to which the estuarine and coastal marine environments of Atlantic Canada are now subjected. Multiple uses by Man of this environment include: mariculture, commercial and recreational fishing, seawater for industrial cooling, waste disposal assimilation from industry, municipalities and agriculture, seabed oil or mineral exploitation and various forms of shipping. Highlighted areas of actual or potential conflict, mainly from my own experience with the Bay of Fundy salmonid mariculture industry, are between mariculture and the traditional fishing industry and mariculture and waste disposal assimilation. In order that the mariculture industry can maintain an optimum level of production, it is imperative that the individual fish farmer maintains optimum environmental conditions at his sites. His objectives are thus quite similar to the concerned environmentalist.

Potential multiple-use resource conflicts are best solved by discussion by representatives of the interest groups involved at a point in time before they occur. This suggests that some form of coastal zone planning is essential for the orderly and responsible development by Man of the marine, just as it is in the freshwater and land environments.

INTRODUCTION

Mariculture is a new industry in Canada, and one that is currently undergoing explosive growth on both the Pacific and Atlantic coasts. Oysters, mainly *Crassostrea gigas*, are produced on the west coast, blue mussels, *Mytilus edulis*, on the east coast in Prince Edward Island and Nova Scotia, and salmonids in both British Columbia and New Brunswick (Table 1). In British Columbia, the salmonids cultured include various species of *Oncorhyncus* and the Atlantic salmon, *Salmo salar*, and in New Brunswick it is principally the Atlantic salmon.

The rapid growth of some sectors of the mariculture industry is demonstrated by the blue mussel and salmonid industries on the Atlantic coast (Table 2). The New Brunswick salmon mariculture industry has grown since 1972 to 34 active farm sites producing in excess of 1000 tonnes in 1987, with an estimated value of $14 million. The predicted production of this one segment of the industry, concentrated in the Western Isles area of the Bay of Fundy, will be 5000 tonnes by 1990. Further expansion is constrained by site availability due to cold winter temperatures or high wave exposure in other parts of the Bay. Because of an abundance of suitable sites, the Pacific coast has a greater potential for growth of its salmonid mariculture industry based on presently used technology.

In this discussion paper, I want to highlight potential or actual conflicts involving mariculture and the traditional commercial and recreational fishery and waste disposal, as well as the potential of self pollution from mariculture itself. Most of the examples given will be from my own experience of the New Brunswick salmonid mariculture industry.

COASTAL ZONE MANAGEMENT AND MULTIPLE-USE RESOURCE CONFLICTS

The coastal zone is that part of the marine environment from the edge of the continental shelf landwards, inclusive of estuaries to the furthest extent of the tidal movement. It is a multiple-use, renewable aquatic resource of considerable importance in Atlantic Canada. Besides mariculture, these uses include (2):

- commercial and recreational fishing,
- seawater for industrial cooling,
- waste disposal assimilation from many sources,
- seabed oil/mineral exploitation, and
- shipping.

Management goals of the coastal zone are considered to be the optimization of benefits to as many as

Table 1. Mariculture production, tonnes wet weight, for 1986 (1).

	Province					
Species	B.C.	Quebec	Nfld.	P.E.I.	N.B.	N.S.
Salmonids	397	10	19	9	679	79
Oysters	3700	50	0	0	0	0
Mussels	6	50	14	1250	3	545

Table 2. Growth of mariculture in Atlantic Canada, as tonnes wet weight, in the period 1980-87 (1 and R. Drinnan, personal communication).

Species	1980	1981	1982	1983	1984	1985	1986	1987
Salmonids	123	114	153	274	272	284	796	1266
Mussels	36	82	174	432	876	886	1859	1789

possible of the users listed above. Conflicts arise where a given resource-use economically harms one of the others appearing in the list above.

MARICULTURE AND TRADITIONAL FISHING

Salmonid mariculture in the Western Isles region of the Bay of Fundy (Figure 1) involves placing Atlantic salmon smolts grown in land-based, freshwater hatcheries into large, floating sea cages, where they remain for at least an 18-month period. The number of sites (34 in early 1988) is expected to increase in 1988-89.

Important local fisheries in the same region include those for scallop, lobster and herring. Landings have fluctuated for juvenile herring from 1275 t in 1971 to 15,205 t in 1982 (Table 3) for the weir fishery. A general decline since 1968 has been attributed to a major resource collapse, particularly the Georges Bank stock (3). It is nevertheless a valuable fishery; for instance, the 1982 Western Isles landings of 15,205 t had a value close to $3 million and a processed value ten times that amount (3). Juvenile herring caught in weirs form the basis of a canned sardine industry. The distribution of 110 weirs in the Western Isles region in 1986 (Figure 2) demonstrates one obvious resource-use conflict with salmonid mariculture, that is a direct competition for suitable sites. Preferred weir sites are those closer inshore because they yield the preferred smaller size of juvenile herring for sardine canning. Similar conflicts for space apply to the lobster and scallop fishery although, because neither uses fixed, passive gear, it is a less obvious conflict.

Herring weir fishing relies on the natural movement of herring near shore. Stephenson considers the following working hypotheses in his attempt to determine whether salmonid cage sites influence the locomotory behavior of juvenile herring (3):

- decreased water quality near salmonid sites causes herring avoidance;

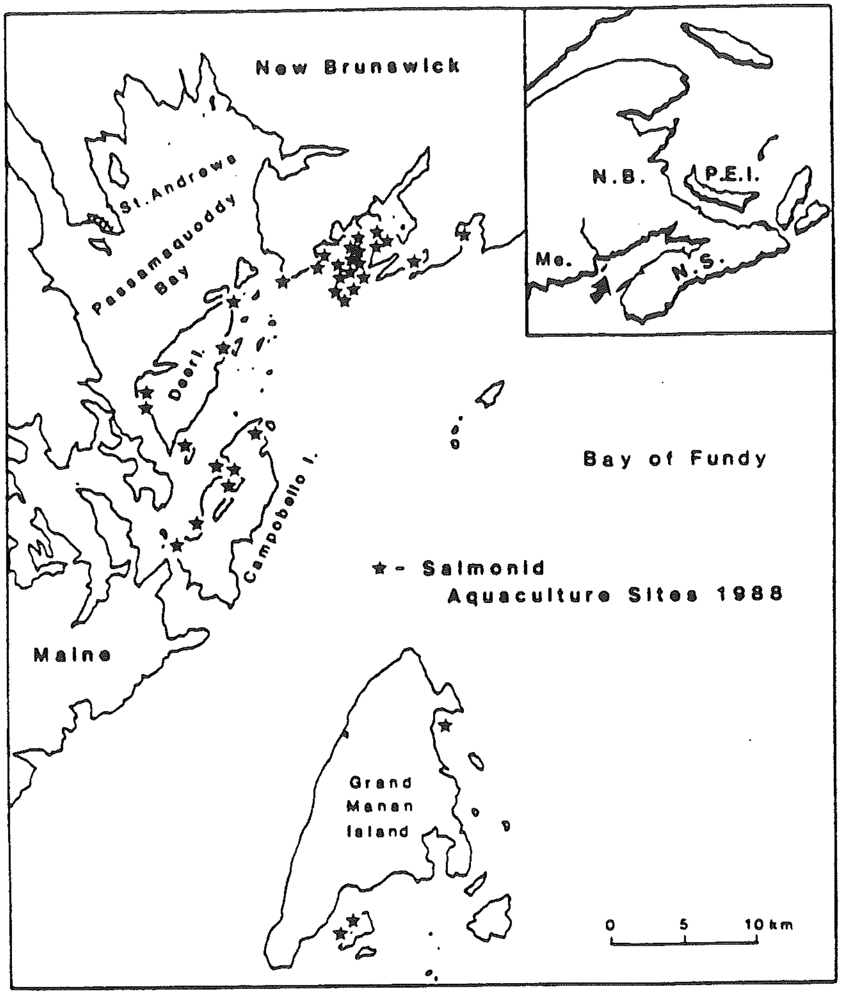

Figure 1. Salmonid mariculture cage sites in the Western Isles region of the Bay of Fundy in 1987.

Table 3. Herring weir catches in the Western Isles region, Bay of Fundy, as tonnes wet weight. From R.L. Stephenson (3).

