Approaches to Marine Ecosystem Delineation in the Strait of Georgia: Proceedings of a D.F.O. Workshop, Sidney, B.C., 4-5 November 1997

C.D. Levings, J.D. Pringle, and F. Aitkens [Editors]

Department of Fisheries and Oceans
Science Branch, West Vancouver Laboratory
4160 Marine Drive
West Vancouver, B.C. V7V 1N6

1998

Canadian Technical Report of Fisheries and Aquatic Sciences 2247

Fisheries and Oceans
Pêches et Océans

Canada

Canadian Technical Report of Fisheries and Aquatic Sciences

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries and aquatic sciences.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in *Aquatic Sciences and Fisheries Abstracts* and indexed in the Department's annual index to scientific and technical publications.

Numbers 1-456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457-714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715-924 were issued as Department of Fisheries and the Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the establishment listed on the front cover and title page. Out-of-stock reports will be supplied for a fee by commercial agents.

Rapport technique canadien des sciences halieutiques et aquatiques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques du ministère des Pêches et des Océans, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications complètes. Le titre exact paraît au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la revue *Résumés des sceiences aquatiques et halieutiques*, et ils sont classés dans l'index annual des publication scientifiques et techniques du Ministère.

Les numéros 1à 456 de cette série ont été publiés à titre de rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

Les rapports techniques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

Canadian Technical Report of
Fisheries and Aquatic Sciences 2247

1998

APPROACHES TO MARINE ECOSYSTEM DELINEATION IN THE STRAIT OF GEORGIA: PROCEEDINGS OF A D.F.O. WORKSHOP, SIDNEY, B.C., 4–5 NOVEMBER 1997

C.D. Levings,[1] J.D Pringle,[2] and F. Aitkens[3] [Editors]

Department of Fisheries and Oceans
Science Branch, West Vancouver Laboratory
4160 Marine Drive
West Vancouver, B.C. V7V 1N6[1].

[2]Department of Fisheries and Oceans
Science Branch, Institute of Ocean Sciences
Sidney, B.C. V8L 4B2

[3] 2023 Meadow Place
Victoria, B.C. V8R 1R2

Cat. No. Fs 97-6/2247E ISSN 0706-6457

Correct citation for this publication:

Levings, C.D., J.D Pringle, and F. Aitkens [eds]. 1998. Approaches to marine ecosystem delineation in the Strait of Georgia: Proceedings of a D.F.O. workshop, Sidney, B.C., 4–5 November 1997. Can. Tech. Rep. Fish. Aquat. Sci. 2247: 165 p.

TABLE OF CONTENTS

ABSTRACT

Levings, C.D., J.D Pringle, and F. Aitkens [ed]. 1998. Approaches to marine ecosystem delineation in the Strait of Georgia: Proceedings of a D.F.O. workshop, Sidney, B.C., 4–5 November 1997. Can. Tech. Rep. Fish. Aquat. Sci. 2247: 165 p.

Management and conservation of marine ecosystems requires information on the boundaries and spatial and temporal variation of these ecological units. Without an agreed-upon scheme for British Columbia's Strait of Georgia, it will be difficult to implement Integrated Coastal Zone Management, with its associated elements of Marine Protected Areas and Marine Environmental Quality. A workshop was held in November 1997 at the Institute of Ocean Sciences, Sidney to discuss this topic with concerned scientists and managers in an attempt to reach consensus on this matter. About 65 people from Fisheries and Oceans, Environment Canada, Province of BC, universities and non-government organizations attended. The participants concluded that we can move ahead on ecosystem delineation for nearshore habitats (e.g. estuaries, rocky shores) where considerable mapping work has been done. However, boundaries and scales are less well understood in subtidal and pelagic habitats. To improve effectiveness, there is also a need for both more intera-gency collaboration on ecological mapping and standarization of methodologies. These Proceedings include seven scientific contributions, transcriptions of the detailed narrative on the questions and answer sessions, and a major literature review on the topic of ecosystem delineation.

RÉSUMÉ

Levings, C.D., J.D Pringle, and F. Aitkens [ed]. 1998. Approaches to marine ecosystem delineation in the Strait of Georgia: Proceedings of a D.F.O. workshop, Sidney, B.C., 4–5 November 1997. Can. Tech. Rep. Fish. Aquat. Sci. 2247: 165 p.

La conservation et la conservation des écosystèmes marins exigent que l'on dispose d'information sur les limites et les variations spatiales et temporelles de ces unités écologiques. S'il n'existe pas de schéma convenu pour le détroit de Georgia, en Colombie-Britannique, il sera difficile de mettre en oeuvre la gestion intégrée des zones côtières, avec ses volets Zones de protection marines et Qualité du milieu marin. Lors d'un atelier qui a eu lieu en novembre 1997 à l'Institut des sciences de la mer, à Sidney, les scientifiques et gestionnaires concernés ont discuté de ce sujet pour essayer d'en arriver à un consensus sur la question. L'atelier regroupait environ 65 personnes représentant Pêches et Océans Canada, Environnement Canada, la province de Colombie-Britannique, des universités et organisations non gouvernementales. Les participants ont conclu que nous pouvons avancer dans la délimitation des écosystèmes pour les habitats proches des côtes (p. ex. estuaires, côtes rocheuses), où d'importants travaux de cartographie ont déjà été faits. Cependant, les limites et les échelles sont moins claires pour les habitats subtidaux et pélagiques. Dans un souci d'efficacité, il faudra une plus grande collaboration inter-organismes dans la cartographie écologique et la normalisation de la méthodologie. Les présents Actes se composent de sept contributions scientifiques, des transcriptions des comptes rendus détaillés des séances de questions et réponses, et d'une revue de la littérature sur le sujet de la délimitation des écosystèmes.

PREFACE

The papers included in this volume were submitted by the authors after the workshop and differ in some respects from the published Agenda for the workshop. Manuscripts were not peer-reviewed; they were read by the editors and edited for clarity only. Discussions after each presentation were taped and transcribed verbatim. The tapes are archived with John Pringle, at the address on the cover.

Following presentation of the papers, a Plenary session focussed on seven questions posed by the organizing committee. The resulting discussions were summarized by the organizers and circulated for comments. Comments received are found in Appendix C. A verbatim text of all the discussions transcribed from tapes made at the meeting is appended as an electronic file (in Word 6.0) on the disc included with this volume. Additional copies are available from John Pringle.

The opinions expressed in the papers and discussions are those of the authors and speakers.

ACKNOWLEDGEMENTS

The editors thank the following: Brian Smiley and Steve Samis for contributing to the organization of the workshop; to all the speakers for submitting drafts of their presentations in a timely fashion; to Ann Thompson for logistical support; and to all participants for both attending the workshop and for their active participation.

INTRODUCTION

Colin Levings and John Pringle
Department of Fisheries and Oceans
British Columbia

Canada's *Oceans Act* recognizes that conservation, based on ecosystems, is fundamental to maintaining biological diversity and productivity in the marine environment. Scientifically defensible methods for establishing the scale and boundaries of ecosystems are essential to develop an oceans management framework. The Strait of Georgia has been recognized by numerous authorities (e.g., Wilson et al. 1994) and agencies (e.g., Howes et al. 1993) as an ecologically sensitive area requiring detailed habitat management and planning. Without a practical scheme at appropriate scales for describing ecosystems, it will be very difficult to implement Integrated Coastal Zone Management (ICZM) in the region.

Methods for marine ecosystem delineation for British Columbia at the national and regional scale (e.g., > 1:500 K) were developed in the late 1980s, as described in Harding (this volume). There have been several proposals to classify the Strait of Georgia ecosystem at larger scales (e.g., 1:300 K) for macroscale planning. For example, the Strait of Georgia was described as a component of the Georgia Basin **ecoregion** by Hirvonen et al. (1995), with Juan de Fuca Strait as a separate entity. However, Land Use Coordinating Office (LUCO) (<http://www.gis.luco.gov.bc/ecoreg.htm>) included both Straits in their description of the Georgia Basin **ecoregion**, and added watersheds on the east coast of Vancouver Island. The same entity, without the watershed component, was described as an **ecosection** by LUCO (<http://www.gis.luco.gov.bc.ca/ecosec.htm>).

Mapping of ecosystem properties, such as productive capacity of specific habitat types, is difficult at the aforementioned scales. Therefore, a variety of different schemes have been proposed for the Strait of Georgia and other coastal areas, using larger scales (< 1:300 K). For detailed planning and assessment, scales have to be usable for micro- and meso-scale planning. For example, LUCO (<http:www.gis.luco.gov.bc/mec.htm>) has developed the ecounit scheme, which considers biophysical entities of at least 15 km^2. For management of fish habitat, 100 m^2 is usually considered the minimum area that managers are concerned with (North and Levings 1996). On the other hand, if habitats for the entire life history of various species are considered, the boundaries need to include regions outside the Strait of Georgia. For anadromous fish such as salmonids, their ecosystem should be a much larger entity, encompassing the catchment basin of their natal streams, estuaries, and adjacent coast, and their range in the northeast Pacific Ocean.

The schemes proposed for micro- and meso-scale planning and mapping for the Strait of Georgia have received very little review in scientific fora and a broad cross section of DFO staff from Pacific region were not involved in their development. For these reasons, and in preparation for implementation of the *Oceans Act* in the Strait of Georgia, a workshop was held at the Institute of Oceans Science, November 4 and 5, 1997. The following summary and collection of extended abstracts resulted from the deliberations at the workshop.

LITERATURE CITED

Hirvonen, H.E., L. Harding, and J. Landucci. 1995. A national marine ecological framework for ecosystem monitoring and state of the environment reporting, pp. 117–129. *In* N.L. Shackell and J.H. Martin Willison [eds.]. Marine Protected Areas and sustainable fisheries. Science and Management of Protected Areas Association, Wolfville, N.S. Canada

Howes, D.E., P. Wainwright, J. Haggarty, J.H. Harper, E. Owens, D. Reimer, K. Summers, J. Cooper, L. Berg, and R. Baird. 1993. Coastal resources and oil spill response atlas for the southern Strait of Georgia, B.C. Ministry of Environment, Lands and Parks, Environmental Emergencies Coordination Office, Victoria, B.C. Canada

North, M.S., and C.D. Levings. 1996. Methods for environmental evaluation in the coastal zone: Some principles and recent experience with fish habitat mapping in coastal British Columbia, Canada, pp. 121–126. *In* Proc. Techno-Ocean'96, Oct. 23–25, 1996, Kobe, Japan. [Available from Techno-Ocean '96 International Symposium Secretariat c/o IBC forum, Kitahama-Matsuoka Bldg 2-1-26, Kitahama, Chuo-ku, Osaka 541 Japan.]

Wilson, R.C.H., R.J. Beamish, F. Aitkens, and J. Bell [eds.]. 1994. Review of the marine environment and biota of Strait of Georgia, Puget Sound, and Juan de Fuca Strait. Proc. BC/Washington Symposium on the Marine Environment, Jan. 13–14, 1994. Can. Tech. Rep. Fish. Aquat. Sci. 1948.

A REVIEW OF ECOSYSTEM CLASSIFICATION: DELINEATING THE STRAIT OF GEORGIA

Jane Watson
Malaspina University College
900 Fifth Street
Nanaimo, BC
V9R 5S5

ACKNOWLEDGEMENTS

A number of people assisted in the preparation of this document. Unpublished manuscripts and reports were made available by Dr. John Harper of Coastal and Ocean Resources Inc., Mark Zacharias of the Land Use Coordination Office, Brian Emmett and Mary Morris of Archipelago Marine Research, and Jacquie Booth of Booth and Associates. Dr. Jeff Marliave of the Vancouver Aquarium, and Chrys Neville and Dr. Colin Levings of the Department of Fisheries and Oceans suggested additional literature. The document benefited from discussions with Dr. John Harper, Mark Zacharias, Mary Morris, and Brian Emmett. Gordon Miller and Pam Olson at the Pacific Biological Station library provided obscure references. Comments on portions of the manuscript were made by Mark Zacharias, Mary Morris, Charles Simenstad, and Colin Levings.

1.0 INTRODUCTION

1.1 Marine Protected Areas Under the Oceans Act

Canada's *Oceans Act*, passed in 1997, authorizes the Minister of Fisheries and Oceans to develop and establish a Canadian strategy for the management of estuarine, coastal, and marine ecosystems. The Oceans Management Strategy (Part II of the *Oceans Act*) identifies three components of this strategy:

1) Marine Protected Areas;

2) Integrated Management of activities in estuaries and coastal waters; and

3) Marine Environmental Quality.

The *Oceans Act* requires that the Marine Protected Areas, Integrated Coastal Zone Management, and Marine Environmental Quality initiatives be established using the ecosystem principle. This means that whole ecosystems must be considered when enacting the Oceans Management Strategy (DFO 1997). To accomplish this, ecosystems — as well as the components and processes within them — must be defined and identified (Hawkes 1994a; Norse 1993; Zacharias and Howes in press; Taylor and Roff in press).

Integrated management of activities in estuarine and coastal waters is often called Integrated Area Management (IAM). In many regions of the world, environmental quality is managed sector by sector, with government agencies dealing with different aspects of marine environment management. This piecemeal approach can result in various agencies and governments making decisions that are often at cross-purposes to each other (Norse 1993). Integrated management usually results in areas being managed for multiple purposes such as:

1) scientific research;

2) baseline monitoring of environmental quality;

3) protecting areas that are critical to the life stages of important commercial or recreational species; and

4) commercial activities, e.g., housing, tourism, fishing, as well as recreational use of undisturbed marine environments.

Marine Protected Areas (MPAs) are often an important component of Integrated Management (Salm and Clark 1984). MPAs are also known as marine harvest refugia or marine sanctuaries. They are areas in the marine environment designated for special protection from human exploitation, usually of living resources (e.g., Carr and Reed 1993; Agardy 1994; Davis 1995). Under the *Oceans Act,* an MPA is specifically defined as:

An area of the sea that forms part of the internal waters of Canada, the territorial sea of Canada or the exclusive economic zone of Canada and has been designated under this section (35. [1]) for special protection.

At a global scale, MPAs have been used for a variety of purposes, including increasing public awareness and support for marine conservation, providing sites for research and monitoring, protecting marine biodiversity, maintaining environmental quality, and as a management tool in the protection of commercially fished stocks of fish and invertebrates (Ray and Grassle 1991; Dugan and Davis 1993; Sobel 1993; Agardy 1994; Kirkegaard and Richardson 1994; Lindeboom 1995; Norse 1995; Clark 1996; Pitcher 1997).

Under the *Oceans Act,* MPAs in Canada can be established to:

a) conserve and protect commercial and non commercial species and their habitats;

b) conserve and protect endangered or threatened species and their habitats;

c) conserve and protect unique habitats;

d) conserve and protect areas of high biodiversity of biological productivity; and

e) conserve and protect any resource or habitat that is necessary to fulfill DFO's mandate (Oceans Act 1997).

Marine Protected Areas are recognized by numerous agencies and levels of government. Parks Canada and Heritage Canada are moving towards a Marine Conservation Area Act (Mercier and Mondor 1995). This proposed legislation will provide for the protection of marine ecosystems and ecosystem components, and is designed to complement legislation within the *Oceans Act* (Parks Canada 1997). Environment Canada is moving towards a protected area strategy, having amended the *Wildlife Act* to include areas out to the 200-nautical-mile limit and to include establishment of marine protected areas (Zurbrigg 1996). The provincial government of British Columbia has enacted the Protected Areas Strategy and has the mandate to protect a minimum of 12% of the province by the year 2000 (BC Government 1993). The provincial strategy is intended to complement federal programs by protecting representative portions of British Columbia's ecosystems, including coastal and marine areas (Zacharias and Howes in press). A joint federal and provincial Marine Protected Areas Strategy has been created to help in the selection and creation of marine protected areas. In addition, the Pacific Marine Heritage Legacy, a cooperative program between Parks Canada and BC Parks for protecting marine and coastal areas, ultimately will include MPAs (BC Government 1996).

The World Conservation Union (IUCN), the United Nations (UNESCO, FAO, and UNEP) and many other international agencies, and national/provincial/state governments have all recognized the need to classify terrestrial, coastal, and marine systems so that representative protected areas can be established (Ray 1976; Hayden et al. 1984; Heywood and Watson 1995; Brosnan 1995; Brunckhorst and Bridgewater 1995; Folke et al. 1996; Zurbrigg 1996). Developing classification systems that identify and delineate marine ecosystems in a manner that is consistent with biophysical features will be an essential component of any MPA program or other initiative under the *Oceans Act* (Hawkes 1994a, Levings and Thom 1994; Ray and McCormick-Ray 1995; Zacharias and Howes in press).

Despite their obvious differences, terrestrial, coastal, and marine areas have been classified in similar manners, often using hierarchical methods. In general, terrestrial ecosystem classifications are based on vegetation or climate (e.g., Udvardy 1975), whereas oceanic ecosystems are classed in terms of physical features such as water masses, temperature, salinity, upwelling, currents, and wind (e.g., Dietrich 1963), and biological features such as phytoplankton (productivity) and commercial fish stocks (e.g., Ware and McFarlane 1989). Coastal classifications (<20 m depth) are generally based on physical features and nearshore processes (e.g., Dolan et al. 1972). Although the classification systems are similar in approach, marine systems present problems not encountered in terrestrial system classifications.

Understanding and protecting ecosystems requires that we define what constitutes an ecosystem (Hawkes 1994a). Describing ecosystems and the biological and physical variables that interact within them in a consistent and definitive manner presents an enormous challenge for physical scientists and biologists alike (Linden 1993).

1.2 The Objective of this Document

Biologists have been classifying terrestrial ecosystems systems for some time (Pielou 1984). A variety of classification systems for terrestrial and marine environments have been developed. Most systems use physical parameters to identify wide-scale (coarse grain) patterns and biological features to identify small-scale (fine grain) repeating ecological units. Although most classification systems have many similarities, numerous authors warn that classification systems developed for one purpose should be examined before they are used in a different application (Bourgeron 1988; Orians 1993).

Ecosystem classifications are often controversial, especially when used for conservation purposes (e.g., Noon and McKelvey 1996). The number of classification units or community types recognized by a classification system is politically and ecologically important, as is the criteria by which they are recognized (Orians 1993). If the system is coarse-grained (large scale), comparatively few sites will need to be protected to preserve the representative communities described within the classification. If the system is fine-grained (small scale), many sites may be needed to ensure that representative community types are protected. How ecosystems or communities are classified also has ecological consequences. For example, combining data from various regions of a pelagic ecosystem (which is described as homogenous but in fact is not) may lead to incorrect interpretation of community structure and biological dynamics (Paine 1988). Thus scientists, managers, and planners alike need to pay attention to the type of classification system used to define ecosystems. The system chosen must be ecologically, practically, and legally defensible (Bourgeron 1988; Orians 1993; Davis 1995); the more rigorous and scientific a system is, the more useful, legally defensible, and valuable it becomes.

This document examines some of the methods used to classify and delineate marine ecosystems, at both a global and local scale. Classification systems that use both physical and biological features are discussed, and some research that may be relevant to delineating and classifying ecosystems in the Strait of Georgia, in biological terms, is examined.

2.0 ECOSYSTEMS AND THE HIERARCHICAL APPROACH

2.1 A Brief History of the Ecosystem Concept

The word ***ecosystem*** was first used by the ecologist Arthur Tansley in terrestrial vegetation studies (Tansley 1935), although the concept was used earlier in marine food web studies by Mobius (1877), and plant community studies by Clements (1916). The ecosystem concept became central to ecological science when Odum (1968) used it as a hierarchical or organizing concept (Golley 1993).

The term ***ecosystem*** has a variety of definitions. In fact, Shrader-Frechette and McCoy (1993) provide 16 separate definitions of ecosystem. In general, ecosystems are defined in the following manner:

A holistic concept of the plants, the animals habitually associated with them and all the physical and chemical components of the immediate environment or habitat which together form a recognizable self-contained entity (Begon et al. 1996).

A spatially explicit unit of earth (or ocean) that includes all of the organisms along with all of the components of the abiotic environment within its boundaries (Liken 1985).

Some conservationists advocate using ecosystem management; setting portions of ecosystems aside rather than protecting species (Peterson and Peterson 1991 *in* Taylor and Roff in press), whereas others caution against using ecosystems as units of conservation, because they cannot be clearly defined (Caughley and Gunn 1996). For conservation and management purposes it is simplest to use "ecosystem" to refer to a multispecies assemblage and its associated range of environments (Taylor and Roff in press). For management (or applied) purposes, ecosystems must be discrete enough that they can be mapped or described on a spatial/temporal scale that best serves the management function (Grumbine 1994, 1997).

Ecosystems are made up of communities. The term ***community*** has been a controversial term (Underwood 1986). Ecologists argue over whether a community is an organized system of integrated and repeated species (Clements 1916) or a haphazard collection of populations with the same environmental requirements (Gleason 1917). Many community ecologists consider communities to be a natural or fundamental unit within an ecosystem (e.g., Thorson 1957), while others view communities as arbitrary units of convenience (e.g., Gray 1974). If communities are natural units, they should be both identifiable and classifiable. In general however, communities grade continuously over space and time, and the definition of a community may be determined by the techniques used to sample or describe it (Mills 1969). Thus, although ecologists classify communities, the community unit may not represent a true "fundamental unit of nature" (Jones 1950; Gray 1974; Krebs 1994). Mills (1969, 1975) discusses the community concept as it pertains to marine ecosystems and their structure.

In contrast, the term ***habitat*** is a more applied term and is often more easily defined. To ecologists, a habitat is any part of the biosphere where a particular species can live (Krebs 1994). In the applied sense, habitat is often defined as a repetitive physical or biophysical unit found within an ecosystem. It may reoccur across several ecosystems and can often be described in terms of the species which inhabit it (Krebs 1994; see discussion in Booth et al. 1996).

The term ***ecotone*** is used to describe zones of transition between adjacent ecological systems (di Castri et al. 1988). Although this term has traditionally been used to describe adjacent terrestrial systems, it can be used to describe adjoining marine systems. Ray and Hayden (1992) suggest that on a global scale the coastal zone (including estuaries and the continental shelf) provides a marine example of an ecotone. Transitional zones are frequently very productive, because "production, consumption and exchange processes" all occur at high rates (Ray and Hayden 1992). Such transition zones are likely to be important under the *Oceans Act* because they may be rare, and because in some cases they may also be areas of high biological diversity (Ray 1988, 1991; Harding and McCullum 1994; Zacharias et al. unpub.).

In addition to various definitions, it has been suggested that there are two approaches to the concept of an ecosystem (O'Neill et al. 1986; Mann 1992). One view of ecosystems is biotic, or structural. In general, population and community ecologists view ecosystems as a group of interacting populations where the biota are the ecosystem, and physical factors, such as water temperature and nutrients, are external influences. This view of ecosystems is generally adopted by biologists such as fisheries managers (Parsons 1991). The other view of ecosystems is physical. This is the process–functional approach in which the ecosystem is composed of physical, chemical, and biological processes within some pre-defined space and time. In such a view, energy and nutrient flow are viewed as more important or fundamental than the taxa involved in the flows. This is the view generally adopted by oceanographers (Parsons 1991).

Ecosystems are frequently delineated by placing geographic boundaries around some subset of nature. In the marine environment, these limits are often based on hydrographic features, bottom topography, and trophic interactions (e.g., zones of primary production) (Steele 1991a; NRC 1996). All ecosystems are open (especially marine systems) with exchange occurring between both adjacent and distant areas. For example, if the Strait of Georgia is an ecosystem, snow levels on interior mountains and their effect on Fraser River run-off, as well as pelagic events that influence water mixing from Juan de Fuca Strait, must all be considered. This means ecosystem boundaries must be defined in terms of geographic, hydrographic, and biological distinctions, but must also recognize processes that cross arbitrary ecosystem boundaries. Spatial scales are an obvious component of ecosystem structure (Levin 1992), but because ecosystems include processes, temporal scales are also important. In the same sense that arbitrary geographic boundaries must be drawn around an ecosystem, temporal scales must also be decided upon, based upon the question or purpose in mind (O'Neill et al. 1986).

2.2 Terrestrial Versus Marine Ecosystems

Terrestrial and marine ecosystems differ in structure and in functional responses to environmental change. The most important differences are the temporal and spatial scales of ecological responses to changes in the physical environment (Steele 1974, 1985, 1991a, 1991b; Parsons 1991; Longhurst 1981; Cole et al. 1989).

The most obvious biological difference between terrestrial and marine systems may be in the source of primary production (Steele 1991b). The phytoplankton of marine ecosystems have high turnover rates compared to the forests or prairies found in terrestrial systems. Furthermore in the open ocean there is a regular increase in the length of lifetime with increasing trophic level, whereas in terrestrial systems this pattern is not so clear (Steele 1991b). The generation time of biological ecosystem components affects the response time of the ecosystem to changes in the physical environment. In the short term (up to 50 years) terrestrial ecosystems are more predictable than oceanic systems, and are usually driven by internal dynamics such as predation or competition (but see later discussion on nearshore ecosystems). In contrast, changes in marine ecosystems — especially the pelagic system — are generally related to long-term climate trends rather than internal dynamics (Gray and Christie 1983; Mann and Lazier 1991; Mann 1992; Dagg 1993; Angel 1994, although see Parsons 1991, 1992a, 1992b). Thus the effects of changing climate on a terrestrial forest ecosystem will be obvious, but only on time scales of millennia, whereas fish populations can change in abundance and distribution in a few decades (e.g., Ware and McFarlane 1989; Denman et al. 1989). In the terrestrial environment recruitment is often linked to stock size, whereas in the marine environment recruitment variability is usually linked to physical explanations such as water currents or climate changes (e.g., Roughgarden et al. 1988; Ware and Thomson 1991; McFarlane and Beamish 1992; Polovina et al. 1994; Brodeur and Ware 1992; Mackas 1992).

Finally, organisms in marine systems — especially those in pelagic systems — are subject to circulation and mixing that affects dispersal, migration, and aggregation (Denman and Powell 1984; Mackas et al. 1985). This means that most pelagic organisms (and benthic animals with planktonic larvae) move in three dimensions, and move between trophic levels as they develop. Thus in the ocean, recruitment failure in one region may be reversed by passive recruitment from another area. On land, a similar process generally requires active migration (NRC 1994).

The nearshore ecosystem has several definitions. For example, the coastal zone lies between terrestrial and oceanic/pelagic system. It has a terrestrial boundary defined by the tide and a seaward boundary defined by the edge of the continental shelf (Ray et al. 1981; Ray 1991; Parsons 1992b). In other cases, the nearshore ecosystem is more encompassing, and includes watersheds. In all cases, nearshore ecosystems are influenced by the proximity of the terrestrial system, but differ substantially from pelagic systems (Pomeroy 1974, 1989). Nearshore ecosystems are very productive and complex, largely because terrestrial, oceanic, and atmospheric processes all interact (Leigh et al. 1987; Ray and Hayden 1992).

Many of the ecological paradigms used in nearshore communities have their roots in terrestrial ecology. The keystone predator hypothesis (Paine 1974) or more recently "top down/bottom up control" (e.g., Hunter and Price 1992) have their roots in terrestrial principles in which biological interactions (predation/competition) control community dynamics (Steele 1991b). Nearshore ecologists are starting to use a more open view of the coastal ecosystem. "Supply-side ecology", as it has become known, focuses on the openness of the life cycles of many organisms, ocean/current dynamics, and biological interactions (e.g., Marliave 1986; Roughgarden et al. 1988; Sewell and Watson 1993). Since the nearshore ecosystem represents an ecological intermediate between terrestrial and pelagic ecosystems, neither purely terrestrial nor oceanographic approaches will work for its delimitation. Descriptions of physical dynamics, such as salinity, temperature, exposure, and circulation patterns, as well as competitive and predatory interactions, may be required to describe or classify ecosystem structure and population variation.

Pielou (1979) summarizes many of these differences and notes that differences in structure and ecosystem function make it difficult to use the same criteria to designate marine (largely pelagic) and terrestrial biogeographic regions. The major differences she lists are that 1) vegetation is not the major structural component of most marine systems, 2) the oceans are joined and truly open, 3) most marine species have larger ranges than terrestrial ones, 4) the limits of dispersal are more subtle, but the closer to land they are, the clearer the boundaries between regions are, and finally 5) latitudinal zonation is more distinct than in terrestrial systems.

2.3 Classifying Ecosystems

One of the oldest and most commonly used criteria to classify ecosystems is climate (Holdridge 1967 *in* Orians 1993). Climate is probably the most important determinant of the nature of terrestrial ecosystems (Major 1951). In 1874, de Candolle 1874 (*in* Orians 1993) proposed that plant distributions were determined largely by moisture and temperature, although in many cases historical factors, such as glaciation, may be more important than current ecological factors in explaining the presence of rare or endemic species (Pielou 1991). Classifications based only on climate usually result in classification units too large to be useful for conservation (Bourgeron 1988; Orians 1993). Most terrestrial classification systems combine climate and vegetation type (e.g., Krajina 1965; Wiken 1986; Banner and Pojar 1987; Demarchi et al. 1990; Meindinger and Pojar 1991). Vegetation is used in terrestrial systems because it is the dominant structural component, and is much easier to sample than more mobile animal communities (e.g., Braun-Blanquet 1965). Soil type is often used to classify terrestrial ecosystems, and in most cases soil type is a reasonable predictor of vegetation (see Begon et al. 1996 for a general discussion).

In contrast to terrestrial systems, classifying marine systems generally involves categorizing criteria such as salinity, nutrients, productivity, exposure, depth, and indicator species (Cowardin et al. 1979; Dethier 1990; 1992a, 1992b; Caddy and Bakun 1994). Despite functional differences, the classification methods are the same as those used in terrestrial systems, with only the criteria and approaches changing slightly. Harper et al. (1993) point out that the parameters used to classify marine systems are usually as well-defined as in terrestrial classifications, but the lines of demarcation in the marine environment may not be. The boundaries that are drawn are usually highly variable on both temporal and spatial scales, are almost always "invisible," and in many cases have been defined by only a few data points (Harper et al. 1993).

There have been a few global attempts to classify marine areas. These classifications have been primarily biogeographical in approach. In most attempts, boundaries are established based on the distribution of specific animal groups. Places that mark the endpoint of many species ranges are considered boundaries, and areas where there is a high degree of endemism comprise provinces.

Ekman (1953) used zoogeography to classify regions of the sea. Briggs (1974) modified this system to recognize three "realms": the continental shelf, the pelagic zone, and the deep benthic zone. He identified faunal provinces for the continental shelf — divisions that have been used in many subsequent classifications. Hesse et al. (1951) advocated an ecological approach. They emphasized that in terrestrial classifications the relationship between plant and animal is obvious, and noted that in the marine environment such relationships are often not so clear, which may explain why most classifications are zoogeographic. Briggs (1974) commented on the difficulties in correlating species distributions and water masses, and separated the pelagic zone into epipelagic, mesopelagic, and bathypelagic. Under Briggs (1974), the deep benthic zone was divided into continental slopes, abyssal plains, and trenches.

There are examples of floristic classifications of the oceans of the world (Setchell 1915; Hutchins 1947; van den Hoek 1975, 1982, 1984). Most of these are based on temperature (Lobban and Harrison 1997). Temperature-related zones of seaweed were first proposed by Setchell (1915). He divided oceans into nine zones which were defined by 5°C ranges of surface-water temperature in the warmest month of the year (the polar zones were divided into 10°C zones). Setchell later divided these zones into provinces using coldest month temperatures. There has been substantial criticism of using temperature to define biogeographic zones (Hutchins 1947; Michanek 1979). Van den Hoek revised Setchell's floristic classification by combining water temperature, geographic location, and latitude (van den Hoek 1984).

Over the last 120 years, over a dozen attempts have been made to divide the marine environment of the west coast of North America into (mostly faunal) provinces (Foster et al. 1988). The exact boundaries of the provinces are usually debated. In all of these attempts, the authors have noted the absence of data required for thorough classification of the biogeographic regions of the marine ecosystem. This is perhaps why there are so few treatments of the topic at a global scale.

3.0 SYSTEMS OF CLASSIFICATION

3.1 Classification

Numerous statistical methods are used to classify communities (ecosystems, biogeographic zones, etc.); these are outlined by Pielou (1984), Digby and Kempton (1987), and Gauch (1982). Classification methods can be hierarchical, in which levels are subclasses of higher levels, or they can be reticulate, with communities defined separately but linked in a network. The classification method of Braun-Blanquet (1965) has been widely used to describe vegetation. This method depends on diagnostic species to produce a hierarchical classification of communities. The vegetation in ecosystems and communities has also been classified using dominant vegetation types, which are groups of stands with the same dominant species. This method is less structured than the Braun-Blanquet method, but since there is often little association between dominant species and the associated plants and animals, communities defined using this method are often very artificial.

A number of authors discuss the different characteristics that ecosystem classifications require (Bourgeron 1988; Orians 1993; Frith et al. 1993a, 1993b; Searing and Frith 1995; Booth et al. 1996). In general they recommend that:

1) The system or method must clearly delineate (using recognizable criteria) repeating community or habitat types that occur within the ecosystem.

2) It must have predictive power, describing the relationships between physical environments and biotic communities.

3) Classification systems used for conservation purposes must correspond to species distributions, so that if characteristic species (representative species or "umbrella" species) are protected, biological diversity will also be maintained (i.e., protecting prominent species will protect less charismatic or well-known species, see Franklin 1993).

4) Classification systems should be hierarchical so that description occurs on different spatial scales, allowing for identification and ultimate protection of lower-level classification units in the system.

5) The system should have a global perspective, in which the higher levels of classification are defined by global processes.

6) In a physical or process-driven classification the criteria used must be determinants of biological community structure.

3.2 IUCN Classification of Coastal and Marine Habitats

Hayden et al. (1982, 1984) classified coastal and marine environments on a global scale using biophysical criteria for the International Union for the Conservation of Nature (IUCN). The system was developed so that marine protected areas could be categorized and incorporated into a world-wide network of protected areas representing the marine ecosystems of the world (Hayden et al. 1984).

Hayden et al. (1984) described pelagic ecosystems using Dietrich's (1963) classification of ocean realms. Dietrich (1963) categorized oceans (from the seaward limit of the coastal zone out) into five subdivisions called oceanic realms. His classification was based upon oceanic currents and climate (Table 1). Hayden et al. (1984) further classed the coastal margins, marginal seas, and marginal archipelagos, based on seasonal movements of air and water masses, into 13 coastal realms. Since currents and climate were used to define coastal and oceanic realms, the boundaries of the coastal realms drawn by Hayden et al. (1984) agreed with Dietrich's ocean realm boundaries. Hayden et al. (1984) then used Briggs (1974) zoogeographic classification of the world's oceans that divided the world's coastal zones into 40 zoogeographic provinces based on the distribution of marine fauna.

TABLE 1. Oceanic realms as defined by Hayden et al. (1984)

Oceanic Realm	Direction of Surface Currents
I	Variable eastward currents
II	Weak and variable currents
III	Trade-wind currents
III^e	Strong equatorward currents
III^w	Westward currents
III^p	Strong poleward currents
IV	Strong westward and equatorward currents
V	Monsoon currents (seasonal reversals)

The outcome of the classification system was the identification of four large-scale (coarse grain) biomes: open oceans, coastal margins, marginal seas, and marginal archipelagos. The biomes divided into two realms (oceanic or coastal), based on seasonal variations in ocean surface currents and wind direction. The oceanic biome included seven types of oceanic realm (Table 1). The remaining nearshore biomes comprised 13 types of coastal realm (Table 2). The coastal realms in turn contained 40 zoogeographic provinces. For the most part, the zoogeographic provinces agreed with the physical classification system, and formed the basis of the binomial classification system, with the coastal or oceanic realm forming the first level and the faunal province comprising the second level. It is at the zoogeographic province level that regional management schemes could be enacted.

Using this classification system, Canada's marine environment is defined by 11 marine biophysical provinces (Hayden and Dolan 1976; Hayden et al. 1984). For example, coastal British Columbia falls into two coastal realms. Vancouver Island falls within the western temperate realm (F) and is located within the Oregonian faunal province, thus it is classed as Western temperate - Oregonian. North coastal British Columbia (Cape Scott northward) is located in the subpolar realm (A), but is still within the Oregon faunal province, becoming Subpolar - Oregonian. Offshore British Columbia is bounded by two ocean realms, II (weak variable currents) and I (variable eastward currents).

The global scale of the classification system means that smaller-sized coastal environments, such as estuaries and fjords, are not considered. Hayden et al. (1984) recommended that such features be described on a regional level and that a system of describing habitat types, including ecological processes and physical features (e.g., Ray and Hayden 1993), be developed within each faunal province.

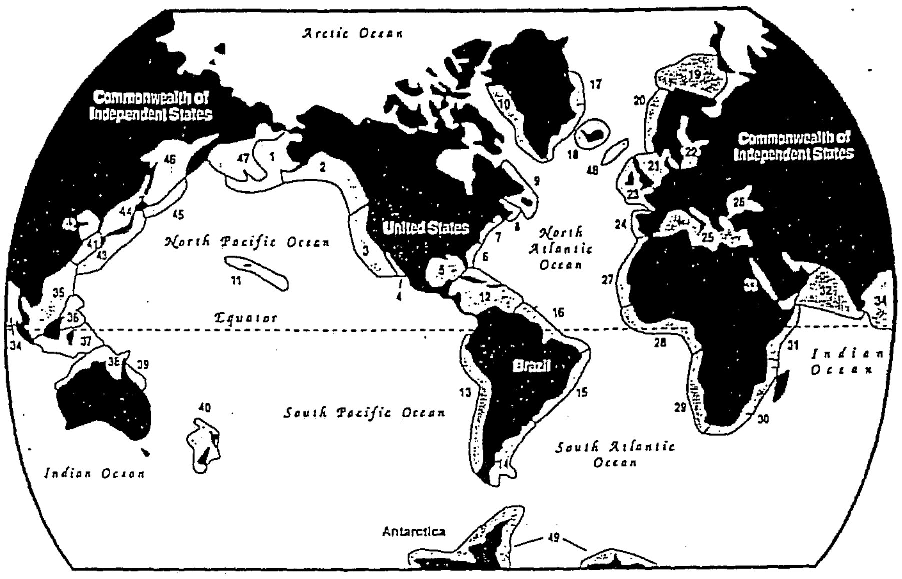
TABLE 2. Currents and windstreams of coastal-margin realms as defined by Hayden et al. (1984). Symbols: ICE = ice margin coast; P = poleward; EQ = equatorward; W = westward; E = eastward; ON = onshore monsoon; OFF = offshore monsoon; / = winter-summer seasonality; * = seasonality in hemisphere source-regions of currents and windstreams. The symbols in parentheses are used to designate the realm.

Coastal Realm	Dominant Directions	
	Current	Windstream
Arctic (M)	ICE	W
Antarctic (L)	W-ICE	W
Subpolar (A)	W	W
Eastern		
Temperate (B)	P	E
Monsoon (J)	EQ/P	ON/OFF
Subtropical (C)	P	P
Tropical (D)	W	W
Intertropical (E)	W*	W*
Western		
Temperate (F)	P	P/EQ
Monsoon (K)	P/EQ	ON/OFF
Subtropical (G)	EQ	EQ
Tropical (H)	EQ	W/EQ
Intertropical (I)	E/EQ	EQ

3.3 Large Marine Ecosystems

Large Marine Ecosystems (LMEs) are defined areas of coastal ocean greater than 200 000 km^2 with distinct hydrographic characteristics, bottom topography, and trophically dependent populations. They generally serve as regional units used in the management of resources such as commercial fish stocks (Sherman and Alexander 1986; Sherman et al. 1988, 1990, 1993; Sherman 1991, 1994; Alexander 1993; Ray and Hayden 1993). Forty-nine large marine ecosystems have been defined (Figure 1). Over 95% of biomass of global marine fisheries are caught in coastal areas that comprise the delineated LMEs (Bakun 1993).