Year	Blisses #104	Deer Island #107	Campobello Island #108	Totals
1968	1143	3245	50	4438
69	1785	1242	1114	4141
70	2203	634	544	3381
71	921	195	159	1275
72	593	929	652	2174
73	1833	9090	2811	13734
74	1255	1090	672	3017
75	1600	475	70	2145
76	1167	1284	688	3139
77	2014	4791	2865	9670
78	718	8416	5620	14754
79	875	3735	3300	7910
80	1005	2178	3009	6192
81	789	6182	2257	9228
82	1529	8899	4777	15205
83	1915	515	1276	3706

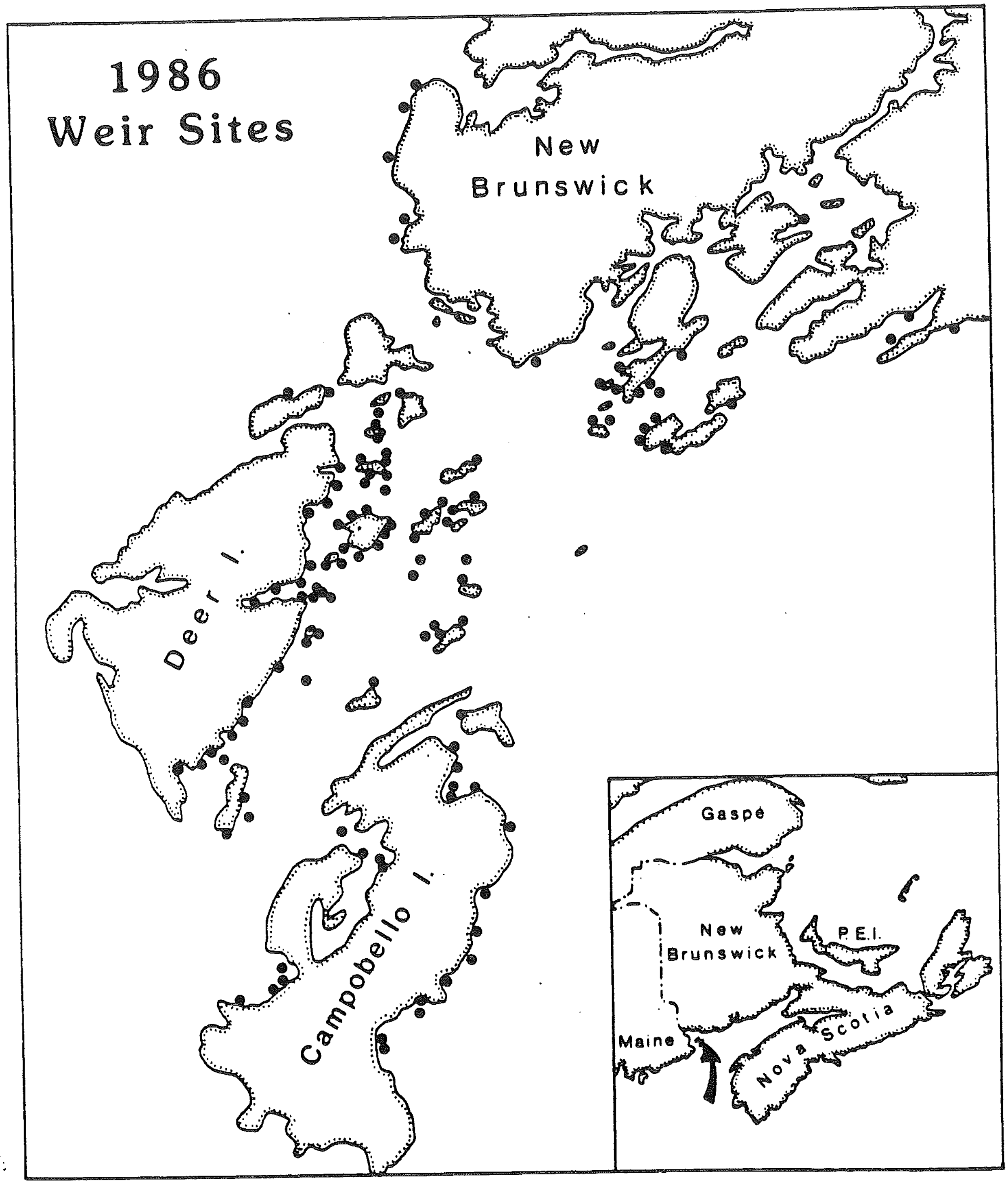

Figure 2. Position of fixed weir sites occupied in the Western Isles region of the Bay of Fundy in 1986.

- avoidance by herring of waste salmonid food which is composed principally of herring;
- predator avoidance by herring of salmon in cages;
- avoidance of noise, e.g., seal scaring devices, and activity associated with salmonid cage sites; and
- physical blockage by salmonid cage sites of fishways normally used by herring.

One completely different way in which mariculture may impact on a traditional fishery is by the introduction of new diseases by importing improved varieties. Similarly, escapees from salmonid culture may result in the genetic dilution and/or loss of local genetic stocks of salmon.

MARICULTURE AND WASTE ASSIMILATION

A primary requirement for successful mariculture is an abundant supply of clean, well oxygenated seawater. Because mariculture is such a new industry, only 15 years old, and because the importance of clean seawater is recognized in the decision regarding siting of a mariculture facility, few examples of this type of conflict can be found in Canada. Assimilation of wastes includes that from industrial sources, municipal sewage treatment works and from agriculture following land runoff in streams and rivers.

Industrial Waste Assimilation

A pulp mill producing corrugated linerboard from hardwood trees is located at Lake Utopia. The effluent from this 200 t/day mill enters the Upper L'Etang in an open stream (Figure 3). This body of water above Route 1 is completely anoxic due to the excessive oxygen demand of the effluent and the buildup of pulp fibres in sediments (2). A survey of dissolved oxygen conditions in the Lower L'Etang at the stations shown in Figure 3 in 1985 showed that levels were normal at stations 9 and 10 (4). The inlet nature of the L'Etang and low freshwater runoff into it help ensure that the pulp mill effluent, and hence low dissolved oxygen levels, remain "bottled up" and do not adversely affect the 20 salmonid mariculture sites located in the more seaward part of it (4). Nevertheless, the presence of the effluent is probably inhibiting the utilization of Scotch Bay, where one or two more salmonid farm sites could be located if the water quality was of higher standard.

Municipal Sewage Waste Assimilation

Because bivalve molluscs, inclusive of scallops, oysters, clams and mussels, filter seawater during feeding, they concentrate and collect any pathogenic micro-organisms which may be present. Conflicts of this kind are much rarer today because of the advances in municipal waste treatment practices.

Historically, however, this problem was a frequent cause of the economic collapse of extensive bivalve culture operations conflicting with the concentration of people in towns and cities required by the Industrial Revolution. One example occurred in the Medway estuary, U.K., at the turn of the present century. Oysters, such as *Ostrea edulis*, were grown on leases close to the city of Rochester and sources of untreated sewage. Cases of typhoid caused by a bacterial pathogen, some of which were fatal, were traced to Medway oysters which helped to kill this industry (5).

More recently, it has been suggested (6) that integrated farming and aquaculture systems involving polyculture of pigs, fowl and fish common in Asia and parts of Europe may pose a serious human health problem. This occurs because human influenza pandemics commonly arise following genetic reassortment of human and avian viruses within the pig.

Agriculture Waste Assimilation

Unlike pulp mill effluents which do not contain high levels of plant nutrients, agricultural runoff frequently does as a result of heavy artificial fertilizer use. In parts of Europe where reliance on nitrate, phosphate and potash fertilizers occurs, (e.g., Denmark-6), this has caused problems in receiving waters. Thus, the Limfjord is so hypernutrified due to agricultural runoff that noxious algal blooms have occurred with consequent deoxygenation when the blooms die and decay. This has led the Danish parliament to curb the agricultural use of artificial fertilizers in an attempt to minimize this effect in the sea.

I know of no documented cases of mariculture:agriculture conflict in Atlantic Canada. However, a reasonable working hypothesis in this area suggests that the toxic mussel problem in the Cardigan estuary, P.E.I., which occurred in December 1987, was caused by a microalgal bloom stimulated by nutrient runoff from nearby tobacco growing fields.

SALMONID MARICULTURE AND SELF POLLUTION

The feed used for growing out salmon consists of

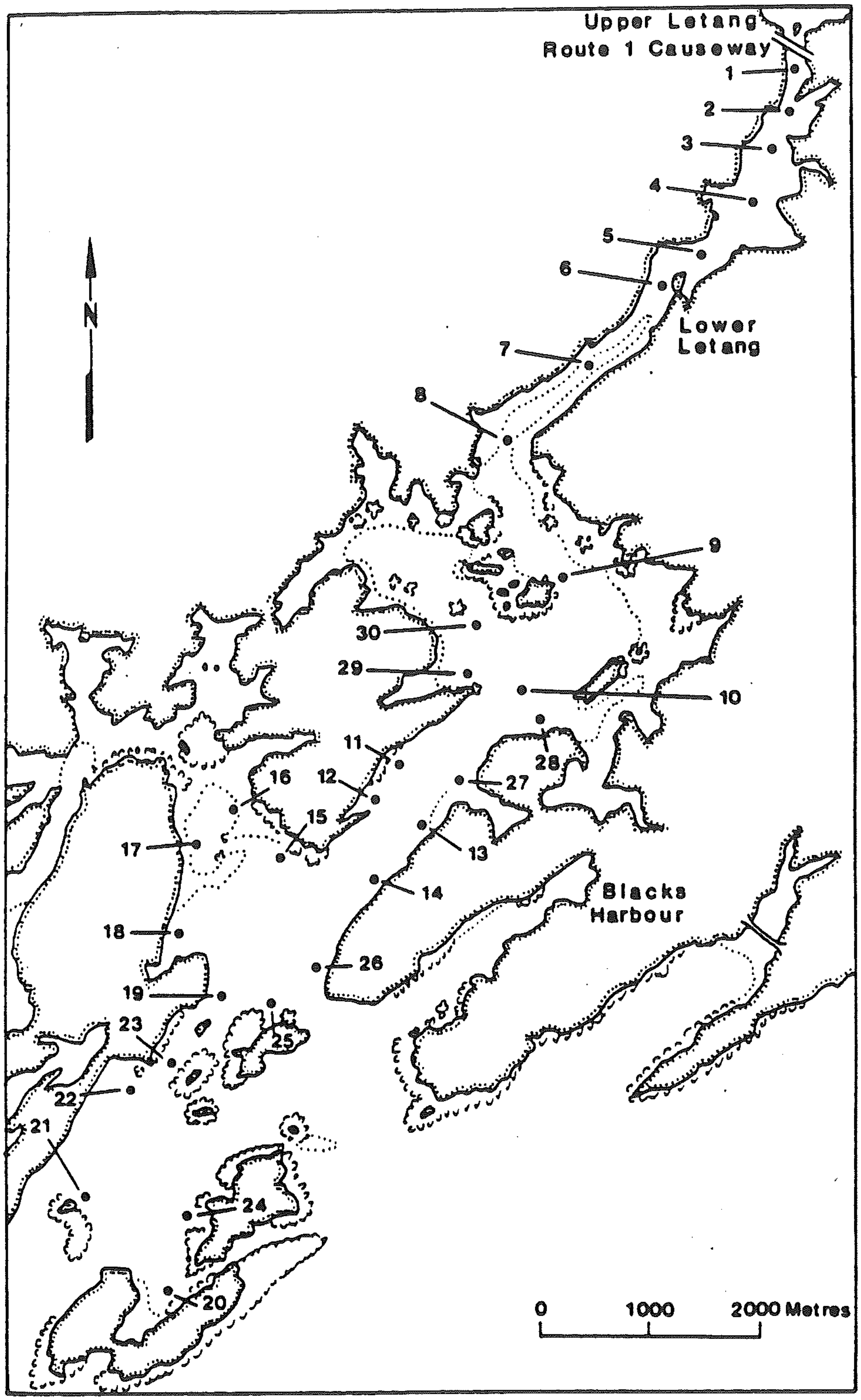

Figure 3. Sampling stations utilized in Lower L'Etang.

a dry pellet or wet feed produced daily from frozen herring. Up to 30% of the food may be wasted during feeding, although good practice would require wastage to be much lower than this (8). Faecal matter is the other waste product. Both waste food and faeces are particulate organic wastes with a high biological oxygen demand rich in nitrogen and phosphorous compounds. Particulate wastes are dispersed by tidal and wave-induced currents. Where currents are weak or absent, the wastes begin to undergo aerobic microbial degradation as soon as they are released. If the bulk of the degradation occurs after settlement on sediments, the local availability of oxygen may be exhausted and a different type of decay - anaerobic microbial degradation - is initiated. Anaerobic micro-organisms use sulphate as the electron acceptor producing hydrogen sulphide during the process of reduction (9).

A survey of benthic conditions around the salmonid cage sites was made in 1985 in Lower L'Etang and thereafter annually throughout the Western Isles area by the Aquaculture Ecology group at the St. Andrews Biological Station. The 1985 survey showed (4) that there had been little buildup of organic material under most cage sites and hence no development of anaerobic degradation within the sediments. The energetic tidal currents are efficient in dispersing wastes over a large area and preventing buildup of organic material. Under some cage sites an as yet undescribed white, microbial slime community is present. It is similar to the freshwater sewage slime communities present downstream of pulp mill effluent or sewage outfalls (10). At Dark Harbour, Grand Manan, the sediments have become heavily polluted and anaerobic decay is underway because this site is almost totally enclosed by harbour walls and the tidal currents are so weak (11).

The process of microbial degradation, coupled with soluble nitrogenous compounds excreted by salmon, adds considerable amounts of phosphorous- and nitrogen-containing compounds in dissolved form. These compounds are plant nutrients and may stimulate the growth of green plants such as attached algae or phytoplankton. This may be beneficial to local productivity or harmful if the stimulation results in a toxic algal bloom. The red tide causing organism, *Gonyaulax excavata*, is harmful to adjacent commercial bivalve mollusc species since they utilize this dinoflagellate during feeding and become toxic to humans. Alternatively, red tides can have toxic effects through the food chain, e.g., in herring (12). Blooms of two species of phytoplankters previously considered to be non-toxic have been associated with mortalities of cultured Atlantic salmon on the west coast (13). A species of diatom, *Chaetoceros convolutus*, and a dinoflagellate, *Heterosigma akashiwo*, coincided with mortalities which reached 43%, but the toxic mechanism has not been identified. Recently, an algal bloom related mortality has been reported (14) in the southern Norwegian salmon industry.

The mariculture industry uses a wide variety of chemicals as biocides, e.g., as therapeutants, anaesthetics, disinfectants or for water treatment (Table 4). Chemicals are also used in construction materials, e.g., to control fouling, and hormones may be used to manipulate sexual or growth rate characteristics. The toxicity and environmental fate of many of these compounds is poorly known. Antifouling compounds containing tributyltin have been shown (15) to cause larval abnormalities and shell malfunction in oysters from Arcachon Bay, France. Tributyltin was used as an antifoulant for net cages in the Bay of Fundy although its use is now restricted in Canada.

DISCUSSION

During this presentation, a range of actual or potential resource-use conflicts involving mariculture and various other users have been outlined. At such an early stage of the development of mariculture in Atlantic Canada, it is difficult to see which factors mentioned are going to become critical. Most fish farmers realize the importance of maintaining environmental conditions at the growout site so the salmonid production can be optimized. It is for this reason that the most fashionable research question in this field is: how can the holding capacity of a defined area be determined for finfish such as salmonids? The corresponding question in the bivalve industry receiving much attention now is: how can the carrying capacity be optimized to minimize food limitation? It is hoped that this interest may result in sufficient research to enable the building of predictive models of holding or carrying capacity for mariculture.

Finally, the concept of marine resource management requires coastal zone planning. I believe that potential multiple-use conflicts can best be solved by discussion in planning meetings before they actually occur in the nearshore marine/estuarine environment.

Table 4. Chemicals registered or approved by the U.S. Food and Drug Administration for use in food fish culture (from Ref. 1).