Recent management of LMEs has focused on understanding how large-scale ecosystems function (Griffis and Kimball 1996). In total, 29 LMEs have undergone syntheses examining principal, secondary, or tertiary forces which control variability in biomass and fisheries yield (Bax and Laevastu 1990; Sherman 1995; Tang and Sherman 1995). However, even though LMEs are defined ecologically, biogeographic patterns (species distribution) are rarely used in their definition.



WORLD MAP OF LARGE MARINE ECOSYSTEMS

1. Eastern Bering Sea
2. Gulf of Alaska
3. California Current
4. Gulf of California
5. Gulf of Mexico
6. Southeast U.S. Continental Shelf
7. Northeast U.S. Continental Shelf
8. Scotian Shelf
9. Newfoundland Shelf
10. West Greenland Shelf
11. Insular Pacific--Hawaiian
12. Caribbean Sea
13. Humboldt Current
14. Patagonian Shelf
15. Brazil Current
16. Northeast Brazil Shelf
17. East Greenland Shelf
18. Iceland Shelf
19. Barents Sea
20. Norwegian Shelf
21. North Sea
22. Baltic Sea
23. Celtic-Biscay Shelf
24. Iberian Coastal
25. Mediterranean Sea
26. Black Sea
27. Canary Current
28. Guinea Current
29. Benguela Current
30. Agulhas Current
31. Somali Coastal Current
32. Arabian Sea
33. Red Sea
34. Bay of Bengal
35. South China Sea
36. Sulu-Celebes Seas
37. Indonesian Seas
38. Northern Australian Shelf
39. Great Barrier Reef
40. New Zealand Shelf
41. East China Sea
42. Yellow Sea
43. Kuroshio Current
44. Sea of Japan
45. Oyashio Current
46. Sea of Okhotsk
47. West Bering Sea
48. Faroe Plateau
49. Antarctic

FIGURE 1. The 49 Large Marine Ecosystems. (From Sherman et al. 1933.)

Inherent in this type of ecosystem approach to fisheries management is the idea that ecosystem processes are best examined on a regional scale (Slocombe 1993; Apollonio 1994; NRC 1996). The LME system lends itself well to this. Within LMEs, domains or subsystems can be characterized (e.g., Croom et al. 1992). For example, the Adriatic Sea is a subsystem of the Mediterranean LME. The U.S. Northeast Continental Shelf LME has four subsystems — the Gulf of Maine, Georges Bank, Southern New England, and the Mid-Atlantic Bight (Sherman et al. 1988). In many cases, the seaward boundaries of extensive shallow LMEs are defined by the Exclusive Economic Zone (EEZ), which extends 200 miles offshore. Other LMEs with narrow continental shelves and clear coastal currents are defined by bathymetry or hydrography (Brisbal 1995). Among the LMEs defined by coastal currents are the Humboldt, California, Kuroshio, Canary, and Benguela Currents.

Under the LME scheme, British Columbian waters fall under the Gulf of Alaska Large Marine Ecosystem, which includes coastal waters north of the California Current out to the edge of the continental shelf and northwest to the end of the Alaskan Peninsula (Sherman 1994). The Gulf of Alaska Ecosystem can be subdivided. The Georgia Basin (Strait of Georgia) is treated as a subsystem by Beamish and Neville (1995), as is the upwelling system off of the west coast of Vancouver Island (McFarlane et al. 1995).

Ray and Hayden (1993) used biogeographic techniques to further delineate two contiguous LMEs. Based on the distribution of 86 species of commercially and ecologically important invertebrates, fish, mammals, and birds, they described 6 slightly overlapping geographic provinces within the Eastern and Western Bering Sea LMEs. They assumed that the distributions of commercially and ecologically important species should reflect natural physical boundaries (see Ricklefs 1990) and used the distribution of the 86 species as interdependent variables in a principal components analysis. Presence or absence of each species was scored in a grid superimposed over the study area.

The analyses defined 6 provinces that explained 69% of the total species variance. Although there was some overlap in the provinces, the authors felt that they were representative of the biological and abiotic environments found in the two LMEs and that with more complete species distribution data, the biogeographic provinces would have been more distinct (Ray and Hayden 1993).

Working at the LME scale, fisheries data can be combined with physical and biological oceanographic data to define domains or regions in marine ecosystems. For example, Dodimead et al. (1963) used physical oceanographic data to identify 4 domains of water in the northeast Pacific Ocean (Thomson 1981). Ware and McFarlane (1989) modified these domains and defined 3 principle oceanographic regions in the northeast Pacific: the Central Subarctic Domain, the Coastal Upwelling Domain, and the Coastal Downwelling Domain. Examining productivity data, they found that the 3 oceanographic domains corresponded to 3 "generic biological production systems" (Parsons et al. 1984): the oceanic (= Central Subarctic Domain), the continental shelf (= Coastal Downwelling Domain), and the upwelling (= Coastal Upwelling Domain). The major differences between these systems were primary production, the size of the dominant phytoplankton species (Parsons et al. 1984), and the number of trophic steps required to transfer energy from phytoplankton to commercial-sized fishes (Ryther 1969). Using large-scale circulation features, primary production, and the distribution of commercial quantities of fish, Ware and McFarlane (1989) examined these physical domains and found they also defined discrete fisheries production zones. Each oceanographic domain corresponded to a fisheries production domain with its own clearly defined commercial fish assemblage. Ocean productivity and water masses have also been shown to affect avifauna in the north Pacific. Wahl et al. (1989) found that the subarctic boundary of Dodimead et al. (1963) most clearly separated different avifaunas of the north Pacific.

In many areas, the LME concept is generally used for coastal fisheries management and to monitor anthropogenic effects (Hemple and Sherman 1993). It is a very large-scale non-hierarchical system. Considerable delineation at a regional scale will be required before it can be used as a useful classification system at a finer scale. However existing studies, such as those by Ware and McFarlane (1989) and Ray and Hayden (1993), demonstrate that large- scale systems can be more finely delineated using ecological and fisheries data.

3.4 Parks Canada—National Marine Conservation Area Natural Regions

In Canada, terrestrial parks are selected to represent the 39 natural regions defined by Parks Canada. In 1979, Parks Canada recognized that marine regions were under-represented, and developed a marine parks policy. One of the first steps in this policy was to develop a systematic method of identifying potential marine parks (Harper et al. 1983).

Paish (1970) subdivided the marine environment of Canada into 9 marine regions *(in* Harper et al. 1983). Although this system was designed to aid in park selection, the marine regions did not provide adequate representation of natural areas, and the criteria used to delineate the areas were primarily physical and poorly documented. Using the system initiated by Paish (1970), Harper et al. (1983) developed a classification system that divided Canadian marine areas into relatively similar units based on biotic, abiotic, and cultural criteria.

The criteria used to delineate regions included physical features such as oceanography, coastal environment, and physiography, as well as biological features such as marine vertebrates and invertebrates (Harper et al. 1983). Experts were consulted to develop a series of maps that defined regions based on specific physical or biological themes (using the criteria listed above). The biological and physical theme maps were independently combined to create a comprehensive map for each region. Three major marine areas — the Atlantic, Arctic, and Pacific — provided the first division of the marine environment. These areas were subsequently divided into marine regions using the comprehensive maps of each region. The method used attempted to keep the number of regions down to a "reasonable number." It further minimized the areas that were "contested," that is it minimized the areas that were inappropriately placed due to the overriding effects of a single biological or physical feature. Regions were delineated by giving approximately equal weight to physical and biological factors. The most uncontested boundaries (based on the areas of expertise of the assembled specialists) were drawn (Harper et al. 1983). The boundaries created through this process were consistent with the IUCN classification developed by Hayden et al. (1984).

Harper et al. (1983) defined 6 marine regions on the Pacific coast of Canada. The Pacific regions averaged 23 000 km^2. The Strait of Georgia falls within the Vancouver Island Inland Sea, which includes the Queen Charlotte Strait, Johnstone Strait, the Strait of Georgia, and the eastern portion of Juan de Fuca Strait (Harper et. al 1983). This area is characterized by low wave energy and comparatively fresh and turbid waters. The Vancouver Island Inland Sea can be divided into 3 major subregions: Queen Charlotte Strait, Johnstone Strait, and Strait of Georgia/Juan de Fuca Strait.

The Canadian Parks Service Marine Regions is not truly hierarchical, as the regions are not nested within smaller and smaller units. Furthermore, no common national criteria was used to delineate regions (Harper et al. 1993). With no specific delineation criteria, the classification system is difficult to revise as new data became available (Harper et al. 1993; MEQAG 1994). The system is unusual in that it requires that all regions have an adjacent terrestrial component.

The Canadian Parks Service Marine Regions system was modified and incorporated into Parks Canada's Marine Conservation system. Regions are now defined as National Marine Conservation Area Natural Regions. (Figure 2, Mercier and Mondor 1995; Parks Canada 1995, 1997).

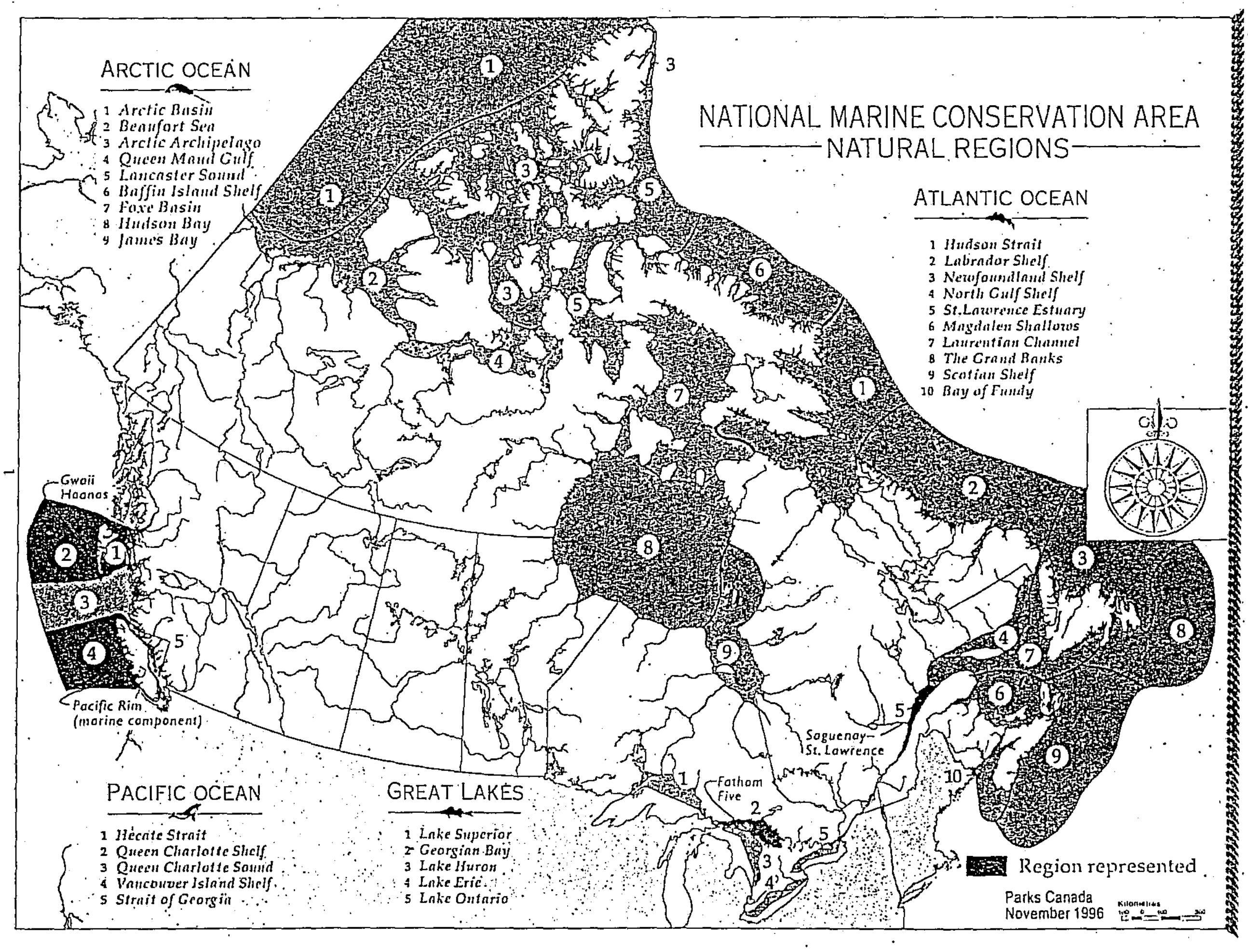


FIGURE 2. National Marine Conservation Area Natural Regions. (From Parks Canada 1997.)

3.5 Environment Canada — Marine Ecological Regions of Canada

In the early 1990s, Environment Canada developed the Marine Status and Trend Monitoring Network for monitoring changes in environmental quality. As part of this process, Harper et al. (1993) developed a hierarchical classification system for the marine regions of Canada, which was subsequently revised as the Marine Ecological Classification system (MEC) for Canada by the Marine Environment Quality Advisory Group (MEQAG).

Harper et al. (1993) used well-defined criteria to delineate marine regions throughout Canada. The Arctic regions were the largest at an average size of 253 000 km^2, whereas the Great Lakes regions were smallest at an average size of 18 000 km^2. The physical criteria selected were chosen because they were ecologically significant, and were generally accepted to limit biological systems (e.g., sea ice limits surface biota, reduces primary production, and affects water column stability [Harper et al. 1993]). Physical features were chosen because they were easy to measure and describe. Four levels of classification were developed: Marine Ecozones (defined using ice regimes and oceanic basins), Marine Ecoprovinces (defined using oceanic regimes and continental margins), Marine Ecoregions (defined using the marginal sea criteria), and Marine Ecodistricts (defined by water mixing and stratification). These ecological divisions followed those used by Wiken (1986) to develop the Canadian Ecological Land Classification System, and as with Wiken's (1986) terrestrial system, the emphasis in the marine classification system was on what is *within* a region, not on the boundaries it describes. The boundaries can be changed based on new data, but the criteria used to define each level of subdivision cannot (Harper et al. 1993).

Harper et al. (1993) defined the following levels of classification:

Marine Ecozones

Marine Ecozones are representative of global-scale marine ecological units. The presence of ice and oceanic basins were the two criteria used to distinguish Ecozones. Ice was considered to be ecologically important because it controls heat exchange and water formation, controls primary production and has specific biota associated with it. Ice cover controls the distribution of many marine mammals and seabirds, and strongly affects intertidal biota. They identified 3 ocean basins: the Arctic, Pacific, and Atlantic. Each basin was deemed to have limited exchange with the others, which was seen to limit species distributions between the basins. In total, Harper et al. (1993) identified 5 Ecozones: 2 in the Arctic, 2 in the Atlantic, and 1 in the Pacific. On a global scale, the Arctic Ocean is dominated by polar easterlies, as well as by permanent and seasonal ice. Both the Atlantic and Pacific are dominated by west winds, but have unique water mass properties when taken in a Canadian context.

Marine Ecoprovinces

Ecoprovinces are characterized by oceanic scale ecological features. Harper et al. (1993) used oceanic surface circulation and continental margins to define units at this level. This is consistent with Hayden et al.'s (1984) IUCN classification system. Circulation patterns influence water temperature, may affect recruitment patterns, and create differences in productivity and distribution of plankton and marine vertebrates. The continental margins were considered in terms of water depth, and in terms of proximity to fresh water. The continental margins were divided into oceanic basins (oceanic), which were deep and saline, and continental shelves (neritic) which were strongly influenced by freshwater, and which were shallower than 300 m (except for fjords). These two regions were seen to have highly different biological and physical features. Three Ecoprovinces were identified for the Pacific Ecozone. These 3 provinces are clearly defined based on physiographic, oceanographic, and biological features. The **Subarctic Pacific Basin** is characterized by a general northward water flow (Alaska Current throughout the year). Its topography includes abyssal plain, continental rise, and continental shelf. Biologically, this region is a summer feeding ground for pelagic fish and has a boreal plankton community. (The Subarctic Pacific Basin was later changed to the Northeast Pacific Ecoprovince - MEQAG 1994). The **Transitional Pacific Basin** is an area of variable currents. Southerly areas are affected by the southward-flowing California Current in the summer, whereas the rest of the area is characterized by weak and variable currents, including the Davidson current along the shelf edge. It includes abyssal plain, continental rise, and continental shelf. Biologically it is a transition zone of southern temperate plankton and northern boreal plankton, as well as a mix of coastal and oceanic plankton. The **Pacific Shelf** is strongly influenced by freshwater runoff, salinities are lower, turbidity is high, and there is estuarine-like stratification. Most of the Pacific Shelf is less than 300 m deep, with the exception of inland fjords. Biologically the waters are very productive and differ in species composition from pelagic regions. Larvae of coastal fish and invertebrates are common in the summer, and planktonic communities are typical of coastal regions (renamed the Pacific Shelf/Fjords Ecoprovince - MEQAG 1994; Harding and Hirvonen 1996 see Table 3).

Three Ecoprovinces were identified within the Arctic Ecozones and six Ecoprovinces were identified within the two Atlantic Ecozones.

Marine Ecoregions

Ecoregions are areas within a marine Ecoprovince characterized by continental-shelf-scale regions that reflect regional variation in salinity, marine flora, fauna, and production. This includes marginal seas (*sensu* Hayden et al. 1984) and marine shelves. Marginal seas were defined as semi-enclosed areas with substantial freshwater input, estuarine-like stratification, high productivity, and estuarine-like and shelf-transitional biotic assemblages (Harper et al. 1993). In contrast, marine shelves were more marine and had more open circulation than a marginal sea.

Harper et al. (1993) used rigorous circulation criteria to define Ecoregions. They identified two marginal seas and one marine shelf in the Pacific Ecozone. The Subarctic Pacific Basin and Transitional Pacific Basin remained as undivided Ecoprovinces, and therefore also comprised Ecoregions. The Strait of Georgia/Puget Sound and Dixon Entrance Ecoregions were identified as marginal seas: semi-enclosed water bodies with significant freshwater input. Dixon Entrance extends from the mainland (including the Stikine, Nass, and Skeena Rivers) out to the Pacific Ocean, north to the US border, and south to Hecate Strait. Water from three major rivers flow into Dixon Entrance and is replaced by oceanic water from below (Thomson 1981). This is an estuarine-like circulation pattern.

Harper et al. (1993) defined the Georgia Strait as an inland sea that included Johnstone Strait, the Strait of Georgia/Puget Sound, and Juan de Fuca Strait. Like Dixon Entrance, the Strait of Georgia is semi-enclosed and has a seasonal input of freshwater from the Fraser River. Both the Strait of Georgia and Dixon Entrance contain populations of birds and fish that depend upon its adjacent large river systems. The Pacific Marine Shelf Ecoregion included the continental shelf, and was characterized by transitional estuarine and marine water masses, with southerly currents in the summer and northerly currents in the winter.

Marine Ecodistricts

Marine Ecodistricts are areas within a Marine Ecoregion that are characterized by unique oceanic mixing processes and biological communities. Using the mixing criteria, Harper et al. (1993) defined 10 Marine Ecodistricts. The Strait of Georgia/Puget Sound Ecoregion is subdivided into the Johnstone Strait, Central Strait of Georgia, and the Juan de Fuca Strait Ecodistricts (the Ecodistrict designation is renamed Ecosection in the provincial classification scheme - see below).