Product	Use
Therapeutants	
Acetic acid	Parasiticide
Formalin	Parasiticide and fungicide
Romet 30 (sulfadimethoxine and orthomeprim)	Bactericide
Salt	Osmoregulatory enhancer
Sulfamerizine	Bactericide
Oxytetracycline (Terramycin)	Bactericide
Anesthetics	
Carbonic acid	Anesthetic
MS 222 (tricaine methane-sulfonate)	Anesthetic and sedative
Sodium bicarbonate	Anesthetic
Disinfectants	
Calcium hypochlorite	Disinfectant, algicide & bactericide
Water Treatment	
Fluorescein sodium	Dye
Lime (calcium hydroxide, oxide or carbonate)	Pond sterilant
Potassium permanganate	Oxidizer and detoxifier
Rhodamine B and WT	Dye
Copper sulfate	Algicide and herbicide
Copper, elemental	Algicide and herbicide
2, 4-D	Herbicide
Diquat dibromide	Algicide and herbicide
Endothall	Algicide and herbicide
Simazine	Algicide and herbicide
Clean-Flo (aluminum sulfate, calcium sulfate and boric acid)	Algicide and herbicide
Glyphosate	Herbicide
Potassium ricinoleate	Algicide
Xylene	Herbicide

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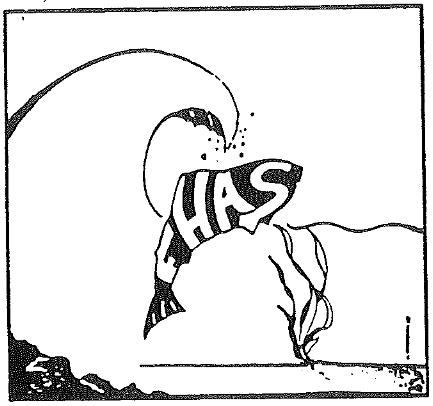
QUESTIONS

Although we haven't reached that stage yet, Europeans have a lot of experience now with development of aquaculture. In some cases the density which is achieved by growers of mussels on rafts significantly impacts upon the structure of the estuary. There are many areas in Spain which no longer produce shell fish because the enormous curtain of mussel cages and strings extending all the way up the estuary prevent tidal flushing. The potential does exist for aquaculture to become eventually an impediment in itself.

Wildish: Of course the s ategy of the aquaculturist is to optimize the position in which he puts his nets or cages. In the case of bivalves it means putting them normal to the flow so that they can intercept as large a fraction of the tidal flow that they can. That's quite difficult in Spain because it's actually a Bay and the flow in there is relatively low and it depends on tidal flushing.



Fish Habitat Protection - The Legal Framework

John Angel

ABSTRACT

While jurisdiction over property is a matter of provincial concern, jurisdiction over the impact of activities on fish in waterways within provincial boundaries is a matter of federal jurisdiction. The legislative mechanism is the Fisheries Act, an act of the federal parliament. Responsibility for the administration of this Act lies with the Minister of Fisheries and Oceans (Canada).

Included in the Fisheries Act is the protection of the natural systems in which fish live, collectively referred to as "fish habitat."

The protection afforded by the Fisheries Act applies to all waterways frequented by commercial or sport fish, including coastal waters, streams, river beds, salt marshes, lakes, etc.

The sections of the Act which deal with fish habitat protection are:

Section 31 - The major section, which prohibits any harmful alteration or destruction of fish habitat.
Sections 20, 28 and 52 deal with fish passage.
Section 53 - Provides for financing of certain hatchery operations.
Section 33 - Provides for certain procedural and legal requirements in complying with Section 31.
Section 55 - Maintenance of fish guards.
Section 56 - Protection of areas set aside for propagation.

INTRODUCTION

The following notes are an attempt to provide a brief overview of the federal law as it applies to fish habitat protection. They are directed at those individuals who work in the field of fish habitat and those who are concerned about the impact of man's activities on that habitat. They are not intended to be a thorough legal analysis of fish habitat law nor may they be construed in any way as a statement of the legal position of the federal government on fish habitat law.

JURISDICTION

As with many issues in a federalist state, jurisdiction over fish habitat is split or shared between our two levels of government—federal and provincial. Provincial jurisdiction is founded in the province's mandate over property within the province while federal participation finds its roots in jurisdiction over fisheries.

Section 92(13) of the Constitution Act, 1982 grants exclusive jurisdiction over "Property and Civil Rights in the Province" to the provinces. Thus any matter which touches on or deals with that property is a matter of provincial concern including all waters which are within the boundaries of a province. Any use of that property is a matter of provincial concern including all waters which are within the boundaries of a province. Any use of that property, again including the waterways, is primarily a provincial government responsibility. It is pursuant to this jurisdiction that provincial governments are empowered to make and enforce laws which protect the environment, including fish habitat.

Section 91(12) of the Constitution Act, 1982 grants exclusive jurisdiction over "Sea Coast and Inland Fisheries" to the federal Parliament. Federal jurisdiction over waterways and over activities conducted in and around those waterways which are within the boundaries of a province is restricted to their impact on fish. This includes the protection of the supporting systems upon which these fish depend for their survival. The Fisheries Act, an act of the federal Parliament, provides for the protection of fish and those natural environmental systems that support fish. Responsibility for the administration of this Act lies with the Minister of Fisheries and Oceans (Canada).

In summary, the provincial government has jurisdiction in the field of fish habitat and the right to make laws respecting the protection of that habitat due to its constitutional jurisdiction over property. The federal mandate over fish habitat (i.e., provincial property) arises by virtue of its constitutional jurisdiction over fish.

FISH HABITAT AND THE FISHERIES ACT

(a) The protection afforded fish habitat by the Fisheries Act applies to all waterways frequented by commercial or sport fish including coastal waters, streams, river beds, salt marshes, lakes, etc.

The major section of the Act which deals with fish habitat protection is section 31 (Appendix "A"). Sub-section 33(1) reads as follows:

> **No person shall carry on any work or undertaking that results in the harmful alteration, disruption or destruction of fish habitat.**

As one can see the prohibition is very broad, encompassing any activity which results in the alteration, disruption, or destruction of fish habitat. The question of when an activity may give rise to a charge depends on the nature and degree of such damage and remains a matter of prosecutional discretion. Sub-section 31(5) defines fish habitat as:

> **Spawning grounds and nursery, rearing, food supply and migration areas on which fish depend, directly or indirectly, in order to carry out their life processes.**

Again, the attempt is to be broad and include all factors which may bear on the life and survival of fish.

Sub-section 31(3) provides for penalties for breaches of sub-section 31(1) which can amount to $5,000 for a first offense and $10,000 for subsequent offenses. In the more serious cases, where the Crown proceeds by way of indictment, the penalty can be up to two years imprisonment.

Sub-section 31(2) provides a mechanism whereby the Minister may grant authority to persons to carry out work or undertakings under specified conditions. In such cases, these persons do not contravene sub-section 31(1).

In addition to the basic punitive framework provided in Section 31, sub-section 33(4) incorporates parts of section 33. These sub-sections consequently apply in respect of offenses committed under section 31 as if they were offenses committed under section 33. They provide for the issue of restraining orders upon conviction, injunctive relief during proceedings, vicarious liability and separate offenses for each day of a continuing offense.

Clearly section 31 is a very comprehensive framework with severe penalties for breaches. It is a difficult section to deal with in the courtroom situation, requiring expert testimony and very technical evidence. Proof of a habitat violation is complex, expensive and time consuming.

(b) Authorization Process (Appendix "B")

Section 33.1 provides a process whereby the Minister may require proponents of works or undertakings to submit plans, specifications, studies, etc., in order to enable the Minister to determine whether there is likely to be any damage to fish habitat. The Minister may, after reviewing such documents and determining that fish habitat damage may occur and, with the approval of the Governor in Council, require such modifications to the plans as he considers necessary in the circumstances. If necessary, the Minister may go so far, again with the approval of the Governor in Council, as to restrict or direct the closing of the work or undertaking for such period as he deems necessary.

(c) Other Provisions

There are various other provisions of the Fisheries Act which deal with fish habitat. Many of these provisions are directory and procedural in nature; and while charges may be laid for noncompliance, they are not considered to be punitive provisions in the same manner as section 31. Rather, they impose obligations on persons who work around waterways to take certain precautions and make provisions for the protection of fish and fish habitat.

(d) Fish Passage

Section 20 - This section requires owners or occupiers of dams and obstructions to provide fish passage devices around such obstructions in such form and capacity as will, in the opinion of the Minister, permit the free passage of fish. Section 20 is composed of 10 sub-sections which impose various duties upon the owners of such fish passage devices including proper maintenance, certain flow rates, installation of fish stops and diverters, etc. The section also provides the Minister with the authority, where an owner refuses to construct a fishway, to construct or have constructed an appropriate device and recover the costs from the owner. Similarly, where an owner refuses to remove obstructions following a request, the Minister may remove such obstruction and recover the cost from the owner.

Section 28 - This section requires that action be taken to install fish guards on intakes, channels, canals, etc., used for irrigation purposes and to properly maintain such guards.