Harper et al. (1993) presented their classification (Table 3) to the Marine Environmental Quality Advisory Group who revised the criteria used to delineate top-level divisions (MEQAG 1994; Harding and Hirvonen 1996). The Northeast Pacific Ecoprovince remained undivided, but the Transitional Pacific Ecoprovince was divided into the Transitional Pacific and Continental Slope Ecoregions (Table 4). The remaining two Ecoregions include the Pacific Shelf/Fjord Ecoprovince — which is undivided at the Ecoregion level — and the Georgia Basin/Puget Sound Ecoregion — which includes only the Strait of Georgia and Juan de Fuca Strait. The revised classification is in Table 4.

TABLE 3. Marine regions of Canada (Harper et al. 1993, revised by MEQAG 1994 see Table 4)

ECOZONES	ECOPROVINCES	ECOREGIONS	ECODISTRICTS
Pacific	Subarctic Pacific	Subarctic Pacific	Subarctic Pacific
	Transitional Pacific	Transitional Pacific	Transitional Pacific
	Pacific Shelf	Strait of Georgia/ Puget Sound	Johnstone Strait
			Central Strait of Georgia
			Juan de Fuca Strait
		Dixon Entrance	Dixon Entrance
		Pacific Marine Shelf	Mainland Fjords
			Hecate Strait
			Vancouver Island Shelf
			Queen Charlotte Sound
Arctic permanent ice	Arctic Basin	Arctic Basin	Arctic Basin
	Arctic Archipelago	Arctic Archipelago	Gulf of Boothia
			Foxe Basin (ice-dominated)
			Ward Hunt Ice Shelf
			Ellesmere/Axel Heiberg Fjords
			SE Baffin Fjords
			Western Archipelago
			Nares Strait
			Baffin Bay (permanent ice)
Arctic, seasonal ice	Arctic, seasonal ice	Beaufort Sea/ Amundsen Gulf	Mackenzie River Plume
			C. Bathurst Polynya
			Beaufort/Amundsen Gulf
		Coronation/Queen Maude Gulfs	Coronation/Queen Maude Gulfs
		Hudson Bay/ James Bay	James Bay
			Hudson Bay
		Eastern Arctic Shelf	North Water Polynya
			North Baffin Fjords
			Lancaster Sound
			Wellington Channel/McDougall Snd
			Foxe Basin (ice free)
			Parry Channel
			Jones Sound
			Baffin Bay (seasonal ice)
Atlantic, seasonal ice	Davis Strait/Labrador Sea	Davis Strait/Labrador Sea	Davis Strait/Labrador Sea
	Atlantic Shelf	Gulf of St. Lawrence	St. Lawrence River
			Gaspe Current
			Magdalen Shallows
			St. Lawrence Trough
			NE Gulf
			North Shore (NW)
		Labrador/Newfoundland Shelf	Hudson Strait
			Ungava Bay
			Labrador/Newfoundland Shelf
Atlantic, no ice	Subarctic Atlantic	Subarctic Atlantic	Subarctic Atlantic
	Temperate Atlantic	Temperate Atlantic	Temperate Atlantic
	Grand Banks	Grand Banks	Grand Banks
	Scotian Shelf/ Georges Bank	Scotian Shelf/ Georges Bank	Bay of Fundy
			Scotian Shelf/ G. Bank

TABLE 4. Marine Ecological Classification System for Canada (MEQAG 1994).

	ECOZONES	ECOPROVINCES	ECOREGIONS	ECODISTRICTS
PACIFIC	Pacific	Northeast Pacific	Northeast Pacific	Northeast Pacific
		Transitional Pacific	Transitional Pacific	Transitional Pacific
			Continental Slope	Continental Slope
		Pacific Shelf/ Fjords	Pacific Shelf/ Fjords	Dixon Entrance
				Hecate Strait
				Queen Charlotte Sound
				Queen Charlotte Strait
				Johnstone Strait
				Vancouver Island Shelf
			Georgia Basin/ Puget Sound	Strait of Georgia
				Juan de Fuca Strait
ARCTIC	Arctic Basin	Arctic Basin	Arctic Basin	Arctic Basin
	Arctic Archipelago	Arctic Archipelago	Arctic Archipelago	Ward Hunt Ice Shelf
				Nares Strait
				Ellesmere/ Axel Heiberg Fjords
				Western Archipelago
				Gulf of Boothia
				Foxe Basin
			Eastern Arctic Shelf	North Water Polynya
				Wellington Ch/ McDougall Sd.
				Jones Sound
				Baffin Bay (seasonal ice)
				Parry Channel
				Lancaster Sound
				North Baffin Fjords
				Baffin Bay (permanent ice)
		Arctic/ Hudson Coast	Beaufort Sea/ Amundsen Gulf	Beaufort Sea
				C. Bathurst Polynya
				Mackenzie River Plume
				Amundsen Gulf
			Coronation/Queen Maude Gulfs	Coronation/Queen Maude Gulfs
			Hudson Bay/ James Bay	Hudson Bay
				James Bay
ATLANTIC	Northwest Atlantic	Davis Strait/ Labrador Sea	Davis Strait/ Labrador Sea	Davis Strait/ Labrador Sea
		Atlantic Shelf	Labrador/ Newfoundland Shelf	Hudson Strait
				Ungava Bay
				Labrador/ Newfoundland Shelf
			Gulf of St. Lawrence	North Shore (NW)
				NE Gulf
				St. Lawrence Trough
				St. Lawrence River
				Gaspe Current
				Magdalen Shallows
	Atlantic	Subarctic Atlantic	Subarctic Atlantic	Subarctic Atlantic
		Temperate Atlantic	Temperate Atlantic	Temperate Atlantic
		Grand Banks	Grand Banks	Grand Banks
		Scotian Shelf/ Georges Bank	Scotian Shelf/ Georges Bank	Scotian Shelf/ Georges Bank
				Bay of Fundy

TABLE 5. British Columbia Marine Ecological Classification System, from the ecosection down (from Zacharias and Howes in press, Howes et al. 1996)

Marine Ecosections	Physiographic Features	Oceanographic Features	Biological Features	Boundary Rationale
Johnstone Strait	Narrow, constricted channels	Protected coastal waters with strong currents; well-mixed, poorly stratified	Migratory corridor for anadromous fish; rich sessile, hard substrate invertebrate community; diverse species assemblage of benthic fish	Johnstone Strait has greater mixing and more channels than areas to south; Queen Charlotte Strait more marine
Continental Slope	Steep sloping shelf	Strong across slope and downslope turbidity currents	Upwelling zone; productive coastal plankton communities and unique assemblages of benthic species	Transitional area between continental slope and abyssal plane
Dixon Entrance	Across-shelf trough with depths mostly < 300m; surrounded by low-lying coastal plains (Hecate Depression)	Strong freshwater influence from mainland river runoff drives north-westward flowing coastal buoyancy current and estuarine-like circulation	Mixture of neritic and subpolar plankton species; migratory corridor for Pacific salmon; some productive and protected area for juvenile fish and invertebrate development	Distinguished from area to south by strong freshwater discharge influence
Strait of Georgia	Broad shallow basin surrounded by coastal lowlands (Georgia Depression)	Protected coastal waters with significant freshwater input, high turbidity and seasonally stratified; very warm in summer	Nursery area for salmon, herring; abundant shellfish habitat; neritic plankton community	Stronger Fraser R. Signature than areas to north or west
Juan de Fuca Strait	Deep trough; a major structural feature accentuated by glacial scour	Semi-protected coastal waters with strong "estuarine-like" outflow current (coast-hugging buoyancy current to north); major water exchange conduit with "inland sea"	Migratory corridor for anadromous fish; moderately productive; mixture of neritic and oceanic plankton species	Much more marine than Strait of Georgia; less "open shelf" than Vancouver Is Shelf
Queen Charlotte Strait	Predominantly shallow (< 200 m), high relief area with deeper fjord areas	High current and high relief area; very well mixed; moderate to high salinities with some freshwater inputs in the inlets and fjords	Very important for marine mammals; migratory corridor for anadromous fish; moderate shellfish habitat	More marine than Johnstone Strait; much more shallow with high relief and high currents than Queen Charlotte Sound
North Coast Fjords	Deep, narrow fjords cutting into high coastal relief	Very protected waters with restricted circulation and often strongly stratified.	Low species diversity and productivity due to poor water exchange and nutrient depletion; unique species assemblages in benthic and plankton communities	Unique physiography and stratification compared to bordering surrounding regions

TABLE 5 continued

Marine Ecosections	Physiographic Features	Oceanographic Features	Biological Features	Boundary Rationale
Hecate Strait	Very shallow strait dominated by coarse bottom sediments; surrounding coastal lowlands	Semi-protected waters with strong tidal currents that promote mixing; dominantly "marine" waters	Neritic plankton communities with some oceanic intrusion; nursery area for salmon and herring; abundant benthic invertebrate stocks; feeding grounds for marine mammals and birds	Marine in nature but much shallower, with associated greater mixing, than areas to the south
Subarctic Pacific	Includes abyssal plain and continental rise; a major transform fault occurs along the west margin and a seamount chain trends NW/SE	The eastward flowing subarctic current bifurcates at coast with northerly flowing Alaska Current ; current flow is generally northward throughout the year	Summer feeding ground for Pacific salmon stocks; abundance of pomfret, Pacific saury, albacore tuna and kack mackerel in summer, boreal plankton community	The northern and western boundaries are undefined. The eastern boundary is coincident with the shelf break. The southern boundary is indistinct but is meant to be located
Queen Charlotte Sound	Wide, deep shelf characterised by several large banks and inter-bank channels	Ocean wave exposures with depths mostly >200m and dominated by oceanic water intrusions	Mixture of neritic and oceanic plankton communities; northern limit for many temperate fish species; lower benthic production	More oceanic (deep) and marine than Vancouver Island Shelf and Hecate Strait
Transitional Pacific	Includes abyssal plain, and continental rise; also includes spreading ridges, transform faults, triple junction and plate subduction zone	Area of variable currents; southerly areas may be affected by southward-flowing California Current in summer but remainder of area characterised by weak and variable currents; Davidson Current along shelf edge flow north in winter, south in summer	Transition zone between southerly, temperate, and northerly boreal plankton communities; mixing of oceanic and coastal plankton communities adjacent to the coastal shelf	The northern boundary is indistinct and approximately coincident with the southern limit of the Alaskan Current (winter). The eastern boundary is at the shelf break. The southern and western boundaries are undefined
Vancouver Island Shelf	Narrow, gently sloping shelf	Open coast with oceanic wave exposures; northward, coast-hugging buoyancy current due to freshwater influence; seasonal upwelling at outer margin	Highly productive with neritic plankton community; northern limit for hake, sardine, northern anchovy, and Pacific mackerel; productive benthic community; rich fishing grounds for benthic fish and invertebrates	More open shelf than Juan de Fuca Strait; more freshwater influence (coastal buoyancy current) than Queen Charlotte Sound

modified from Hirvonen et al., 1996; Harper et al., 1993, and Howes et al., 1997.

3.6 The Marine Ecoregions of British Columbia

In 1995, the classification of the Marine Regions of Canada was reviewed by a specialist workshop in British Columbia to determine the applicability of the classification boundaries for protected areas planned by the provincial government. At this meeting, a slightly revised set of Ecosections (equivalent to Ecodistricts in the Environment Canada Scheme), Ecoregions, and Ecoprovinces was drawn up (Table 5). The workshop also recommended that the new Ecosections be verified, and that a further subdivision of the marine environment was required (Zacharias and Howes unpub.). These modifications, together with what are now known as "Ecounits," make up the British Columbia Marine Ecological Classification System (BCMEC).

The BCMEC is a five-tiered hierarchical system that includes, at its two lowest levels, the 12 Ecosections (equivalent to Ecodistricts in the Marine Ecological Classification System for Canada) and the 619 smaller **Ecounits**. The Ecounit level of the hierarchy was developed for use in marine planning, coastal zone management, and marine protected area planning (Wainwright et al. 1995; Howes et al. 1996). The Ecounits are undergoing further refinement and subdivisions as new data and modelling techniques become available (Mark Zacharias, Land Use Coordination Office, pers. comm.).

The Ecounit level of subdivision is based upon small-scale physical features, including current regimes, depth, subsurface relief, seabed substrate, and wave exposure (Wainwright et al. 1995). These criteria were chosen because they are known to affect the structure of biological communities and because data for these criteria existed. Temperature and salinity are also important to biological communities, and are likely good criteria for Ecounit classification, but systematic province-wide data were not available. These data will be incorporated as they become available (Howes et al. 1996; Zacharias and Howes unpub.).

Current data from the Canadian Hydrographic Service (CHS) charts were used to divide areas into those of high current (>3 knots) and low current (<3 knots). Depth and subsurface relief were estimated from CHS charts and bathymetry maps. Substrate data from Geological Survey of Canada sediment maps were categorized as hard, sand, mud, or unknown. Much of the offshore regions of the B.C. coast were placed in this last category. Exposure was based on fetch and wind speed, similar to the method developed in the British Columbia Physical Shore-Zone Mapping System (Howes et al. 1994; Zacharias and Howes in press). Exposure data were obtained from CHS charts and the Provincial Oil Spill and Response Information System. Zacharias and Howes (unpub.) delineated the ecounits by combining the five data sets into a single map. The Ecounits were then grouped into 65 classes based on unique combinations of the five criteria used to classify the Ecounits. Three Ecounits in the Subarctic Pacific and Transitional Pacific Ecosection account for 75% of the marine Ecosection areas (Zacharias and Howes unpub.).

Zacharias and Howes (unpub.) used the Ecounit themes to verify the Ecosection level of the BCMEC. They found that the 12 Ecosections differed from each other by at least two Ecounit-level criteria, and were well distinguished from each other by the five criteria used (Zacharias and Howes unpub.).

The BC Marine Ecosystem Classification assumes the water column is vertically homogeneous, with horizontal differences in the water column reflecting changes in the underlying water mass. However, vertical relationships between species and habitat/water column may not agree with the horizontal relationship (Zacharias and Howes unpub.). Thus Ecounits may not adequately represent vertical water column characteristics. Taylor and Roff (in press) address this by adding a vertical component to the classification. They separate benthic and pelagic environments, divide the pelagic zone into photic and non-photic zones, and separate intertidal and subtidal environments (Taylor and Roff 1997). They predict that their physiographic and oceanographic features should define biological communities at the finer scale of resolution.

The Ecounit level of the BCMEC was developed to increase the resolution of the classification, ultimately for selecting candidate sites for marine protected areas. Zacharias and Howes (in press) analyzed the area (km^2) of marine protected areas (very loosely defined as parks, etc.) within each Ecosection and Ecounit. Using GAP analysis techniques (see Jennings 1995; Short and Hestbeck 1995; Davis and Reiners 1996), they were able to identify areas that are under-represented or are likely to be under-represented (using Ecounit criteria) by the Federal-Provincial MPA strategy. The Ecounit level of classification proved to be well-suited for this analysis (Zacharias and Howes in press).

Eventually, biological information will be used to subdivide the Ecounit level of classification. However, the abundance and distribution of many marine species in B.C. is unknown or poorly understood. Preliminary attempts to include biological data are presently underway (Mark Zacharias, Land Use Coordination Office, & Mary Morris, Archipelago Marine Research, pers. comm.). Recently, Zacharias et al. (unpub.) incorporated values of currents, primary productivity, salinity, and temperature generated by a simulation model of oceanographic processes in the Georgia Basin (Stronach et al. 1993) into the BCMEC. They combined the two datasets (BCMEC and the model data), and classified the combined data using a tree-based regression and principal components analysis. The resulting classification was then evaluated using intertidal field surveys. Site and species data were clustered and compared to the clusters generated using the combined physical and model-based data. Although there were some inconsistencies, the field sampling generally agreed with the new classification, and indicated that substrate composition and wave exposure were as important as water properties in defining a biological community (Zacharias et al. unpub.). Efforts to relate the shoreline units (from the Physical Shore Zone Mapping System see below) to biological assemblages (from the Biological Shore Zone Mapping System see below) are presently underway (Mary Morris, Archipelago Marine Research, pers. comm.).

3.7 Ecological Classification of Coastal California

In 1981, the National Bureau of Land Management, the Pacific Outer Continental Shelf Office, and the US Fish and Wildlife Service described the coastal region of Central and Northern California to consolidate the information needed to assess the environmental effects of development proposed for Central and Northern California (Jones and Stokes 1981a-c). The classification considered physical, chemical, biological, and socioeconomic features, although emphasis was ecological and focused on biological interactions within the coastal zone.

The five ecosystem types recognized by Cowardin et al. (1979) (Figure 3) and the terrestrial ecosystem were identified and subsequently modelled using energy circuit language (Odum 1967). This characterized the relationships between the physical and biological components of each area. As with most other characterizations, emphasis was placed on physical factors known to control biological structure. Designated species (endangered species or representative species) were included in the models.

The marine ecosystem included a series of subsystems (zones or habitats) which were related by the flow of material and biota. Habitats were subsequently identified within each of the six ecosystems. Habitats, as defined by Cowardin et al. (1979), were identified and described (Jones and Stokes 1981a-c). The study provides a detailed look at coastal California, and while it identifies habitat types, repeating ecological units were not clearly defined.

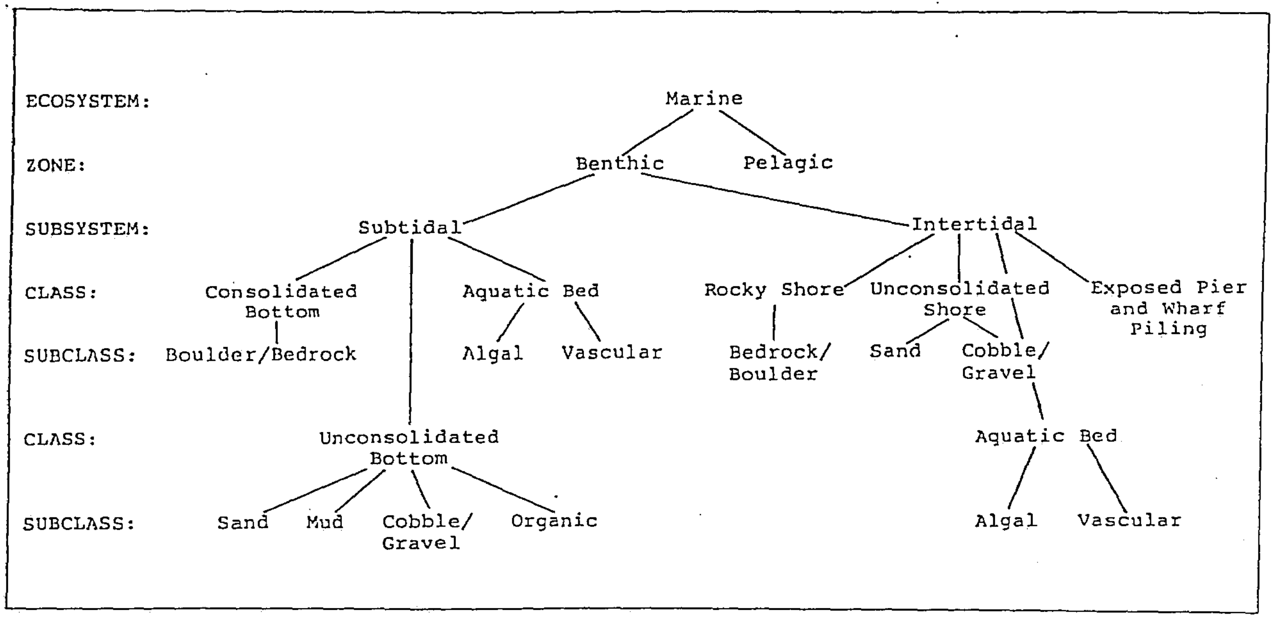


FIGURE 3. The Cowardin system of nearshore classification. (Jones and Stokes 1981b.)