Section 52 - This section creates an offense for failure to provide appropriate fish passage devices and flow rates. The penalty is $5,000 per day that the offense continues.

Section 53 - The Minister may direct that lump sum payments or annual sums be paid by owners of obstructions to finance hatchery operations in order to maintain annual returns of migratory fish.

SUMMARY

In summary the Fisheries Act provides for a three pronged approach to fish habitat protection. Firstly, there are sections 20, 28, 52, and 53 which impose specific obligations upon and give direction to persons having occasion to conduct work around waterways. Secondly, section 33.1 grants Ministerial authority to demand submission of plans and specifications of works and undertakings to determine whether fish habitat damage is likely to occur. These two measures are an attempt to prevent fish habitat damage or to provide for the livelihood of fish if their habitat is altered. The third measure is the very powerful and punitive section 31 which seeks to punish offenders who have carried on works or undertakings which have already resulted in fish habitat alteration, disruption or destruction.

APPENDIX "A"

Harmful alteration, etc., of fish habitat

31.(1) No person shall carry on any work or undertaking that results in the harmful alteration, disruption or destruction of fish habitat.

Alteration, etc., authorized

(2) No person contravenes subsection (1) by causing the alteration, disruption or destruction of fish habitat by any means or under any conditions authorized by the Minister or under regulations made by the Governor in Council under this Act.

Punishment

(3) Every person who contravenes subsection (1) is guilty of an offence and liable

(a) on summary conviction, to a fine not exceeding five thousand dollars for a first offence, and not exceeding ten thousand dollars for each subsequent offence; or

(b) on conviction on indictment, to imprisonment for a term not exceeding two years.

Application of section 33

(4) Subsections 33(6) to (9) apply in respect of an offence under this section as if it were an offence under section 33.

"Fish habitat" defined

(5) For the purposes of this section and sections 33, 33.1 and 33.2, "fish habitat" means spawning grounds and nursery, rearing, food supply and migration areas on which fish depend directly or indirectly in order to carry out their life processes.

APPENDIX "B"

Minister may require plans and specifications

33.1 (1) Every person who carries on or proposes to carry on any work or undertaking that results or is likely to result in

(a) the deposit of a deleterious substance in water frequented by fish or in any place under any conditions where that deleterious substance or any other deleterious substance that results from the deposit of that deleterious substance may enter any such water, or

(b) the alteration, disruption or destruction of fish habitat.

shall on the request of the Minister or without request in the manner and circumstances prescribed by regulations made under paragraph (3) (a), provide the Minister with such plans, specifications, studies, procedures, schedules, analyses, samples or other information relating to the work or undertaking and with such analyses, samples, evaluations, studies or other information relating to the water, place or fish habitat that is or is likely to be affected by the work or undertaking as will enable the Minister to determine

(c) whether there is or is likely to be a deposit of a deleterious substance by reason of such work or undertaking that constitutes or would constitute an offence under section 33 and what measures, if any, would prevent such a deposit or mitigate the effects thereof; or

(d) whether the work or undertaking results or is likely to result in any alteration, disruption or destruction of fish habitat that constitutes or would constitute an offence under section 31 and what measures, if any, would prevent such a result or mitigate the effects thereof.

FORUM

Fish Habitat Protection: Responsibilities of Government and Industry

Chair: Jim Gourlay

Panel: André Ducharme
Lincoln McLeod
Peter Darnell
Donald Dodds
George Baker

INTRODUCTION

Jim Gourlay (Eastern Woods and Waters)

I have been asked to chair, adjudicate, referee, umpire--I am not sure which--this forum. I will ask our panelists shortly to give very brief opening statements, and then you, the audience, will be invited to participate in what we hope will be a wide open and wide-ranging discussion of what has gone before in the preceding two days.

In Sydney, Nova Scotia, I am told, you get up in the morning and listen to the birds cough. The question before us is: who is responsible for that; and who is ultimately responsible for ensuring that these things do not happen in the future? Government is unquestionably charged with the responsibility for looking after what are, after all, publicly owned natural resources. But government is also charged with nurturing industry in all its forms, to ensure a healthy economy. Are those conflicting responsibilities? Do we require an Ecological Auditor General to oversee these things on the public's behalf? From the point of view of industry, I am sure that anyone in the corporate world will declare that their primary responsibility is to their shareholders and employees, to remain viable. They must remain transfixed by the bottom line of the balance sheet, and to this end minimise costs and maximise income. We must therefore ask if ecological responsibility is a cost, and added to the debit side of the ledger. If so, industry must minimise that cost, and hence we have another conflict.

Does industry, in fact, have any responsibility--moral or otherwise--beyond submitting to the laws of the land?

PANELISTS' COMMENTS

André Ducharme (Habitat Management Branch, Department of Fisheries and Oceans)

My position is essentially that of the Department of Fisheries and Oceans. I honestly believe that industry should be well pleased that we have a new policy, that we have a new programme to implement that policy, and that that policy stipulates we should be consistent and fair. We have often been accused in the past of not being consistent and fair. Also comforting to industry, I believe, is that we shall continue to use the same two tools that we have always used: Protection and Compliance. We are, of course, mandated to do that--to enforce the Fisheries Act. But in this policy, we have also given ourselves some alternatives to prosecution. One of those we are all here currently involved in--Communication and Education. We aim to inform industry where we are coming from, to encourage those in industry to stand with us, and inform them of how they can help us fashion our future in habitat protection.

We have also given ourselves a renewed strategy of consultation with the public and with industry. Also, although we haven't been much involved to date, we will become involved in cooperative ventures with industry, and with any other interested group.

Lincoln McLeod (Nova Scotia Department of Fisheries)

As Director of Aquaculture and Fisheries, I am not so much involved in conservation as I am in development. However, we are also responsible for administering the federal-provincial agreement on trout, and there obviously is a strong conservation responsibility.

At the present time we are preparing a draft plan for the management of the trout fishery and other inland species, which we will shortly be presenting to the federal government. We propose to divide the Province of Nova Scotia into five areas, and to establish an Advisory Committee which will bring together all participants--combatants if you will--to advise us on how to manage our inland fisheries. I think this is a keystone of what fisheries habitat protection is all about.

If I had the power, I would instruct all those who have activities on the water's edge to read Gerard La Forest's "Water Law in Canada" because it provides a good chronological account of those undertakings occurring on or near the water. Not only that, but it chronicles the establishment of case law related to these undertakings.

On the aquaculture side, the Aquaculture Act and regulations is not a strong piece of legislation with regards to habitat protection, but it does have some in there. An important aspect is that we allow for public consultation before we issue a lease, or allow anyone to enter the estuary. These public hearings are very important for the aquaculturist, to allow him to determine whether and how he can recover the very significant investment in an amicable environment.

I think the establishment of round-table discussion groups is very important, and I am very encouraged by what has gone on here during the past three days.

Peter Darnell (Aquaculture Association of Nova Scotia)

We in the aquaculture industry require the highest water quality standards. The shellfish farmer must meet stringent government regulations on bacterial contamination in order to market his products. Indeed, aquaculture leases will not be granted until the proposed "grow-out" area has been proven to be clean. The finfish farmer must also have clean water in order to raise his fish. As Dr. Wildish mentioned yesterday, the aquaculturist can be a polluter of the marine environment. The Norwegian salmon industry has discovered this the hard way. Waste material can build up underneath cages if sites without adequate water exchanges are chosen. However, unlike many other industries, if we pollute, we are fouling our own nests. We will feel the negative effects most keenly. We are obviously interested in maintaining high water quality standards.

With regard to the question of fish habitat management, the aquaculture industry may play the role of a monitor: the fish farmer is at his site every day--any change in the marine environment is immediately noted. As a consequence, our industry is forcing government to do more water quality monitoring.

The further we fish farmers get into this business, the more we recognise how little we understand the medium in which we are operating. We therefore are generating a lot of research. I believe that this increased knowledge will benefit not only our fish, but all of the fish out there in the marine environment.

Donald Dodds (Nova Scotia Wildlife Advisory Council)

I would like to take a somewhat different tack on this question. Most of the other panelists have talked from the perspective of their own particular responsibilities. I would like firstly to discuss the question of the responsibilities of government and industry, and then note where I believe a couple of the problems lie.

It obviously is a responsibility of government to attempt to maintain the quality of fish habitat, and improve it where the Crown has jurisdiction. This is achieved through legislation and regulation. It is also partly a government responsibility on private lands through guidelines, through progressive policies such as incentives, through extension and education. It is also the responsibility of government through legislation to allow for the minimising and even elimination of various pollutants being added to our waterways and general environment.