3.8 Habitat Classification Systems

At the lowest level, hierarchical classification systems are habitat classification systems. Habitat classification systems may have all the attributes of an ecosystem classification system, except that they delineate biotic and physical community components on a small scale (fine-grain resolution) and are generally not placed in a global context. Habitat classification systems used in British Columbia and around the world have been reviewed by Frith et al. (1993a), Booth et al. (1996), Robinson and Levings (1995), Hay et al. (1996), and Robinson et al. (1996). Consequently, only a brief overview of the major classification methods is provided here.

Classification methods used to classify the world's wetlands (estuaries and marshlands, including fresh, brackish, and salt water down to 6 m below LW (Matthews 1993) were reviewed in a special issue of the journal Vegetatio (Vol 118:1-2) in 1995. Introductory and summary articles by Scott and Jones (1995) and Finlayson and van der Valk (1995) provide comprehensive overviews. Levings and Thom (1994) also review estuarine classification. Some of the classification methods used to describe estuaries also include shallow marine habitats. Estuaries are often considered to be clearly defined ecosystems.

In the U.S., the most widely used system is that of Cowardin et al. (1979; Cowardin and Golet 1995), although expansions to this method, designed primarily for the marine zone, have been proposed by Dethier (1990, 1992a, 1992b). The Cowardin system is hierarchical, comprising systems, subsystems, classes, and subclasses (Figure 3), together with a series of modifiers that assess water regime, chemistry, and soil. Both Cowardin's and Dethier's methods describe coastal, nearshore, and estuarine habitats by breaking them into ecological units with homogenous features. The systems can be placed in a global context (with some minor modifications). As with most systems, the upper levels of Cowardin et al.'s (1979) classification are based on physical features and the lowest levels are based on biological features (characteristic species).

Estuarine classification systems used in Puget Sound include Bortelson et al. (1980), Downing (1983), and Simenstad et al. (1991). Bortelson et al. (1980) divided nearshore habitat into intertidal wetlands and subaerial wetland to map losses in wetland/delta areas in Puget Sound. This system lacked fine-scale resolution, but the level of resolution was determined by the quality of the historical data available (mostly survey maps). Downing (1983) used geological features to discuss processes affecting the coast of Puget Sound. Beaches were classed according to substrate type (sand, mud, sand/mud, gravel, etc.). He also summarized a classification method used by the Washington State Department of Ecology (*in* Downing 1983), which described coastlines based on the major processes affecting coastline formation: erosion, deposition, neutral, and modified. Coastlines formed by deposition included mud flats, marshes, and eelgrass beds. Neutral and erosional coastlines were gravel, cobble, and rock. Modified coastlines were formed (or most strongly affected) by anthropogenic factors and included seawalls, piers, log booms, and docks. Simenstad et al. (1991) used eight habitat types (modified from the Cowardin system and the Dethier system) to develop sampling protocols for the eight habitat type. Although this is not technically a classification system, it is commonly used to describe habitats in Puget Sound (Levings and Thom 1994).

In British Columbia, an estuarine classification system was developed by Hunter et al. (1982) for the Ministry of Environment. The fundamental unit in this system is habitat type. Habitats are defined by substrate, vegetation, salinity, and position on the shore, but characteristic species are not used. Vegetation is categorized into broad categories. At present the B.C. government has two projects underway which are revising the estuarine classification system for B.C. These revisions will incorporate the B.C. Ecosystem Classification and Terrestrial Ecosystem mapping criteria (Mary Morris, Archipelago Marine Research, pers. comm.).

The Canadian system of wetland classification is a hierarchical classification system that includes five classes of wetland, within which are a number of forms (Ward et al. 1992; Zoltai and Vitt 1995). It differs from the Cowardin system in that it is based on wetland functions — the relationships between biotic and abiotic components. The resulting units have implications about the hydrology, water quality, and vegetation interactions of a particular wetland (Zoltai and Vitt 1995). In contrast, the Cowardin system is more objective; it depends almost exclusively on observable features, and does not require process-related classification decisions.

The coastal and estuarine classification for fish habitat (Williams 1989,1990; Williams et al. 1993) was developed for the Department of Fisheries and Oceans as a standard methodology for describing fish habitat. The system is hierarchical and divides habitat into estuarine and marine, and then further classifies shoreline units into vertical location, and ultimately physical components (see Feakins 1991). A biological component based on that of Hunter et al. (1982) is used to describe vegetation. The system is intended to be used in referrals processed in foreshore development projects.

Pritchard (1989) reviews estuarine classification schemes used to help understand transport processes in the marine environment. Hume and Herdendorf (1988) describe an estuarine classification system developed for New Zealand. Estuaries were grouped into five classes reflecting the processes that shaped the basin comprising the estuary. The processes include those of fluvial erosion, marine fluvial erosion, tectonic forces, volcanic forces, and glacial forces. The five classes are further subdivided, based on coastal hydrological and sedimentation processes. Other estuarine classification systems are described by Bucher and Saenger (1994), Bulger et al. (1990), and Hughes (1995).

There are several shoreline classification and mapping systems in use in British Columbia. The Physical Shore Zone Mapping System developed for B.C. by Howes et al. (1994) is used to subdivide the shore zone into along-shore units; one of 34 shoreline types, based on substrate, sediment type, width, and slope. Across-shore components are geomorphologic. The system is hierarchical, and surveys are conducted using Aerial Video Imagery. The Biological Shore Zone Mapping System was developed by Searing and Frith (1995; see Frith et al. 1993b) and was first developed and tested in the Queen Charlotte Islands (Harper et al. 1994). This system is a mapping system and database. It is designed to be used with the Physical Shore Zone Mapping System and as a tool for identifying biological and community-based relationships with the physical environment. The system is provided as a temporary measure for the collection of data that will be used to develop a predictive classification system based on biological criteria. Booth et al. (1996) provide examples of how the biological and physical shore zone mapping systems can be used together.

Emmett et. al. (1994) used the physical shoreline mapping system to describe the biota in the shallow subtidal in Hakai Recreation Area. They created biophysical units that combined key species and important physical habitat features. The units were based on criteria that included exposure, substrate, slope, and indicator species. This system has the advantage of identifying repetitive ecological units, but in its present form may be appropriate for only a small portion of the B.C. coast. Searing and English (1983) also described, but did not classify, three marine areas in B.C. for Parks Canada. Other regional descriptions of nearshore habitat includes that of Lee et al. (1982), who described areas within Pacific Rim National Park.

The Shorekeeper's Guide (Desrochers et al. 1997) is based on The Coastal/Estuarine Fish Habitat Description and Assessment Manual (Williams 1989, 1990; Williams et al. 1993). It outlines descriptive mapping methods, intended to allow individuals without formal biological training to describe and monitor beach-fronts. It is a non-hierarchical system. The British Marine Nature Conservancy Review Program has developed a hierarchical classification method that can be used to classify benthic marine/estuarine habitats from the intertidal zone through to depths of 200m on the continental shelf of Britain (Hiscock and Mitchell 1980; Hiscock and Connor 1991; Connor et al. 1995; Hiscock 1995). The system was developed to encourage scientifically based decisions on the use of nearshore habitats. The system classifies communities into "biotopes" or repeating ecological units (see Whittaker et al. 1973). Each site is classified based on specific features listed under the headings physiography, salinity, exposure, currents, geology, tidal zone, substratum, and habitat features. The various combinations of features listed under each heading describes a large number of biotopes, each with a potentially unique species assemblage. A list of conspicuous species is made, and ultimately each species assemblage is associated with a suite of physical attributes. The classification system, at its lowest level, is based on descriptions of species assemblages and in this way is a biological classification system (Earll 1992 *in* Connor et al. 1995). This system is complementary to classification systems developed for France (Dauvin et al. 1994 *in* Connor et al. 1995) and the Mediterranean (Augier 1982 *in* Connor et al. 1995; Bellan-Santini 1985).

Other shoreline classification examples include those by Polhemus et al. (1992) for the inland waters of the tropical Pacific, the Nature Conservancy (1996) for the tropical western Atlantic, a nearshore vegetation classification for NOAA (Klemas et al. 1993), Shepphard et al. (1995) for the Caribbean, and the use of GIS systems in Belize (Mumby et al. 1995).

4.0 REGIONAL CLASSIFICATION, AS IT APPLIES TO THE STRAIT OF GEORGIA

4.1 Overview

Numerous efforts have been made to classify discrete marine communities and habitats within ecosystems (e.g., Jansson 1972; Backus and Bourne 1987; Barange et al. 1992; Koutitonsky and Bugden 1991; GLOBEC 1988, 1991a, 1991b, 1991c, 1992; Kideys 1994; Burroughs and Clark 1995). Regional-scale classification requires more detailed ecological information than is needed in a global classification system. The increased detail needed at the regional level often means that there are no widely accepted units or criteria for classification and only local examples exist. Thus, regional-scale (fine-scale) classifications are highly site/region specific (for example, they use area-specific species) and there is little opportunity for comparison between ecosystems.

In many cases, small-scale classification (fine-grain) seeks only to characterize communities in terms of their relationships to other communities within a region. Regional classifications can likewise relate communities to environmental factors. Ideally, the goal of classification is to characterize the community and then interpret the results in terms of its relationship to the environment (Gauch 1982). In most marine ecosystem classifications, communities are defined in terms of species groups, and the resulting groups are compared to the range of environmental factors in which they occur. Ultimately, regional-scale classifications should be highly predictive; environment should be a good predictor of the community, and reciprocally the community should be a good predictor of the environment (see Schoch and Dethier 1996).

Oceanographic and biological research has been conducted within the Strait of Georgia for nearly a hundred years. Consequently, our knowledge of both physical and biological features is good, compared to other marine regions of B.C. The following sections examine regional-scale classification studies conducted both within and outside the Strait of Georgia.

4.2 Strait of Georgia: Physical Description

The Strait of Georgia is an inland sea that encompasses 6800 km^2 (Thomson 1981, 1994). At the deepest point it is 420 m deep, but averages 155 m. The Strait is connected to the Pacific Ocean via Johnstone Strait in the north and Juan de Fuca Strait in the south. Long narrow fjords stretch inland from its eastern shore.

Water movement in the Strait of Georgia is affected by tide, river discharge, wind, ocean influx, and topography (Thomson 1981; Levings et al. 1983). Tides are mixed-semi diurnal, and account for 80-90% of the current variance in the Southern Strait of Georgia, 50% of the current variance in the Northern Strait, and 100% in narrow passes (Stronach et al. 1993). Differences in water density (salinity) also influence water flow. The Fraser River water flows into the Central Strait and undergoes a generally northward movement affecting surface currents (Stockner et al. 1979). Cold saline water enters from Juan de Fuca and Johnstone straits and sets up a counter-clockwise circulation in the deeper waters of the Strait. Wind affects circulation in the surface waters, and shallow sills formed by glaciers determine the oceanographic features of the adjoining fjords (Waldichuk 1971; Thomson 1981), as does river discharge at their heads (Pickard 1961).

Temperature and salinity vary with season, proximity to the Fraser River, and depth. The water column is highly stratified, and can be divided into two layers. Temperatures in the lower layer (>50 m) remain between 8–10°C all year. Likewise, salinity ranges from $30.5^{0}/_{00}$ in the summer to $31^{0}/_{00}$ in the winter. In the surface layer (< 50 m), seasonal and geographic variations in temperature and salinity are pronounced. In February/March, surface temperatures are 5–6°C. By mid-May, near-surface temperatures can rise to 15°C and by July, when highly stable stratification has set up, surface temperatures may reach 20°C. In highly mixed areas, summer water temperatures rarely exceed 10°C. During freshet, a layer of sediment-laden brackish Fraser River water ($15^{0}/_{00}$), called the "plume," forms over the Central and Southern Strait (LeBlond 1983). The position of the plume is strongly influenced by local winds (Stronach et al. 1993). In the Northern Strait, summer salinity levels rarely drop below $25^{0}/_{00}$. During the winter, surface salinities usually stabilize around $25^{0}/_{00}$ throughout the Gulf (Thomson 1981, 1994).

Dissolved oxygen in the lower layer (>50 m) ranges from 3.0 – 4.0 ml L^{-1} seasonally. In areas of high water movement, dissolved oxygen levels are generally 5.6 ml L^{-1}. Water in fjords is similar to the Strait itself, except that the sills reduce exchange, and dissolved oxygen levels can drop below 1 ml L^{-1} or become anoxic (Tunnicliffe 1981; Levings et al. 1983).

Within the Strait of Georgia, wave height is restricted by fetch and rarely exceeds 2 m (Thomson 1981; Howes et al. 1994). Fetch profoundly affects shorelines. Exposed shores are characterized by coarse sediments, whereas sheltered shorelines (with less fetch) are characterized by finer sediments (Howes et al. 1994; Harper 1995). Shorelines are generally rock or sand, whereas bottom sediments are predominantly mud (Levings et al. 1983).

The Strait of Georgia can be divided into three oceanographic areas on the basis of pelagic primary productivity (Stockner et al. 1979, Figures 4 and 5). The Northern Strait extends from the southern tip of Texada Island north to Discovery Passage. It is an area of generally low currents (except in Discovery Passage). Water movement in the Northern Strait is influenced by density differences created by Fraser River run off and by cold water streaming in from the north (Thomson 1981). The Central Strait extends from Texada Island south to a line drawn from Sidney across to Pt. Roberts. With the exception of narrow passes, it is an area of moderate tidal action, strongly influenced by the Fraser River. The Central Strait receives most of the Fraser River discharge and is brackish and turbid during the summer months. The Southern Strait has strong tidal currents. It is influenced by Fraser River water, with brackish water extending into portions of the Southern Strait during the summer months. Saline oceanic waters are prevalent during the winter.

The oceanography of the Strait of Georgia is reviewed or described by Hutchinson and Lucas (1931), Tully and Dodimead (1957), Waldichuk (1957, 1971), Barnes and Ebbesmeyer (1978), Thomson (1981), LeBlond (1983), Crean et al. (1988 *in* Thomson 1994) and Thomson (1994). Harrison et al. (1984) provide a bibliography of the biological oceanography of Georgia Strait.

4.3 Physical Parameters

Water bodies can be classified using their physical characteristics, including salinity, temperature, nutrient loading, chemistry, irradience, turbidity, and physical processes (e.g., Bary 1961; Bary and Pieper 1970; Jerlov 1977; Carpenter and Carpenter 1979; Parson et al. 1984; Caddy 1993). Physical factors in turn directly affect the distribution, abundance, and community structure of pelagic and benthic communities, as well as high trophic level vertebrates (e.g., Bary 1963; Elphick and Hunt 1993; Oviatt et al. 1995). There is an enormous literature that describes marine ecosystems in terms of physical-oceanographic properties. A very brief review is provided here.

Surface waters of the northeast Pacific Ocean are primarily affected by seasonal heating and cooling, rainfall, evaporation, and wind-driven mixing. Based on physical characters, Dodimead et al. (1963) identified 4 oceanographic domains in the northeast Pacific Domain. Ware and McFarlane (1989) examined the distribution and commercial quantities of fish in the north Pacific and defined 3 discrete fisheries-production zones. These zones were largely associated with those domains described by Dodimead et al. (1963), and provide evidence of a strong link between large-scale circulation patterns and fisheries production.

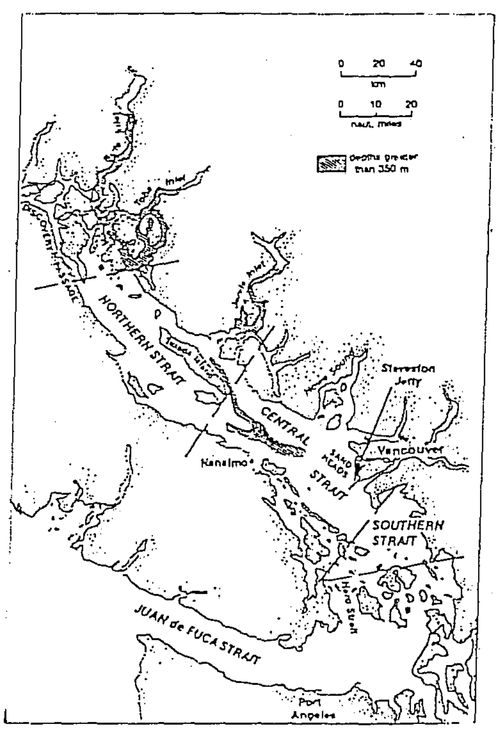


FIGURE 4. The three regions within the Strait of Georgia. (From Thomson 1981.)

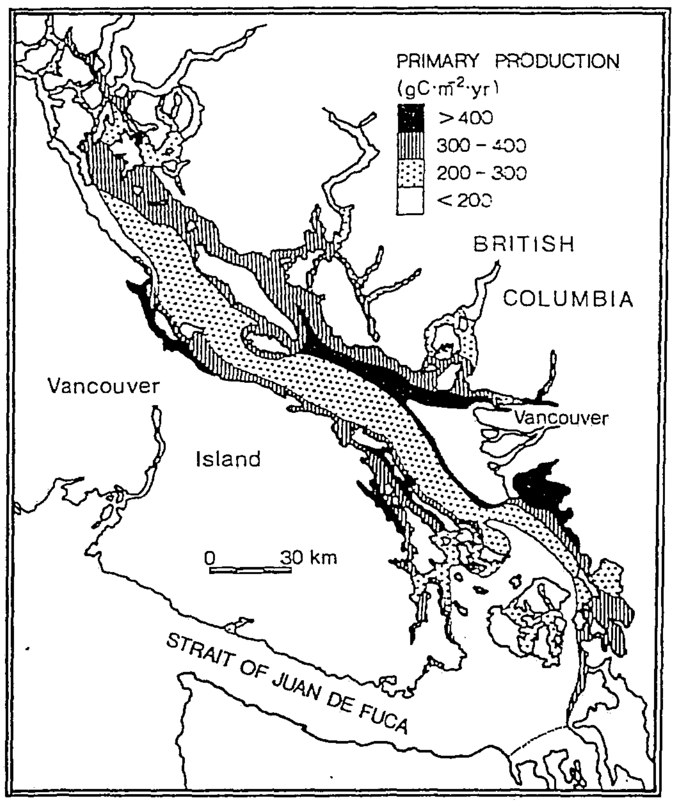


FIGURE 5. Generalized spatial pattern of annual phytoplankton production in the Strait of Georgia (Stockner et al. 1979).

Other studies have also linked fisheries production to physical parameters. De Lafontaine et al. (1991) divided the Gulf of St. Lawrence into 4 regions, based on topography and physical oceanography. Using existing descriptions of phytoplankton, zooplankton, and ichthyoplankton, they characterized plankton communities and found that the distribution, abundance, and dynamics of the plankton in each region differed, possibly reflecting differences in topography and oceanography.

Caddy and Bakun (1994) classified coastal marine ecosystems on nearshore nutrient supply. They proposed 3 categories of nutrient enrichment processes: coastal upwelling, tidal mixing, and land-based runoff. They used these classifications as a means of identifying groups of regional (small-scale) ecosystems that were similar in terms of nutrient enrichment. Their classification system was developed to monitor anthropogenic effects of nutrient enrichment upon marine ecosystems.

4.4 Classifying Patterns of Productivity / Phytoplankton

Phytoplankton can be described in terms of productivity (chlorophyll a), distribution, or species composition. Phytoplankton communities are affected by physical and biological factors such as mixing, light, turbidity, nutrients, salinity, temperature, grazing, and sinking (Harrison et al. 1983; Parsons et al. 1984). In plankton communities, biological and physical features are tightly linked. Chlorophyll a concentrations and sea surface temperatures, for example, often show similar patterns, reflecting patterns of water movement (e.g., Mackas et al. 1985).

Coastal areas, including inland seas and continental shelves, are amongst the world's most productive regions (Denman and Powell 1984; Pauly and Christensen 1995). Upwelling, or turbulent mixing brings nutrient-rich water to the surface and increases nearshore productivity (Springer et al. 1996). Primary production, estimated by the concentration of chlorophyll a or accessory photosynthetic pigments, is easily mapped using traditional or remote sensing methods and is commonly used to classify areas at local and global scales (Smith and Baker 1982; Pauly and Christensen 1995; Richardson 1996). Koblents-Mishke (1983), for example, classified global ecosystems based on primary production.

Patterns of primary productivity in the Bering Sea were described by Springer et al. (1996). The highest levels of production (phytoplankton) occurred at shelf edges, where nutrient-rich waters upwelled. Zooplankton, squid, and fish were concentrated along the same margin and attracted large numbers of marine birds and mammals. Similar patterns of productivity and trophic interactions are described by O'Reilly et al. (1987) for the well-mixed waters of George's Bank.

The distribution of plankton communities has been described at a global scale. McGowan (1974), Reid et al. (1978), and Hayward and McGowan (1979) describe characteristic associations of plankton in the gyres systems of the Atlantic and Pacific. The abundance and composition of these assemblages is very uniform and appears to represent old and stable systems (McGowan 1974).

Phytoplankton productivity, distribution, and community composition has been well studied in the Strait of Georgia (e.g., Legare 1957; Gilmartin 1964; Buchanan 1966; Stockner et al. 1977, 1979; Mackas et al. 1980; Haigh and Taylor 1990, 1991; Yin et al. 1996; Yin et al. 1997). Harrison et al. (1983) described the phytoplankton community in the Strait as being typical of cold temperate waters and similar to phytoplankton communities at similar latitudes in the southern and northern hemispheres of the Atlantic and Pacific.

The species composition, abundance, and timing of plankton blooms is strongly affected by mixing and turbidity (Parsons et al. 1981). The spring plankton bloom generally begins in the Central and Southern Strait, where vertical stability occurs first. Phytoplankton increases later in the Northern Strait as the water column stabilizes (Stockner et al. 1979). Eventually, plankton abundance declines as grazers reduce biomass and nutrients or light become limiting (Harrison et al. 1983).

Diatoms dominate other phytoplankton throughout the Strait (Shim 1976), and are most abundant in the spring and early summer, especially where nutrient levels are high (around the Fraser River plume, at fjord entrances, and at boundary areas). The distribution of primary production reported by Stockner et al. (1979) and Parsons et al. (1981) reflect these patterns. Flagellates are most common in the mid to late summer, forming large surface blooms if nutrients are available, or aggregations at the pycnocline if nutrients are limiting (Haigh and Taylor 1991). Haigh and Taylor (1991) reported that patchy mosaics of plankton occurred in the Northern Strait in the late summer when nutrients were limiting. These patches included diatoms on the turbulent west side of the Strait, nanoflagellates on the more stratified eastern side, and dinoflagellates associated with frontal boundaries in the north. They suggested that diatoms grew best in highly-mixed regions where they did not sink, whereas flagellates were common in highly stratified water.

Terrestrial runoff also affects the abundance and distribution of phytoplankton. Stockner et al. (1977) found that inlets with medium to high runoff were more likely to support flagellates than low runoff inlets, which generally supported diatoms. The sediments in low runoff inlets reflect this and are primarily composed of diatom frustules. McQuoid and Hobson (1997) have documented the history of diatom communities in Saanich Inlet over the last 100 years using sediment cores. Long-term fluctuations in diatom abundance are also being examined using frozen core samples that date back to the last glaciation.

Historically, there have been debates about production levels and patterns of production in the Strait (Stockner et al. 1979, 1980; Parsons et al. 1970, 1980, 1981; see Harrison et al. 1983 for a discussion). In general the highest levels of chlorophyll a occur in nutrient-rich waters associated with the Fraser River and the cold oceanic waters that enter the Strait from north and south. The lowest levels of productivity occur within the highly turbid plume. Thus, phytoplankton productivity and community composition vary among the three geographic regions, between the east and west shores, and between the centre and edge of the Strait (See Figure 5 - from Stockner et al. 1979).

4.5 Classifying Zooplankton Communities

The distribution and abundance of zooplankton is affected by both biological and physical factors (Harrison et al. 1983; Mackas et al. 1985). Large-scale patterns (both temporal and spatial) are generally caused by long-term processes such as population growth, predation, competition, and advection. Small-scale patterns are created by rapid physical and biological processes such as the formation of fronts (Mackas et al. 1985; Mackas and Fulton 1989). Many zooplankton undergo a daily vertical migration, moving from deep water in the day to shallow water at night, possibly to avoid visual predators such as fish and birds that forage at the surface.

Zooplankton represent an important component of both pelagic and nearshore ecosystems, converting phytoplankton to animal biomass and providing an important food source to many higher trophic levels (Mackas and Fulton 1989). The abundance of fish, birds, pinnipeds, and cetaceans is seasonally related to the abundance of zooplankton (Nemoto 1959; Outram and Haegele 1972; Wahl et al. 1989; Olesiuk et al. 1990; Tanasichuk et al. 1991; Joiris 1992; McFarlane and Beamish 1992; Springer et al. 1996; Burger et al. 1997).

Upwelling ecosystems — regions where cold nutrient-rich waters upwell into surface waters — are often classified in terms of zooplankton communities (e.g., Peterson et al. 1979; Mackas and Sefton 1982; Thomas and Emery 1986; Robinson 1994). Barange et al. (1992) examined the distribution pattern of 21 species of euphausiid in the Benguela upwelling system off South Africa. Using a principle components analysis, they identified three assemblages of euphausiids. Analysis of physical factors indicated that boundaries between the assemblages were maintained by differences in bottom topography, latitude, and oceanography. Mackas (1992) identified three subregions of an upwelling system off southwestern Vancouver Island based on bathymetry and current patterns. He found that zooplankton biomass, species composition, and seasonality, as well as temperature, salinity, nutrients, and phytoplankton biomass varied sharply among the three regions. Likewise, Kuznetsov et al. (1993) described highly mixed regions in the Sea of Okhotsk in terms of levels of phytoplankton and zooplankton abundance, and attributed the extreme patchy distribution of plankton to highly complex patterns of water movement.

Long-term temporal variation in zooplankton communities has been described. Brodeur and Ware (1992) analyzed zooplankton collections from subarctic Pacific for three periods, 1956–1959, 1960–1962 and 1980–1989. They mapped zooplankton concentrations for each period and found large interannual- and decadal-scale changes in zooplankton biomass in the subarctic gyre. The changes in zooplankton biomass contributed to changes in abundance/survival of pelagic fish, particularly salmon. They point out that temporal variations in zooplankton biomass reflect a variety of large-scale unpredictable oceanographic events. Similar relationships are reported by McFarlane and Beamish (1992). Tanasichuck (1995) reports dramatic temporal shifts in the dominant species of euphausiid at La Parouse Bank off Vancouver Island. These changes appear to be associated with changes in water temperature and upwelling patterns coincident with El Niño events.

Although most classification of zooplankton are of holoplankton, meroplankton can also be classified. Doyle et al. (1993) used numerical classification to compare larval fish communities and distribution on both coasts of North America. They identified distinct multispecies communities with clear spatial patterns for both coasts. The distributional boundaries of the larval fish assemblages varied seasonally, reflecting changes in oceanographic features.

The distribution and ecology of zooplankton in the Strait of Georgia have been well studied (e.g., Fulton 1973; Gardner 1977; Mackas et al. 1980; Arai and Mason 1982; Larson 1987; Mackas and Louttit 1988; Mackas 1992). Harrison et al. (1983) provide an overview of plankton ecology within the Strait and describe spatial and temporal changes in 4 general zooplankton communities.

During the winter, the **surface or epipelagic** community is dominated by small (<2 mm) copepods (Mackas and Fulton 1989). This changes in the spring when nauplii and zoea larvae recruit to the epipelagic community. Mackas and Louttit (1988) described extremely dense aggregations of the copepod *Neocalanus plumchrus* in the epipelagic community along the margin of the Fraser River plume during the spring. Abundant copepod prey appear to result in increased abundance of juvenile salmon and herring at the plume edge (St. John et al. 1992). During the summer, gelatinous zooplankton become abundant in the epipelagic community. Arai and Mason (1982) compared the species of gelatinous zooplankton found in surface waters mid-strait to those from neighbouring shallow bays and found that they differed. In the fall zooplankton numbers decline as the epipelagic community returns to winter conditions.

The **midwater community** occurs from the bottom of the mixed layer to a depth of 250 m. It is dominated by euphausiids. The largest concentrations of euphausiids occur during the winter in the inlets adjoining the Strait (Heath 1977; Romaine et al. 1995). In the Strait, humpback whales, which prey on euphausiids, were historically harvested from inlets during the winter (Merilees 1985). Mackas and Fulton (1989) provide biomass distribution maps of euphausiids.

The **deepwater community** (below 250 m) is dominated by copepods from July – March. The deepwater community is relatively stable during the fall and winter.

The **nearshore community**, found in estuaries, bays, and small inlets, is highly variable but probably an important source of prey for juvenile salmon (Healey 1979). Sibert and Reimer (1976) described the sediment types within the Nanaimo River Estuary. Sibert (1979) then sampled the different sediment types and described the meiofauna associated with these sediments. Sibert (1979) found that nematodes and copepods were the most abundant taxa. Nematodes were most abundant in the spring and fall, whereas harpactocoid copepod were most abundant during the late summer to early fall, and were important in the diet of juvenile chum salmon.

4.6 Classifying Benthic Fauna and Benthic Communities

Much as vegetation is used in terrestrial ecosystems, assemblages of benthic species are often used to describe marine ecosystems in biological terms. This may be because, much like terrestrial plants, they are relatively immobile as adults, exist in one dimension, and are comparatively easy to document. Biologist have searched for indicator species or factors that define benthic communities for nearly a hundred years. Petersen (1913 *in* Thorson 1957) was the first to develop the concept of an indicator species in benthic studies. He characterized benthic communities in terms of dominant species. Building on Petersen's ideas, Thorson (1957) developed the "parallel benthic community hypothesis" in which he described repeating communities of infaunal invertebrates on a global scale. His synthesis of the available data on infaunal distributions encouraged many studies which all described "parallel communities." In a similar vein, Kutznetsov (1978) suggested that convergent feeding adaptations, or "morphological parallelism," could be used to classify benthic fauna.

Numerous authors have defined regions based on the distribution of infaunal communities (Cerame-Vivas and Gray 1966; Masse 1972; Boesch 1973; Buzas and Culver 1980; Franz and Merril 1980; Franz et al. 1981). The distribution of infaunal communities is generally related to environmental factors such as sediment grain size (Jones 1950; Gray 1974, 1981), sediment deposition (Lie 1974), depth, salinity (Chapman and Brinkhurst 1981), oxygen (Levings 1980; Tunnicliffe 1981), and organic matter (Brinkhurst 1991; Brinkhurst et al. 1994). Epifaunal communities are often described in terms of water motion, exposure, substrate type, and biotic interactions (Paine 1974; Foster et al. 1988; Schoch and Dethier 1996). Reviews of infaunal community structure can be found in Gray (1974, 1981), Burd (1991), and Snelgrove and Butman (1994). A review of the factors affecting intertidal epifaunal communities can be found in Foster et al. (1988) and Ricketts et al. (1985).

There are numerous examples of infaunal community classification. Pocklington and Tremblay (1987) used polychaete presence/absence data in a cluster analysis to identify three distinct faunal zones in the Northwest Atlantic. The northernmost Labrador Zone was strongly affected by the cold Labrador Current and had fewer species than the other zones. The Acadian Zone was affected by the stratified waters of Gulf of St. Lawrence and Nova Scotia Current. The Acadian Zone shared an equal number of species with the Labrador and the Virginian Zone, but also had a unique suite of species. The Virginian zone was the most diverse and included species typical of warmer southern water.

Pocklington and Tremblay (1987) defined faunal provinces as regions with communities of characteristic taxonomic composition (with or without high levels of endemism). Using polychaete distribution, they identified two provinces between Hudson Strait and Cape Hatteras: the Arctic and Boreal provinces. They viewed the Labrador Zone as being part of the larger Arctic Province which extended north. The Acadian and Virginian Zones made up the Boreal Province, because they displayed a much greater species diversity than the Labrador Zone. These divisions agree with those reported by other researchers, suggesting that similar factors may have affected invertebrate distribution along the east coast of North America.

Dunbar et al. (1980) described and mapped the distribution of marine communities in the Gulf of St. Lawrence. Using biological and physical parameters, they described the Gulf in terms of shoreline features, bathymetry, water masses and circulation, surface temperature, salinity, oxygen, ice cover, tides, sediments, primary production, ice biota, birds, mammals, fishes, benthos, seaweed, and plankton. Dunbar and colleagues drew distributional maps and evaluated the general distribution patterns of each criteria. These subjective evaluations were then used to identify different biogeographical regions. The species used to delineate the biogeographic regions fell into three major groups, which were divided into 11 non-exclusive faunal zones.

Faunal distributions in fjords have also been classified. The distribution of molluscs in Norway was examined along a fjord/offshore gradient by Buhl-Mortensen and Hoisaeter (1993). The distribution of molluscs collected at 10 stations along the fjord was related to environmental variables. At each station, a total of 15 environmental variables were recorded under the headings of grain size, organic matter, C/N ratios, and depth. Samples were numerically classified, and fell into 3 groups representing the offshore region, the outer fjord, and the inner fjord. Most of the observed variance between groups was explained by sill depth (restricting larval dispersal), sediment type, and distance from the offshore area. Thus distribution patterns were best explained in terms of dispersal and habitat.

Hansen and Ingolfsson (1993) examined species distribution in rocky intertidal communities in the subarctic fjords of Iceland. They used a number of statistical techniques to identify community types along 20 transects. Species distributions were related to environmental factors, including a fjord index (position along the fjord), substrate roughness, slope, and wave exposure. Classification of the 20 transects resulted in 5 nondistinct community types which were related to the fjord index. They were unable to draw clear conclusions about the distribution of community types in Icelandic fjords, but point out that the communities resembled subarctic communities throughout the north Atlantic.

Ardisson and Bourget (1992) examined the temporal and spatial patterns of recruitment of intertidal invertebrates in the estuary and Gulf of St. Lawrence. They found that 12 species could be used to characterize the entire Gulf–Estuary area, and that the most striking changes in community composition and distribution coincided with physical and hydrographic changes along an estuary gradient.

Benthic community structure has been relatively well studied in the Strait of Georgia (e.g., Ellis 1971). Early descriptions of benthic communities in the Georgia Basin include those of Shelford and Towler (1925 *in* Shelford 1935) and Shelford (1935); both of these studies describe major community types based on characteristic species assemblages. Soft-sediment communities in Puget Sound were described by Lie (1974) who attempted to identify ecologically significant groups, and examined the relationship between communities and environment. Bousfield (1957) classified communities based on sediment type. Swinbanks (1979) examined the environmental factors affecting communities of animals and plants living within and on sediments at Robert's Bank and Boundary Bay. Rocky shores were described by Stephenson and Stephenson (1972) as part of their global analysis of intertidal zonation. Lambert (1994) describes general invertebrate community types and anthropogenic factors threatening invertebrate communities.

Levings et al. (1983) divide the Strait of Georgia into major habitat types. They review studies conducted in intertidal habitats including, rocky shores, mudflats, and vegetated intertidal areas. Subtidal habitats included those shallower than 20 m, and those greater than 20 m. Habitats greater than 20 m deep were further divided into basins, channels, and fjords. They concluded that the distribution of benthic communities in the Strait of Georgia is partly determined by sediment type, depth, and water-column characteristics and partly by biological factors. Levings and Thom (1994) assessed habitat loss in the Strait of Georgia and Puget Sound. To accomplish this, they divided the Strait of Georgia/Puget Sound into nine categories of aquatic habitat. These categories included sand, mud, marsh, riparian vegetation, unvegetated subtidal, eelgrass, intertidal algae, kelp beds, and rock/gravel.

Based on his study of Puget Sound, Lie (1974) concluded that discrete communities were absent in Puget Sound, despite the presence of strong environmental gradients. This is in contrast to the distinct communities described in the deep basins of the Strait of Georgia by Bernard (1978). Bernard subjectively identified six community types based on the macrofauna collected from 300 stations. Bernard's communities were based on dominant species, which he felt were most related to sediment type. He noted that the most varied communities were found in areas of greatest substrate diversity. Bernard's community types roughly agree with the three general substrate categories — coarse, fine, and diamicton (diamicton = gravel, sand, and mud) — described by Luternauer et al. (1983). Ellis (1969) described "ecologically significant" components of sediment communities in the Strait of Georgia but did not identify discrete community types. Ellis (1969) based his communities on his research in the Strait of Georgia (Ellis 1967, 1968a, 1968b, 1968c).

Burd (1991) compared benthic samples collected from six geographically distant areas (two in the Strait of Georgia) to nullify the hypothesis that large and small macrofauna were distributed differently under differing environmental conditions. The comparisons were made by statistically comparing both the abundance and biomass of species at each site. Data were analyzed using a cluster analysis and a bootstrap method to test for significant differences among the resulting clusters. Both biomass and species data were compared to environmental data available for each of the six sites. In the overall analysis, most stations within a given area remained grouped with samples nearest them. Burd (1991) suggested that the distribution of the benthic fauna studied was spatially conservative, but showed clear environmentally-related patterns, despite considerable geographic distance among sites. She further suggests that analyses of this type may be useful in identifying general benthic community types (Burd 1991).

Foreman (unpub. *in* Levings et al. 1983) identified five faunal assemblages on shallow rocky substrates in the Strait of Georgia. The assemblages were delineated in terms of depth, and were compared to algal assemblages identified by Lindstrom and Foreman (1978). The invertebrate and algal communities overlapped, suggesting similar factors affected the distribution of all the assemblages (Levings et al. 1983).

Marliave and Roth (1995) examined the use of the kelp *Agarum* as a nursery area by prawns, and demonstrated another link between epifaunal and algal communities. *Agarum* was typical of the deep-algal community described by Lindstrom and Foreman (1978). Dayton (1975) concluded that *Agarum* was restricted to deep water because it was out-competed by other species of kelp.

The distribution of species in fjords adjoining the Strait of Georgia has been examined by Tunnicliffe (unpub. *in* Levings et al. 1983), Burd and Brinkhurst (1992), Burd (1991), and Farrow et al. (1983). Farrow et al. (1983) examined the distribution of cliff-dwelling suspension and filter-feeding invertebrates in Knight Inlet. They found that particulate matter, coming from meltwater, influenced the abundance of the two feeding groups. As particulate load decreased nearer the mouth of the inlet, the abundance of filter-feeding organisms increased. Levings et al. (1983) describe three types of epilithic communities found in BC fjords. Pickard (1961) classified the inlets (fjords) of mainland BC based on runoff. Inlets with medium or small runoff had high surface salinities and poorly marked haloclines and thermoclines. In contrast, inlets with large runoffs had lower surface salinities and more clearly-defined haloclines and thermoclines. Furthermore, large runoff inlets had higher and more variable dissolved oxygen levels (Pickard 1961). These characteristics can affect biotic community composition (e.g., Stockner et al. 1977). The concept of classifying inlets by runoff characters is important because it links the watershed (a terrestrial component) to the estuary or inlet (a marine component).

Although spatial changes in faunal communities are usually classified, temporal changes must also be recognized. Snapshot pictures of benthic communities may represent a frozen picture of a community in change. Chapman and Brinkhurst (1981) described seasonal shifts in the composition and distribution of infaunal communities (oligiochaetes) in the Fraser River Estuary. They were able to relate changes in seasonal fluctuations to interstitial salinities. Nyblade (1979) described long-term changes in discrete intertidal communities structure in the San Juan Islands.