It is also a responsibility of industry, including, as Jim mentioned, the stockholders, and should, I believe, be a part of production costs and ultimately of consumer cost. But this also includes in our system federal-provincial arrangements in cost sharing, relative to abatement, which have been used very successfully.

Further than that, I believe it is the responsibility of individuals, even where legislation and guidelines may be present, because regulations are not always followed or activities monitored. Individuals also have responsibilities wherever cattle and stream banks come into contact,wherever spraying is done, wherever people have gardens, wherever they have pesticide containers that must be disposed of, and so on.

There are two problems. Politically there is a problem in the development of policy, and in the bureaucracy there is a problem of developing the mechanisms for delivery of that policy once it has been formulated and the regulations established. I believe that these processes are being hindered or confused at the present time by the rapid growth of vested interest groups as far as the politician and policy is concerned, and I believe that "Parkinsonism" in the rapidly growing bureaucracy represents an impediment to the delivery of these policies to maintain fish habitat and improve the situations that we have presently.

George Baker (Nova Scotia Tidal Power Corporation)

My opinions on the respective responsibilities of industry and government have to be coloured by my own experience. I want to talk for just a moment about the Annapolis project. This was certainly a case of an engineering work impacting upon an estuary and its fish habitat. It was different from other estuarine projects in that the estuary had itself been substantially cut off from the sea in 1960 by construction of a causeway. The tidal plant had the effect of increasing the exchange of fresh and seawater, and thus taking the estuary back in part towards its natural condition. We had an environmental assessment before we began. It predicted low mortality for certain types of fish. We carried out a number of changes during the construction--fixing up the old fishway and installing a new one according to a DFO design. We also carried out morphological studies on American shad, which we regarded as a "marker species." When the plant started, our first concern was to determine what the fish mortality was. Work was done first in 1985, and we were given the results: 43% mortality plus or minus a further large uncertainty factor. We did not think that work was impeccable in terms of test procedures, and it was repeated the next year with more refined techniques. We got the figure of 20% mortality plus or minus some uncertainty factor. Last year we obtained results from another hydroelectric station that suggest that techniques for measuring mortality on passage through turbines might yield results that are too high by about three times. So the bottom line of our experience is that we do not know what the mortality rate at Annapolis is, and we do not really know how to find out.

Some way through that process we decided that there was indeed mortality, and that we should be finding ways of keeping fish out of the turbines. We did find out that the nice fish pass that DFO had designed had one little flaw: the fish didn't like it. They were intent on going through the turbine instead. So we began last year to look at means of diverting fish. Although we have some indications of things that might work, there are some paradoxes, and so at this time I have to say that we do not know what the score is on that point.

Apart from the question of mortality, the dominant effect of the plant in regard to fish habitat is what the plant does to the headpond water--the quality, the regime, and the productivity. Acadia biologists and the Acadia Centre for Estuarine Research began gathering baseline data during the construction phase of the plant and have continued to monitor conditions since then. From what they have found we think that the quality of water has not suffered, that productivity has improved, and that although the biota have changed somewhat, it has not been in any adverse sense. But we do not know whether that translates into better survival of fish, or whether it doesn't.

The main thing that may affect fish in the estuary, may be the effect on striped bass. It is my understanding that if fish larvae enter saltwater too soon before the yolk sac is used up, they perish. If they don't get to saltwater within a very short time after the yolk sac is used up, they also die. And that if there isn't any food there they die. This may explain why striped bass have great difficulty in having a successful year class. In fact at Annapolis there was not a successful year class for eight years in a row, ending in 1982 or 1983. What we do affects the salt wedge and the distribution of salt in the estuary. Are we helping the bass or hurting them? Again, we don't know, and we don't know how to find out.

From my point of view, the Department of Fisheries and Oceans would probably have a responsibility for ensuring that the basic and applied science is in place so that an industrial entity that wishes to cooperate would find some tools to analyse the situation and provide meaningful cooperation.

Another aspect is that we feel that the Annapolis plant, by very minor modifications of its operating procedures, might be able either to hurt or to help fish. Without a good analysis, without finding out more than we have been able to find out, we do not know what it is we should be doing.

Apart from that, the impacts as predicted by the environmental assessment have turned out to be very much as predicted. There is no evidence of an erosion problem, and the imputation that clams have been killed by sedimentation below the causeway, has a serious flaw in it: the small amount of sediment moved down by the plant does not reach the areas where it is claimed the clam populations are harvested and the crop has started to fail. On the other hand, most observers know that that fishery has been overharvested to an amazing extent. The situation reminds me of a car mechanic who, when faced with an engine that won't work, suggests that the ignition system is faulty in design, when he should know that there is no gas in the tank.

I have two other comments regarding the respective responsibilities of industry and government. I do think that DFO's new policy is very good. The fact that it includes education deserves full marks, as does this Seminar. I think that DFO's new policy, and policies in total, should not just look at the control of new developments, but they should look at the improvement and optimization of things that exist now. I am sure that most industries would be willing to cooperate even to the extent of internalising some costs that are not required to be internalised under the law.

DISCUSSION

Doug Robinson (Clearwater Industries): *Much of what is put into rivers and estuaries come from municipalities--both rural and urban. How do we address that problem?*

McLeod: I said earlier that it is important to recognise the sociology of the community. If we are to have an impact on that sociology, then education, and the presence of open and consultative policies are all very important. Pollution by municipalities is something that has gone on throughout Canada's history. Other counties have attacked it with some success. Here in Atlantic Canada we have attacked it through federal-provincial agreements on sewage abatement facilities. While those agreements were good, they didn't go far enough because they did not provide trained operators in most cases, with the result that they became point sources of pollution; which was worse than we had before. There is no question about the impact of pollution on shellfish consumption.

At this stage we do not know the full impact or extent of the eutrophication of estuaries. We are seeing evidence of it in the Baltic Sea and in regard to PSP problems.

How do you internalise the cost of pollution abatement at the municipal level? Most people would argue that water should be unpriced--it has always been there and is a natural resource. One of the great things about our nation is that we have lots of water (maybe), but we have not internalised the price of our water, and most definitely we have not internalised the price of our waste. That applies in every industry. I don't think any municipal employee wishes to pollute others' water or harm others' business, or diminish their neighbour's right to take their children down to the beach to dig clams. Through seminars such as this, television, and political involvement, we can increase awareness. Remember that we are all part of government--the distinction between government and the citizen is artificial. I think the national effort to establish round table groups to advise governments is a very progressive step and I think seminars such as this represent another progressive step.

One final point: we charge a farmer for damage to a fish habitat, but to my knowledge we have never taken a municipality to court despite the fact that the problems are greater, more area and more species of fish are affected. But that apparently is not in our current sociology of things to do. I think that is changing.

Gourlay: There were a great many things in what you have just said. I would like to raise one for more discussion. It relates to the conflict to which I alluded earlier, namely government as industry, as polluter, but also as watchdog. Do we need some independent alternative body--an ecological auditor general, if you will--to do this job for us?

Baker: If you want a comment from a member of the panel, I would think that the last thing we want is another body--for anything. I think that the federal government is already sufficiently compartmentalised. For example, DFO has a clear mandate to do certain things with regard to the fishery and its protection, whereas those responsible for promoting development, encouraging industry, and so on, are in quite different departments. I am sure that Fisheries' mandate is not going to be weakened because some other department has a different mandate.

Ducharme: I agree with much of what has been said. I hope that we can reply with a confident "yes" to the question of whether DFO is doing its job. I realise, of course, that much of our job lies ahead of us.

I would like to comment on an issue raised earlier by Mr. Baker, when he indicated he would like to see some retroactivity designed into our policy. Although that policy was not drawn up with retroactivity in mind, that does not necessarily mean that we cannot devote some of our energy, apply some of our technology, to correcting problems that belong to the past. When we redesign a fishway--one that works--for a dam that has been in existence for 30 or 40 years, we are doing that in effect. However, I feel compelled to state that the resources needed to carry out such work--resources in terms of people and dollars--are not growing. If anything, they are decreasing. It is a time of severe restraint. This means that it is not possible for the technical people in DFO to respond positively to your desire for retroactivity and at the same time to respond to Linc McLeod's desire to see the monumental problem of domestic sewage being distributed all along the shores of Nova Scotia, being dealt with. Some might suggest that we lay a charge against one of the municipalities. But you can see that for DFO, which is trying to operate on the principle of consistency, it would be necessary to take to court every municipality in Nova Scotia. It is an astronomical problem. The solution cannot be in going to court for this. The solution has to be, as Linc indicated, in raising awareness, in creating a climate where our political leaders find the gumption to determine that we will deal with that problem. Then the technical people can be instructed to prepare a plan, and in turn we will inform them that the plan will cost whatever it may be. If they have the money, then we will be in business. It won't happen overnight. It took decades--even a hundred years--to create the situation that exists, for example, in Halifax harbour. It may take a decade or two to rectify it, and we should not be surprised at the time factor. If we could clean ourselves up in Nova Scotia in two decades, I would say we are being very efficient.

Gary Rice (Nova Scotia Power Corporation): *As an engineer responsible for all of the hydro plants in Nova Scotia, including the Annapolis, I had a pretty hard day yesterday. I should at least have a little bit of a kick back. Sometimes we see the scientists much like the infantrymen who rush in when the battle is over and bayonet the dead. However, we do have extremely good cooperation from those in DFO, and* *have a number of exciting projects under way. The problem that I see is not the definition of the problem, but the definition, and more importantly, the evaluation of the solution. I recognise that this may be, as André indicates, partly a matter of lack of resources, rather than a reluctance on their part. For example, in the work we are doing at Hell's Gate, or the enhancement on the Cheticamp River, there does not seem to be the follow up evaluation that is necessary by the experts to tell us: "Yes this is good" or not.*

Ducharme: I agree that we have not been following up on projects as well as we would have liked. It is not from lack of wanting to; it is for lack of resources. That is the main reason. At the time when we should have been returning to a project that we have jointly worked on, to provide the evaluation to determine how effective it was, at that time we were on another battlefield. We have the bayonet on, although it is not bloody most of the time! When it does become possible to return to the site, often so much time has elapsed that it is beginning to lose meaning. We do occasionally get reports from our fishery officers who are living near the site, but one has to realise that the fisheries officer in the field is not a complete evaluation team in himself. He can provide a quick indication of simple observations--whether fish are moving up a fishway, for example--but if it is more complex than that it requires a planned, directed and designed response from head office.

Gourlay: I would like to ask Gary Rice or George Baker whether you feel that in some senses, as engineers, circumstances have overtaken you. When you talk about solutions, it seems to me that some have to be engineering solutions, not just scientific ones. Has the education of engineers failed to keep pace in terms of the implications of what you do?

Rice: I quite agree with you. The education of the engineer is not keeping up. Perhaps we have to blame academia here.

Hank Kolstee (Nova Scotia Department of Agriculture): *I would like to propose that DFO more often take an effort to provide alternative scenarios that would assist proponents to design their projects more satisfactorally. At present it is the proponent's responsibility to provide the design, but then DFO enters and says, that the project cannot be approved as it is, but without offering alternatives.*

Ducharme: I understand your concern. We do indeed attempt to offer that kind of advice, but often we do not know what the alternatives are. It may be that the only alternative is not to carry out the project. The situation with regard to agriculture is an extremely complex one. I think it is fair to say that we are trying to effect compromises with you, although you probably often feel that DFO is throwing too many monkey-wrenches in your wheels. We will try to work out compromises with you, and to find alternatives, but you must recognise that we often do not know what the alternatives are. We must find those solutions together. We may have to employ clever consultants to work between us--we do have engineers on our staff, but they are not agricultural engineers.

Peter Winchester (Department of Fisheries and Oceans): *At present in the province of Nova Scotia there is water pricing--at least in the municipality of Halifax. The problem is a) different users pay different fees, and (b) the price isn't high enough. At a recent aquaculture conference I found that some users were paying for water while others were not. That is an inconsistency that I cannot comprehend. User groups should be paying for clean water--that will bring to the attention of the political people that pristine water is the most important thing that we have.*

Gourlay: I think that you are once again identifying the question of public awareness.

Darnell: I agree that public awareness is a key factor here. Just recently DFO posted the area of Mahone Bay with regard to faecal contamination, and you wouldn't believe the amount of comment that it caused. But the fact is that the situation had not changed radically--the last survey was three years ago--but now there are signs about it. People are now very much aware of the problem. The town of Mahone Bay, which is dumping raw sewage into their harbour is now much more likely to entertain the notion of sewage treatment now that they know the extent of the problem they have. Awareness is the key to the problem.

Dominy: The Pearse Commission on water also called attention to the question of water pricing. Recently, the Canadian Council of Resource and Environment Ministers has called for a national survey of water pricing practices. The early results are now coming in. There appears to be no pattern of consistency in water pricing policy. That is an area of possible solution to many problems--namely the correct pricing of water.

Graham Daborn (Acadia Centre for Estuarine Research): I would like to go back to an issue raised by Gary Rice with regard to the respective responsibilities of government and industry for a clean environment. He pointed out that industry often has difficulty obtaining an answer from government agencies when they are asked for advice because the response is very often that "We don't know" either the solution or the cause of a problem generated by a particular development. Part of the reason for that is that we do not audit or monitor the effectiveness of remedial measures that are taken in each case. Nobody commits the resources to monitor each mitigation in order that we may learn from it. Government agencies do not have the resources--they are out fighting another fire. I think that it is here that industry must accept the responsibility to provide the resources to monitor each development for however many years are required. Then the industry might expect, some time down the road, to get better advice than they got the first time.

Gourlay: I would like to pursue the question of public awareness. To my mind, things change when there is the political will for that change. But if you do not have an educated and aware public it is highly unlikely that the political will will be generated. As an example, one might take the Tusket River in Yarmouth County. It had been acidifying for years, but no one seemed to care, because it wasn't visible. Then we had a tin mine which had trouble with its effluent, whereupon people could see what was going into the river. The political furor was immediate--and it was fixed.

McLeod: We have, in cooperation with the Department of Education, prepared a package on trout that will be distributed to all schools in the province, explaining why there are trout in some places and not others, and so on. That is one way of creating awareness--getting people involved in the resource itself. Another programme is the "Adopt a stream" programme, which aims to get people out to rehabilitate and manage local streams. These types of programmes have worked very well in British Columbia.

Gourlay: Are we being well served by the media in terms of these issues?

Ducharme: I must say I have been gratified by the response of the media, the interest they have shown, in this seminar. But in the past I was somewhat afraid of speaking to the media because I feared that my statements would be misconstrued, or twisted for some other purpose. It may have been unjustified. But I always felt that the media was more interested in controversy or sensational things. A new policy to conserve fish habitat was not sensational enough. I wish the media would search for those things that they may see as boring: what is behind the new policy? What research does DFO carry out? What does it plan to do next year? That could help us a great deal.

Dodds: Very little has so far been said about what the forestry industry is currently doing with regard to fish habitat. In fact it is doing a great deal, and some of it is very exciting. As many of you know, the provincial government has established three new policies: a wildlife policy, a forestry policy, and more recently a parks policy. Each of the wildlife and forestry policies have been accompanied by legislation and regulations in which specific mandates have been established for government in relation to wildlife and forestry practices. The groundwork has been laid for further development of wildlife-forestry integration. There are other things, such as the St. Mary's River project, that are in part sponsored by government. This project seeks to provide better information on the question of wildlife habitat and forestry activity. Public awareness initiatives are also numerous in this area.

Neil Bellefontaine (Department of Fisheries and Oceans): It is necessary to have a sustained programme to raise public awareness. The posting of shellfish beds this year was a deliberate policy of our Department to increase awareness of the public of how much of the coastline is no longer available for the harvesting of shellfish. People do not see the incremental changes that are taking place--only the dramatic events. We all, government and media alike, must find ways to sustain the awareness of the public.

Don Gordon (Bedford Institute of Oceanography): In this forum, focused as it is on government and industry, we are forgetting a most important participant--the universities. They can play an important role in the process. Firstly, by helping organise such gatherings as this, to bring together all of the parties. Secondly, in terms of their course programmes. Eventually we are going to need people with the appropriate training in habitat management: the blending of the social, the scientific, and the engineering. Universities may also play an important role in terms of the audit of developments, since university scientists working in more basic science can take a more objective viewpoint than those in government, who are often constrained by policy.

Gourlay: There is also the specialist--the science writer, who can ostensibly speak to both the scientist and the public. We do have a difficulty in translating science into something that the public can understand.