4.7 Classifying Benthic Algae and Eelgrass Communities

Physical and biological factors affect the distribution of benthic algae (including sea grasses). Environmental parameters include light, water motion, depth, substrate and temperature, salinity and nutrients (Druehl 1967, 1978; Druehl and Hsiao 1977; Foster and Schiel 1985; Schiel and Foster 1986; Foster et al. 1988; Morris 1996). Biological factors include grazing, competition (including the introduction of exotic species), and disease (Foreman 1977; Harrison 1982a, 1982b; Carlton and Geller 1993; Watson 1993). Ecological reviews of marine plants can be found in Philips (1984-eel grass), Foster and Schiel (1985-kelp), Schiel and Foster (1986-kelp), and Foster et al. (1988-intertidal algae).

The geographic distribution of algae is probably controlled by broad-scale oceanographic conditions (Scagel 1963; Druehl 1981; Bolton 1994 - see earlier section). There are no clear-cut biogeographical changes in algal distribution in British Columbia, although the southern extent of some northern species occurs in B.C., as does the northern extent of some southern species (Scagel et al. 1989). At a smaller scale, algal distribution is controlled by various local environmental factors (Druehl and Hsiao 1977; Druehl 1978). *Macrocystis* for example, is excluded from the Strait of Georgia by the combination of warm and low salinity water during the summer (Druehl 1978). Algal distribution can also be affected by substrate type.

The distribution of intertidal algae is frequently attributed to physical parameters (Foster et al. 1988; Foster 1990). Fuller et al. (1991) described six species assemblages on rocky intertidal coasts of Ireland and proposed that the distribution of these communities was related to both physical and biological factors. Recently, Schoch and Dethier (1996) tried to infer the distribution of intertidal species over large areas using geomorphological data. They categorized complex shorelines into distinct sections with similar abiotic features. The sections were clustered (using geomorphological features) into groups with similar habitats. They analyzed the relationship between the geomorphological features and the biotic communities and found that biotic assemblages could be predicted based on substrate characters. Shoreline slope and specific substrate type explained much of the variation in the distribution of intertidal plants and animals (Schoch and Dethier 1996).

Algal communities in subtidal regions have also been classified on a regional level. Anderson and Stegenga (1989) described three community types on the Eastern Cape of South Africa. Although they sampled only 31 quadrats, analyses revealed three algal communities that could be described in terms of exposed, semi-exposed, and sheltered conditions. Hily et al. (1992) described five algal assemblages growing on soft substrate and shells. The algal communities extended along an exposure gradient. Frequent winter storms disrupted some areas more frequently than others, and resulted in community structure that also reflected algal succession and grazing pressure, essentially a temporal gradient.

Watson (1993) examined temporal changes in algal community structure and classified algal communities off NW Vancouver Island based on biomass and species composition. Using a cluster analysis, she identified three distinct community types that could be defined in terms of age: early successional (0-5 yrs), stable climax (>5 -10 yrs), and declining climax (>10 yrs). This emphasizes the importance of the temporal component in ecosystem or community classification.

In the Strait of Georgia algae were first collected and described in the early 1900s (Scagel et al. 1989; Hawkes 1994b). Commercial kelp beds between Denman Island and Oyster River were mapped in the early 1970s as part of a provincial project identifying commercial algae stocks (Levings et al. 1983). This research included delineation of intertidal and shallow subtidal algal communities in the northern Strait of Georgia. The B.C. Ministry of Agriculture, Fisheries and Food has recently updated and digitized kelp-bed maps for coastal British Columbia., including the Strait of Georgia (see Truscott 1996).

Lindstrom and Foreman (1978) investigated benthic community structure and productivity within the Strait of Georgia. They described intertidal and subtidal algal communities off Bath

Island in the Central Strait. Six methods of classification were used. Classification by species produced six community types that could be described in terms of desiccation, substrate-type, and light.

Foreman (1977) defined 10 general algal community types within the Strait of Georgia (Foreman 1977; Foreman and Kallahin 1994). These community types were clearly identified by characteristic species, but also represented successional stages that ranged from assemblages dominated by encrusting coralline algae ("urchin barrens") to well-developed kelp communities dominated by *Laminaria* spp. Foreman (1977) followed algal succession after a green urchin grazing event, and concluded that algal communities went through a predictable successional sequence, which resulted in a climax community determined by depth (Foreman 1977, 1984).

Morris (1996) developed a predictive model of nearshore subtidal habitat. She used biological data collected by Foreman (Foreman and Root 1975; Foreman 1975, 1976, 1977, 1979) to define algal assemblages and the Physical Shore Zone Mapping System (see earlier section) to define physical parameters. She identified nine algal community types that were linked to four substrate types and four depth intervals. The model was tested by using it to predict nearshore substrates from the shore-zone parameters collected from eight subtidal transects from Saltery Bay Provincial Park. Morris predicted algal community types using the nearshore substrate predicted by the model. She found that algal assemblages could be best predicted for three general habitat types: 1) shallow (<5 m) bedrock boulder substrate 2) shallow (<7 m) sand, mud pebble substrate, and 3) deeper (>5 m) boulder/ bedrock. She concluded that her nearshore subtidal biophysical classification model could be used to generally predict nearshore habitat in wave-exposed areas within the Strait of Georgia.

Eelgrass communities occur in shallow coastal embayments and estuaries of the northern hemisphere and represent one of the most productive ecosystems in the world (Phillips 1984). Eelgrass is important in stabilizing coastal sediments (Phillips and McRoy 1980; Phillips 1984), provides a direct and indirect source for detrital-based nearshore food webs (Sibert et al. 1977; Sibert 1979), provides habitat and protection for many marine species (e.g., Healey 1979; Baldwin and Lovvorn 1994; Connolly 1994; Thom et al. 1995), and acts as important cyclers of nutrients (see Phillips and McRoy 1980). Classification of eelgrass habitat often falls under estuarine classification, because eelgrass is an important component of many estuaries (see earlier section).

One of the most threatened habitat types within the Strait of Georgia may be estuarine habitats including eelgrass beds (Copping et al. 1994). Levings and Thom (1994) attempted to estimate the overall loss in eelgrass habitat from the Strait of Georgia and Puget Sound. In most cases, eelgrass habitat loss is attributed to harbour and port development (Levings 1991) or changes in water flow (Jay and Simenstad 1994). The most extensive eelgrass beds occur in Boundary Bay and Roberts Bank (Ward et al. 1992). A variety of smaller eelgrass beds also occur, but have been less well studied and characterized (see Natio 1987; Feakins 1991).

Classification of eelgrass beds must consider temporal changes in eelgrass density and production on both a seasonal and longer-term scale. Nelson (1997) found that eelgrass biomass and productivity in Washington State increased during the 1991–1992 El Niño event. Eelgrass density and production has been related to seasonal changes in irradience and water turbidity (Thom and Albright 1990). In many cases the species composition of eel grass beds has also changed with the introduction of *Zostera japonica* into the Strait of Georgia/Puget Sound

(Harrison 1982a). *Zostera japonica* is generally found higher in the intertidal zone than the native species *Z. marina*. Changes in eelgrass abundance (*Zostera* spp.) and species composition may result in changes in community structure, especially in the composition of the infaunal community (Harrison 1987; Posey 1988).

The fauna of eelgrass beds has been well studied. Sibert and Reimer (1976) examined the sediment structure of the Nanaimo River estuary, which contained eelgrass. Sibert later examined epifauna in terms of sediment type (Sibert 1979), and recognized the importance of eelgrass detritus in driving estuarine food webs (Sibert et al. 1977). Kichuki (1966, 1980, *in* Phillips 1984) divided the fauna of a Japanese eelgrass ecosystem into permanent residents, seasonal residents, transients, and causal species. In contrast, Thayer et al. (1975) classified the faunal community associated with the eelgrass ecosystem into guilds, including deposit feeders and suspension feeders. In a similar manner, Stauffer (1937) organized the faunal community into functional groups, which were not related to taxonomy. These groups included epiphytes, epibenthos, infauna, and nekton.

5.0 SUMMARY

Coastal marine ecosystems are very diverse and productive. Human activities causing habitat loss, pollution, over-exploitation, introduction of exotic species, and global climate change presently threaten these systems (Clark 1974; Waldichuk 1983; Bakun 1990; Carlton and Geller 1993; Hallegraff 1993; Suchanek 1994; Taylor and Horner 1994; Schmitt et al. 1994; West et al. 1994; Mahaffy et al. 1994; Harrison et al. 1994; Johnson et al. 1994; Wilson et al. 1994; Beamish et al. 1995). The British Columbia/ Washington Marine Science Panel (Copping et al. 1994) identified habitat loss as the single most serious threat to the Strait of Georgia/Puget Sound, and recommended that nearshore/estuarine habitat, representing ecosystem diversity, be protected.

The IUCN defines a protected area as an area "of land and or sea especially dedicated to the protection and maintenance of biological diversity and associated natural resources ...". Increasingly, protected areas are becoming an important component of conservation initiatives around the world (Norse 1995). Under Canada's *Oceans Act*, MPAs can be established for a number of purposes; as a management tool in commercial fisheries, to protect species and their habitats, to conserve endangered or threatened species, to maintain environmental quality, and to provide undisturbed areas for monitoring and research. Marine Protected Areas may provide a tool that can be used to help meet the various components of the *Oceans Act*. The joint Federal Provincial Marine Protected Areas Strategy has been created to help select and create marine protected areas that are representative areas of B.C.'s marine ecosystems (B.C. Government 1993).

Canada's *Oceans Act* advocates using the ecosystem principle to establish marine reserves. This emphasizes that ecosystems, rather than individual species or habitats, be protected. Marine reserves must be selected to represent the diversity of communities found within the Strait of Georgia ecosystem(s). This will require that the Strait of Georgia, and its biological communities and processes, are identified and classified into ecosystems.

The marine environment is more complex and dynamic than terrestrial ecosystems, consequently terrestrial classification systems are not appropriate for marine ecosystems (Steele

1991b). At present there are no generally agreed-upon classification system for marine ecosystems.

To be useful, a classification system must be scientifically rigorous, hierarchical, and must clearly delineate repeating ecological units within an ecosystem (Orians 1993). In general, most classification systems use physical parameters to identify large-scale (coarse grain) areas with similar physical attributes, and use biological criteria to identify repeating biological communities on a small scale (fine grain).

The IUCN has developed a biogeographical classification system that uses oceanographic features and zoogeographic provinces to produce a global classification system (Hayden et al. 1984). The Large Marine Ecosystems, used mostly in fisheries management, delineates 49 marine regions that encompass coastal areas out to the edge of the continental shelf. Both of these are global systems that do not identify regional community types.

The Marine Ecological Classification System for Canada (MEC), used by Environment Canada, is a hierarchical system that identifies 10 unique Marine Ecodistricts in B.C. The Strait of Georgia comprises one of these Ecodistricts. The British Columbia Marine Ecosystem Classification system, which is derived from the MEC, is a five-tiered system developed by the provincial government. It includes, at its lowest level, 619 Ecounits that are defined based on current regimes, subsurface relief, seabed substrate, and wave exposure. The applicability of the Ecounit-level of classification to identify Ecounit types that are under-represented by protected areas (including parks, etc.) has been tested in the Strait of Georgia (Zacharias et al. in press). The Physical Shore-zone Mapping system for B.C. and the Biological Shore-zone Mapping System have been used to identify Ecounits within the BCMEC (Howes et al 1994; Zacharias et al. unpub.).

There are numerous examples of regional classifications of ecosystems. Most of these studies identified biological communities within an ecosystem and correlated community occurrence with physical factors. In many cases clear patterns are not apparent, which underscores the difficulty in clearly delineating general community types. In general, low-trophic level organisms such as phytoplankton and zooplankton were highly variable in space and time, but were easily delineated using physical variables such as temperature, light, nutrient-level, productivity, and turbidity.

Bird distributions were one of the biological features used in the delineation of the MEC (MEQAG 1994). Large mobile animals such as whales and pinnipeds generally fall outside the classification schemes (Taylor and Roff in press). However, their food sources may represent a parameter used to classify communities. Springer et al.(1996) found that zooplankton abundance was an excellent predictor of fish, whale, pinniped, and bird distribution. Likewise Laws (1985) reported a similar pattern for the short-chained marine ecosystem he described in the Antarctic. Thus, although high trophic level predators may not be classified, the classification may identify ecological regions or communities that are important to them (see Tanasichuk 1995).

At the largest scale of resolution, the boundaries of biogeographical regions describe the distribution of many species. At the regional scale, boundaries may be taxon-specific; for example, the distributions described for the kelp in the Strait of Georgia may not agree with the boundaries described for the urchins. Physical parameters are often included to overcome this problem. However, characterizations based on environmental parameters assume that environmental homogeneity will lead to homogeneity in the structure and processes within the community. This is generally true for terrestrial plants, but may not be true for animals, and is unknown for the marine environment (Heywood and Watson 1995).

Even though most regional-scale classifications have apparently focused on the description of benthic communities, this usually involves sedentary invertebrates whose distributions appear to be hard to delineate. In many cases, subtidal species are hidden from view and their distributions are incompletely or poorly known. In the case of intertidal organisms, biological interactions between species and interactions with the environment may be unpredictable (Foster et al. 1988; but see Schoch and Dethier 1996). Additionally, temporal variability in community composition and distribution must be incorporated into classification systems. This will provide a major challenge to the classification of many systems (e.g., Tegner and Dayton 1987).

Efforts to ensure environmental quality, to integrate management strategies, and to establish protected areas in the marine environment lags behind terrestrial efforts in concept, management, and public awareness (Heywood and Watson 1995). In the past, the focus of marine conservation has largely been on the protection of large charismatic animals rather than on ecosystems. The ecosystem approach to marine conservation and management will ensure that the environmental quality of marine ecosystems, along with essential functions and components, are protected.

LITERATURE CITED

Agardy, M.T. 1994. Advances in marine conservation, the role of marine protected areas. Trends in Ecology and Evolution 9:267–270.

Alexander, L.M. 1993. Large marine ecosystems: A new focus for marine resources management. Marine Policy 17:186–198.

Anderson, R.J., and H. Stegenga. 1989. Subtidal algal communities at Bird Island Eastern Cape, South Africa. Botanica Marina 32:299–311.

Angel, M.V. 1994. Long-term, large-scale patterns in marine pelagic systems, pp. 403–439. In Giller, P.S., A.G. Hildrew, and D.G. Raffaelli [eds.]. Aquatic ecology: scale pattern and process. Aquatic Ecology, Proc. of the 34th symposium of the British Ecological Society, Cork, 1992. Blackwell Scientific Pub. 649 p.

Apollonio S. 1994. The use of ecosystem characteristics in fisheries management. Rev. Fish. Sci. 2(2):157–180.

Arai, M.N., and J.C. Mason. 1982. Spring and summer abundance and vertical distribution of hydromedusae of the central Strait of Georgia, British Columbia. Syesis 15:7–15.

Ardisson, P.L., and E. Bourget. 1992. Large-scale ecological patterns: discontinuous distribution of marine benthic epifauna. Marine Ecol. Prog. Ser. 83:15–34.

Augier, H. 1982. Inventory and classification of marine benthic biocoenoses of the Mediterranean. Nature and Environment Series 25, Council of Europe, Strasbourg. 57 p.

Backus, R.H., and D.W. Bourne [eds.]. 1987. Georges Bank. MIT Press, Cambridge, Mass. 593p.

Bakun, A. 1990. Global climate change and the intensification of coastal upwelling. Science 247:198–201.

Bakun, A. 1993. The California Current, Benguela Current and Southwest Atlantic Shelf Ecosystems: A comparative approach to identifying factors regulating biomass yields, pp. 199–224. *In* Sherman K., L. Alexander, and B. Gold [eds.]. Large marine ecosystems: Stress, mitigation and sustainability. Am. Assoc. Advance. Sci., AAS Press, Washington, D.C.

Baldwin, J.R., and J. Lovvorn. 1994. Expansion of seagrass habitat by the exotic *Zostera japonica* and its use by dabbling ducks and brant in Boundary Bay, British Columbia. Marine Ecology Progress Series 103:119–127.

Banner, A., and J. Pojar. 1987. Ecosystem classification of the coastal western hemlock zone, hypermaritime subzone within the midcoast, northcoast and Queen Charlotte Islands timber supply areas. [Authors' preliminary draft.]

Barange, M., S.C. Pillar, and L. Hutchings. 1992. Major pelagic borders of the Benguela upwelling system according to euphausiid species distribution, pp. 3–17. *In* Payne A., K.H. Brink, K.H. Mann, and R. Hilborn [eds.]. S. Afr. J. Mar. Sci. 12:3–17.

Barnes, C.A., and C.C. Ebbesmeyer. 1978. Some aspects of Puget Sound's circulation and water properties, pp. 209–228. *In* Kjerfe, B. [ed.]. Estuarine transport processes, Univ. South Carolina Press, Columbia, S.C.

Bary, B. McK. 1961. Diel vertical migrations of underwater scattering mostly in Saanich Inlet, British Columbia. Deep-Sea Res. 14:35–50.

Bary, B. McK. 1963. Distributions of Atlantic pelagic organisms in relation to surface water bodies, pp. 51–67. *In* Dunbar, M.J [ed.]. Marine Distributions. Univ. Toronto Press, Downsview, Ont.

Bary, B. McK., and R.E. Pieper. 1970. Sonic scattering studies in Saanich Inlet, British Columbia: a preliminary report, pp. 601–611. *In* Farquhar G.B. [ed.]. Proc. of the International Symposim on Biological Sound Scattering in the Ocean. Maury Centre for Ocean Science MC Rep 005.

Bax, N.J., and T. Laevastu. 1990. Biomass potential of large marine ecosystems: A systems approach, pp.189–205. *In* Sherman K., L.M. Alexander and B.D. Gold. [eds.]. Large marine ecosystems, patterns, processes and yields. American Association for the Advancement of Science. Washington D.C.

Beamish, R.J and C.M. Neville. 1995. Large-scale climate-related changes in the carrying capacity for salmon in the Strait of Georgia. Abstract, p. 141. *In* Tang, Q., and K. Sherman. [eds.]. The Large Marine Ecosystems of the Pacific Rim: A report of a symposium held in Quingdao, People's Republic of China, 8–11. October 1994. A Marine Conservation and Development Report. IUCN, Gland, Switzerland. x + 168 p. (authors are incorrectly listed in publication.)

Beamish, R.J., B.E. Riddell, C. M. Neville, B.L. Thomson, and Z. Zhang. 1995. Declines in Chinook salmon catches in the Strait of Georgia in relation to shifts in the marine environment. Fish. Oceanogr. 4:3:243–256.

Begon, M., J.L. Harper, and C.R. Townsend 1996. Ecology: Individuals, populations and communities. 3rd ed. Blackwell Science, Oxford.

Bellan-Santini, D. 1985. The Mediterranean benthos: Reflections and problems raised by a classification of the benthic assemblages, pp.19–48. *In* M. Moraitou-Apostolopoulou and V. Kiorrtsis [eds.]. Mediterranean Marine Ecosystems. NATO Advanced Research Institute workshop on Mediterranean Marine Ecosystems. NATO. Conf. Ser. 1 (Ecol) Vol 8.

Bernard, F.R. 1978. British Columbia faunistic survey: subtidal and deepwater megafauna of the Strait of Georgia. Can. Fish. Mar. Serv. Manuscr. Rep. 1488 41 p.

Boesch, D.F. 1973. Classification and community structure of the macrobenthos in the Hampton Roads area, Virginia. Mar. Bio. 21:226–244.

Bolton, J.J. 1994. Global seaweed diversity: patterns and anomalies. Botanica Marina 37:241–245.