FISH HABITAT AWARENESS SEMINAR

22-24 June 1988

Final Programme

Wednesday 22 June

12:00 - 14:00	**REGISTRATION AND BUFFET LUNCH** Wheelock Lounge
	INTRODUCTORY SESSION Beveridge Arts Centre (BAC) Room 132
14:00	Welcome Introductory Remarks - Neil Bellefontaine
14:15 - 15:00	Theme Presentation Topic: **Introduction to Fish Habitat - W. Rowat** Assistant Deputy Minister Atlantic Fisheries Operations, DFO
15:00 - 15:15	Coffee
15:30	**FRESHWATER ENVIRONMENTS** BAC Room 132 Chair: Dr. G.R. Daborn (Acadia Centre for Estuarine Research)
15:30 - 17:00	**Characteristics of Freshwater Fish Habitat - André Ducharme** Habitat Management Branch DFO
18:00 - 19:30	Supper Wheelock Hall

Freshwater Environments
BAC Room 132
(Cont.)

19:30 - 21:00	**Fisheries Habitat Policy - C.L. Dominy** DFO, Habitat Management Branch, Ottawa
21:00	Movie Presentations BAC Rooms 141 and 138

Thursday 23 June

07:00	Breakfast Wheelock Hall

Freshwater Environments
BAC Room 132
Cont.

08:30 - 09:15	**Effects of Physical Modifications on Freshwater Fish Habitat - Dr. Dale Bray** University of New Brunswick
09:15 - 09:45	**Effects of Terrestrial Cover Removal - Robert Rutherford** DFO, Halifax
09:45 - 10:15	**Siltation Effects on Fish Habitat - Dave Morantz** DFO, Halifax
10:15 - 10: 30	Coffee
10:30 - 11:15	**Freshwater Quality Parameters - Dr. J.G. Ogden III** Dalhousie University
11:15 - 12:00	**Toxicological Aspects in Freshwater Environments - Dr. Jack Uthe** DFO, Halifax
12:00 - 13:30	Lunch Wheelock Hall
13:30 - 17:45	ESTUARINE AND COASTAL ENVIRONMENTS BAC Room 132 Chair: Dr. Mike Brylinsky (Acadia Centre for Estuarine Research)
13:30 - 14:30	**Characteristics of Estuarine and Coastal Waters - Dr. Ken Mann** DFO, Halifax
14:30 - 15:15	**Effects of Physical Modifications on Estuarine and Coastal Fish Habitats - Dr. Graham Daborn** Acadia Centre for Estuarine Research
15:15 - 15:30	Coffee
15:30 - 16:15	**Aspects of Water and Sediment Quality in Relation to Fish Habitat - Dr. Scott MacKnight** Oceanchem Group
16:15 - 16:45	**The Special Case of Migratory Fish - Dr. Michael Dadswell** Acadia University
16:45 - 7:15	**Shellfish Habitat in the Coastal Zone - Dr. David Scarratt** DFO, Halifax
17:15 - 17:45	**The Special Case of Aquaculture - Dr. David Wildish** DFO, St. Andrews
18:30	Reception Wheelock Lounge
19:00 - 21:00	Banquet Wheelock Hall Guest Speaker: Dr. Alex Colville - "Politics and the Environment"

Friday 24 June

	Breakfast Wheelock Hall
08:30	**PERSPECTIVES AND POLICY** BAC Room 132 Chair: Dr. J. Sherman Boates (Acadia University)
08:30 - 09:15	**Perspectives 1: Terrestrial Resource Industries - Edward Bulley** Bowater-Mersey, Inc.
09:15 - 10:00	**Perspectives 2: Aquatic Resource Industries - Douglas Robinson** Clearwater Industries
10:00 - 10:15	Coffee
10:15 - 11:00	**Habitat Law - John Angel** DFO, Ottawa
11:00 - 12:30	**FORUM** **Habitat Protection: Responsibilities of Government and Industry** Chair: Jim Gourlay (Editor, Eastern Woods and Waters) Panel: André Ducharme George Baker Peter Darnell Dr. Don Dodds Lincoln McLeod
12:30	Lunch Closing Remarks - Neil Bellefontaine

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Final Attendance List
for Fish Habitat Awareness Seminar
June 27, 1988

Mr. Roger Allbright, Environment Canada
Ms. Diane Amirault, Acadia University
Mr. John Angel, Department of Fisheries and Oceans
Mr. George C. Baker, Nova Scotia Tidal Power Corporation
Mr. Tim Barker, Department of Fisheries and Oceans
Mr. Ron Barkhouse, Nova Scotia Tidal Power Corporation
Mr. Neil Bellefontaine, Department of Fisheries and Oceans
Ms. Mary Benedict, Nova Scotia Power Corporation
Mr. Dave Bezanson, Michelin Tires Limited
Dr. Sherman Boates, Acadia University
Ms. Susan Bolton, Association of Science Teachers
Ms. Valerie Bradshaw, Department of Fisheries and Oceans
Dr. Dale Bray, University of New Brunswick
Mr. Barry Brown, Minas Basin Pulp and Power Company Limited
Mr. Donald Brown, SWNB
Dr. Michael Brylinsky, Acadia University
Mr. Edward Bulley, Bowater Mersey Paper Company Limited
Mr. David Cashen, Association of Science Teachers
Mr. Christopher Clarke, Bowater Mersey Paper Company Limited
Ms. Colleen Clarke, Rivers and Lakes Adv.
Mr. Peter Comeau, Acadia University
Dr. Graham Daborn, Acadia University
Dr. Michael Dadswell, Acadia University
Mr. Peter Darnell, Indian Point Marine Farms
Dr. Don Dodds, Wildlife Advisory Committee
Mr. L. Dominy, Department of Fisheries and Oceans
Mr. Tony Duke, Nova Scotia Department of Lands and Forests
Mr. André Ducharme, Department of Fisheries and Oceans
Ms. Alison Evans, Minas Basin Pulp and Power Company Limited
Mr. John Gilhen, Nova Scotia Museum
Mr. Mike Gochell, Environment Canada
Ms. Wooi Khoon Gong, Bedford Institute of Oceanography
Mr. Carl Goodwin, Department of Fisheries and Oceans
Dr. Don Gordon, Bedford Institute of Oceanography/Department of Fisheries and Oceans
Mr. Jim Gourlay, Eastern Woods and Waters
Ms. Claude Groindool, Translator
Mr. Charles Hickman, Nova Scotia Salmon Association
Mr. Larry Hildebrand, Environment Canada
Mr. Dave Holt, Eastern Woods and Waters
Mr. Brian C. Keating, Department of Fisheries and Oceans
Mr. Frank King, Department of Fisheries and Oceans
Mr. Hank W. Kolstee, Nova Scotia Department of Agriculture and Marketing
Mr. Mark Landry, University of New Brunswick
Mr. Bill Leblanc, Canadian National Railway
Mr. Maurice Levesque, Department of Fisheries and Oceans
Ms. Francoise Longhurst, Translator
Mr. John Machell, Environment Canada
Dr. Scott MacKnight, Oceanchem Group
Mr. David MacNearney, Salmon Propagation Association Co-op
Dr. Ken Mann, Department of Fisheries and Oceans
Mr. Lincoln McLeod, Department of Fisheries and Oceans
Mr. Max Miller, Department of Transportation and Communications
Mr. D.C. Milligan, Cobequid Salmon
Mr. Randy Milton, St. Mary's River Project
Mr. Dave Morantz, Department of Fisheries and Oceans
Mr. James Morrow, Coalition Against Pesticides
Mr. Dallas Moyer, Eastern Fishermen's Federation
Mr. Charles G. Murphy, Department of Fisheries and Oceans
Mr. Tony O'Carroll, Halifax County Municipality Department of Planning and Development
Dr. J.G. Ogden III, Dalhousie University
Mr. Roy Parker, Environment Canada
Mr. Peter Partington, Department of Fisheries and Oceans
Mr. Don Piercey, Department of Transportation and Communications
Mr. R.G. Rice, Nova Scotia Power Corporation
Mr. Dale Richards, Truro
Ms. Barbara Riley, Seafood Producers Association of Nova Scotia
Mr. Douglas Robinson, Clearwater Fine Foods
Mr. William Rowat, Department of Fisheries and Oceans
Mr. Robert Rutherford, Department of Fisheries and Oceans
Ms. Maureen Ryan, Halifax County Municipality Department of Planning and Development
Mr. Barry Sabean, Nova Scotia Department of Lands and Forests
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