Booth, J., D. Hay, and J. Truscott. 1996. Standard methods for sampling resources and habitats in coastal subtidal regions of British Columbia. Part 1: Review of mapping with preliminary recommendations. Can Tech. Rep. Fish Aquat. Sci. 2118. 53 p.

Bortelson, G.C., M.J. Chrzastowski, and P. Hickey 1980. Historical changes of shoreline and wetland at eleven major deltas in the Puget Sound Region, Washington. U.S. Dep. Interior, U.S. Geological Survey. Atlas HA-617.

Bourgeron, P.S. 1988. Advantages and limitations of ecological classification for the protection of ecosystems. Cons. Biol. 2:218–220.

Bousfield, E.L. 1957. Ecological investigations of shore invertebrates of the Pacific coast of Canada. Natl. Mus. Can. Bull. 147:105–155.

Braun-Blanquet, J. 1965. Plant Sociology: The study of plant communities. Hafner, New York, N.Y.

Briggs, J.C. 1974. Marine Zoogeography. McGraw-Hill, New York, N.Y. 475 p.

Brinkhurst, R.O. 1991. Benthic ecology on the west Canadian continental shelf. Cont. Shelf. Res. 11:8–10:737–754.

Brinkhurst, R.O., E. Cassilas, and J.Q. Word. 1994. Marine benthos of British Columbia Washington State boundary waters, pp. 187–204. *In* Wilson, R.C.H., R.J. Beamish, F. Aitkens, and J. Bell [eds.]. Review of the marine environment and biota of Strait of Georgia, Puget Sound and Juan de Fuca Strait: Proc. of the BC/Washington Symposium on the Marine Environment, Jan 13 & 14, 1994. Can. Tech. Rep. Fish. Aquat. Sci. 1948.

Brisbal, G.A. 1995. The Southeast South American shelf large marine ecosystem: Evolution and components. Mar. Policy. 19:1:21–38.

British Columbia Government. 1993. A protected areas strategy for British Columbia. Victoria, B.C.

British Columbia Government. 1996. Initiatives for the conservation of biodiversity in British Columbia, Victoria, B.C. 30 p.

Brodeur, R.D., and D.M. Ware. 1992. Long-term variability in zooplankton biomass in the subarctic Pacific Ocean. Fish. Ocean. 1:1:32–37.

Brosnan, D.M. 1995. Integrating science and policy: The Oregon territorial sea plan as a case study. Recent Advances in Marine Science and Technology.

Brunckhorst, D.J., and P.B. Bridgewater. 1995. Marine bioregional planning: A strategic framework for identifying marine reserve networks and planning sustainable use and management. Marine Protected Areas and Sustainable Fisheries. Acadia Univ. Press, Toronto, Ont.

Buchanan, R.J. 1966. A study of species composition and ecology of the protoplankton of a British Columbia inlet. PhD thesis. Univ. British Columbia, Vancouver, B.C.

Bucher, D., and P. Saenger. 1994. A classification of tropical and subtropical Australian estuaries. Aquat. Conserv. Mar. Freshwat. Ecosyst. 4:1:1–19.

Buhl-Mortensen, L., and T. Hoisaeter. 1993. Mollusk fauna along an offshore - fjord gradient. Mar. Ecol. Prog. Ser. 97:209–224.

Bulger, A., B.P. Hayden, M.G. McCormick-Ray, M.E. Monaco, and D.M. Nelson. 1990. Towards a biogeographic estuarine salinity classification. NOAA Strategic Assessment Branch, Rockville, MD

Burd, B.J. 1991. Qualitative and quantitative studies of benthic infaunal communities in B.C. coastal waters. Ph.D. thesis, Univ. Victoria, Victoria, B.C. 375 p.

Burd, B., and R.O. Brinkhurst. 1992. Benthic infaunal surveys of British Columbia fjords 1988 to 1990. Report of Hydrography and Ocean Sciences 114:1–37.

Burger, A., J.A. Booth, and K. Morgan. 1997. A preliminary identification of processes and problems affecting marine birds in coastal and offshore areas of British Columbia. Can. Wildlife Serv., Pacific and Yukon Region. Tech. Rep. Ser. No. 277.

Burroughs, R.H., and T.W. Clark. 1995. Ecosystem management: A comparison of Greater Yellowstone and Georges Bank. Env. Manage. 19:5:649–663.

Buzas, M.A., and S.J. Culver. 1980. Foraminifera: distribution of provinces of the western north Atlantic. Science 209:687–689.

Caddy, J.F. 1993. Contrast between recent fisher trends and evidence for nutrient enrichment in two large marine ecosystems: The Mediterranean and the Black Seas, pp. 137–147. *In* Sherman K., L. Alexander, and B. Gold [eds.]. Large Marine Ecosystems: Stress, Mitigation and Sustainability. American Association for the Advancement of Science. AAS Press, Washington, DC. 376 p.

Caddy, J.F., and A. Bakun. 1994. A tentative classification of coastal marine ecosystems based on dominant processes in nutrient supply. Ocean. Coast. Manage. 23:(3):201–211.

Carpenter, D.J., and S.M. Carpenter. 1979. A comparison of optical and biochemical classifications of ocean waters. Deep. Sea. Res. 26(7A):763–773.

Carlton, J.T., and J.B. Geller. 1993. Ecological Roulette: The global transport of nonindigenous marine organisms. Science 261:78–82.

Carr, M.H., and D.C. Reed. 1993. Conceptual issues relevant to marine harvest refuges: Examples from temperate reef fishes. Can. J. Fish. Aquat. Sci. 50:2019–2028.

Caughley, G., and A. Gunn. 1996. Conservation biology in theory and practice. Blackwell Science.

Cerame-Vivas, M.J., and I.E. Gray. 1966. The distribution pattern of benthic invertebrates of the continental shelf of North America. Ecology 47:260–270.

Chapman, P.M., and R.O. Brinkhurst. 1981. Seasonal changes in interstitial salinities and seasonal movements of subtidal benthic invertebrates in the Fraser River estuary, B.C. Estuarine Coastal and Shelf Sci. 12:49–66.

Clark, C.W. 1996. Marine reserves and the precautionary management of fisheries. Ecol. App. 6(2)369–370.

Clark, J. 1974. Coastal ecosystems: Ecological considerations for management of the coastal zone. The Conservation Fund, Washington, D.C.

Clements, F.E. 1916. Plant Succession: An analysis of the development of vegetation. Carnegie Institution.

Cole, J., G. Lovett, S. Findlay [eds.]. 1989. Comparative Analyses of Ecosystems: Patterns Mechanisms and Theories. Springer Verlag, New York, N.Y.

Connolly, R.M. 1994. A comparison of fish assemblages from seagrass and unvegetated areas of a southern Australia estuary. Aust. Jour. Mar. Freshwat. Res. 1994. 45:1033–1044.

Copping, A., R.J. Beamish, C. Ebbesmeyer, C. Garrett, B. McCain, and T. Pedersen. 1994. The shared marine waters of British Columbia and Washington. Rep. to B.C./Washington Environmental Cooperation Council by the B.C./Washington Marine Science Council, Aug. 1994.

Connor, D.W., K. Hiscock, R. L. Foster-Smith, and R. Covey. 1995. A classification system for benthic marine biotopes, pp. 155–166. *In* Eleftheriou, A., A. D. Ansell and C. J. Smith [eds.]. Biology and Ecology of Shallow Coastal Waters. European Marine Biology Symp. Hersonissos, Crete, (Greece), 1993. Olsen and Olsen, Fredensborg-Denmark.

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. Fish and Wildlife Service, U.S. Dep. Interior. FWS/OBS-79/31 59 p.

Cowardin, L.M., and C.F. Golet. 1995. US Fish and Wildlife Service 1979 Wetland Classification: A Review. Vegetatio 118:139–152.

Crean, P.B., T.S. Murty, and J.A. Stronach. 1988. Mathematical modelling of the tides and estuarine circulation: The coastal seas of southern British Columbia and Washington State. *In* Bowman M.J. et al. [eds.]. Lecture notes on Coastal and Estuarine Studies 30. Springer Verlag. 471 p.

Croom, M.M., R.J. Wolotira, and W. Henwood. 1992. Proposed biogeographic subdivision of the Northeast Pacific marine realm. Unpub. rep. subm. to IUCN, Lauzanne, Switzerland. 35 p.

Dagg, M. 1993. Grazing by the copepod community does not control phytoplankton production in the subarctic Pacific Ocean. Prog. Oceanog. 32:163–183.

Dauvin, J.C., G. Bellan, D. Bellan-Santini, A. Castric, J Comolet-Tirman, P. Francour, F. Gentil, A Girard, S. Gofas, C. Mahe, P. Noel, and B. de Reviers. 1994. Typologie des ZNIEFF-Mer. Liste des parameters et des biocoenoses des cotes francaises metroplitaines - Collection

Patrimoines Naturels Vol. 12 Secretariat Faune-Flore Museum National d'Histoire Naturelle, Paris. 70 p.

Davis, D.S. 1995. A systems approach to the identification of marine protected areas. Marine Protected areas and sustainable fisheries. Acadia Univ. Press, Toronto, Ont.

Davis, F., and W.A. Reiners. 1996. The nature of GAP analysis. BioScience 46:390–394.

Dayton, P.K. 1975. Experimental studies of algal canopy interactions in a sea otter-dominated community at Amchitka Island, Alaska. Fish. Bull. 73:230–237.

de Candolle, A.P.A. 1874. Constitution dans le regne vegetal des groupes physiologiques applicables a la geographie ancienne et moderne. Archives des Sciences Physiques et Naturelles, Geneva Switzerland.

de Lafontaine Y., S. Demers, and J. Runge. 1991. Pelagic food web interactions and productivity in the Gulf of St. Lawrence: A perspective. *In* J.C. Therriault [ed.]. The Gulf of St. Lawrence: small ocean or big estuary? Can. Spec. Publ. Fish. Aquat. Sci. 113:99–123.

Demarchi, D.A., R.D. Marsh, A.P. Harcombe, and E.C. Lea. 1990. The environment, pp. 55–144. *In* Campbell, R.W., N.K. Dawe, I. McTaggart Cowan, J.M. Cooper, G.W. Kaiser, and M.C.F. McNall [eds.]. The Birds of British Columbia, Vol. 1. Royal BC Museum, Victoria, B.C.

Denman, K.L., H.L. Freeland and D.L. Mackas. 1989. Comparisons of time scales for biomass transfer up the marine food web and coastal transport processes, pp. 255–264. *In* R.J. Beamish and G.A. McFarlane [eds.]. Effects of ocean variability on recruitment and an evaluation of parameters used in stock assessment models. Can. Spec. Publ. Fish. Aquat. Sci. 108.

Denman, K.L., and T.M. Powell. 1984. Effects of physical processes on planktonic ecosystems in the coastal ocean. Oceanogr. Mar. Biol. Ann. Rev. 22:125–168.

Department of Fisheries and Oceans Canada (DFO). 1997. An approach to the establishment and management of Marine Protected Areas under the *Oceans Act*: A discussion Paper. Jan. 1997.

Desrochers, B., G. Jamieson, C.D. Levings and B. Smiley. 1997. Shorekeepers' Guide to Surveying and Mapping Backshore and Intertidal Habitats, Plants and Animals: Coastal British Columbia. Technical Survey Module. Draft March 1997.

Dethier, M.N. 1990. A marine and estuarine habitat classification system for Washington State. Washington Natural Heritage Program. Department of Natural Resources, Olympia, Wash. 59 p.

Dethier, M.N. 1992a. Sampling biodiversity of the marine intertidal zone of the Olympic coast. The Northwest Environmental Journal 8:139–233.

Dethier, M.N. 1992b. Classifying marine and estuarine natural communities: An alternative to the Cowardin system. Nat. Areas. J. 12(2)90–98.

di Castri, F, A.J. Hansen, and M.W. Holland. 1988. A new look at ecotones. Emerging international projects on landscape boundaries. Biology International Special Issue 17, International Union of Biological Sciences, Paris.

Dietrich, D. 1963. General Oceanography: An introduction. Interscience Publishers. New York, N.Y. 588 p.

Digby, P.G.N., and R.A. Kempton. 1987. Multivariate Analysis of Ecological Communities. Chapman and Hall, London.

Dodimead, A.J., F. Favorite, and T. Hirano. 1963. Salmon of the North Pacific Ocean - Part II. Review of the oceanography of the subarctic Pacific Region. Int. North. Pac. Fish. Comm. Bull. 13. 195 p.

Dolan, R., B.P. Hayden, G. Hornberger, J. Zieman and M. Vincent 1972. Classification of the coast environments of the world Part I. The Americas. Univ. Virginia, Charlottesville, VI. 163 p.

Downing, J.P. 1983. The coast of Puget Sound: Its processes and development. Washignton Sea Grant Publication, Univ. Washington, Seattle, Wash.

Doyle, M.J. W.W. Morse, and A.W. Kendal. 1993. A comparison of larval fish assemblages in the temperate zone of the northeast Pacific and the northwest Atlantic Oceans. Bull. Marine Science 53:2:588–644.

Druehl L.D. 1967. Vertical distribution of some benthic marine algae in a British Columbia Inlet, as related to some environmental factors. J. Fish. Res. Board Can.

Druehl, L.D. 1978. The distribution of *Macrocystis integrifolia* as related to environmental parameters. Can. J. Bot. 56:69–79.

Druehl, L.D. 1981. Geographic distribution, pp. 306–325. *In* Lobban, C.S., and M.J. Wynne [eds.]. The biology of seaweeds. Univ. California Press, Berkeley, Calif.

Druehl, L.D., and S. Hsiao. 1977. Intertidal kelp response to seasonal environmental changes in a British Columbia inlet. J. Fish. Res. Board. Can. 34:1207–1211.

Dunbar, M.J., D.C. MacLellan, A. Filion, and D. Moore. 1980. The biogeographic structure of the Gulf of St. Lawrence. Marine Sciences Centre Manuscript No. 2, McGill Univ., Toronto, Ont.

Dugan, J.E., and G.E. Davis. 1993. Applications of Marine Refugia to Coastal Fisheries Management. Can. J. Fish. Aquat. Sci. 50:2029–2042.

Earll, R.C. 1992. The SEASEARCH habitat guide: an identification guide to the main habitats found in the shallow seas around the British Isles. Marine Conservation Society Britain. 119 p.

Ekman, S. 1953. Zoogeography of the sea. Sidgewick and Jackson, London. 417 p.

Ellis, D.V. 1967. Quantitative benthic investigations. I. Satellite Channel biomass summaries and major taxonomy rank orders. February 1965–May 1967. Fish. Res. Board. Can. Tech. Rep. 25.

Ellis, D.V. 1968a. Quantitative benthic investigations. III. Locality and environmental data for selected stations (mainly from Satellite Channel, Strait of Georgia and adjacent inlets). February 1965 – December 1967. Fish. Res. Board. Can Tech. Rep. 59.

Ellis, D.V. 1968b. Quantitative benthic investigations. IV. Biomass summaries and major taxon rank orders from selected stations (mainly from Satellite Channel, Strait of Georgia and adjacent inlets) February 1965 – December 1967. Fish Res. Board. Can. Tech. Rep. 60.

Ellis, D.V. 1968c. Quantitative benthic investigations. V. Species data from selected stations (Strait of Georgia and adjacent inlets) February 1965 – May 1966. Fish. Res. Board. Can. Tech. Rep. 73.

Ellis, D.V. 1969. Ecologically significant species in coastal marine sediments of southern British Columbia. Syesis 171–182.

Ellis, D.V. 1971. A review of marine infaunal community studies in the Strait of Georgia and adjacent inlets. Syesis 4:3–9.

Elphick, C.S., and G.L. Hunt 1993. Variations in the distributions of marine birds with water mass in the northern Bering Sea. Condor 95:33–44.

Emmett, B., L. Burger and Y. Burger. 1994. An Inventory and Mapping of Subtidal Biophysical Features of the Goose Island Hakai Recreation Area, British Columbia. A report submitted by Archipelago Marine Research Ltd. (#200 – 525 Head St. Victoria, BC. V9A 5S1) to BC Parks Northern BC Region. 73 p.

Farrow, G.E., J.P.M. Sytvitski and V. Tunnicliffe. 1983. Suspended particulate loading on the macrobenthos in a highly turbid fjord: Knight Inlet, British Columbia. Can. J. Fish. Aquat. Sci. 40: Supplement 1:273–288.

Feakins, T.F. 1991. Sooke Harbour and Basin Fish Habitat Inventory. Can. Manusc. Rep. Fish. Aquat. Sci. 2131: 94 p.

Finlayson, C.M., and A.G. van der Valk. 1995. Wetland classification and inventory a summary. Vegetatio 118:1–2:185–192.

Folke, C., C.S. Holling, and C. Perrings. 1996. Biological diversity, ecosystems and the human scale. Ecological Applications, 6(4)1018–1024.

Foreman, R.E. 1975. Nanaimo River Estuary macrophyte study: seasonal aspects of macrophyte distribution and standing crop on Nanaimo River estuary mudflats. B.E.R.P. Report 75–3. Dept. Bot., Univ. British Columbia, Vancouver, B.C. 41 p.

Foreman, R.E. 1977. Benthic community modification and recovery following intensive grazing by *Strongylocentrotus droebachiensis*. Helgol. Wiss. Meeresunters 30:468–484.

Foreman R.E. 1976. Nearshore ecosystem study. Annual Report. B.E.R.P. Report 76 –3 Dept. Bot., Univ. British Columbia, Vancouver, B.C. 76 p.

Foreman, R.E. 1979. Nearshore biophysical inventory program: 1978-1979. B.E.R.P. Report 79–1. Dept. Bot., Univ. British Columbia, Vancouver, B.C. 33 p.

Foreman, R.E. 1984, Studies on *Nereocystis* growth in British Columbia, Canada. Hydrobiologia 116/117:325–332.

Foreman Consulting Ltd., and Kallahin Surveying 1994. Coastal biophysical habitat classification. Draft rep. for contract PPS3–131.

Foreman, R.E., and J. Root. 1975. Macrophyte studies in the Strait of Georgia,. A review of the current status of macrophyte knowledge and research. B.E.R.P Report 75–2. Dept. Bot., Univ. British Columbia, Vancouver, B.C. 41 p.

Foster, M.S. 1990. Organization of macroalgal assemblages in the Northeast Pacific: the assumption of homogeneity and the illusion of generality. Hydrobiologia 192:21–33.

Foster, M.S., A.P. DeVogelaere, C. Harrold, J.S. Pearse, and A.B. Thum. 1988. Causes of spatial and temporal patterns in rocky intertidal communities of Central and Northern California. Calif. Acad. Sci. Memoir 9.

Foster, M.S., and D.R. Schiel. 1985. The Ecology of Giant Kelp Forests in California: A Community Profile. Biological Report 85(7.2) US Fish and Wildlife Service.

Franklin, 1993. Preserving biodiversity, species, ecosystems or landscapes. Eco. Appl. 3:202–205

Franz, D.R., and A.S. Merril. 1980. Molluscan distribution patterns on the continental shelf of the Middle Atlantic Bight (north-west Atlantic). Malacologia 19:209–226.

Franz, D.R., E.K. Worley and A.S. Merril. 1981. Distribution patterns of common sea stars in the middle Atlantic continental shelf of the northwest Atlantic (Gulf of Maine to Cape Hatteras). Biol Bull. 160:394–418.

Frith, H.R., G. Searing, P. Wainwright, J. Harper, and B. Emmett. 1993a. Review of habitat classification systems and an assessment of their suitability to coastal B.C. Unpublished report submitted to Environmental Emergency Services Branch by L.G.L. 9768 Second St. Sidney BC V8L 3Y8.

Frith, H.R., G. Searing, and P. Wainwright. 1993b. Methodology for a B.C. Shoreline Biotic Mapping System. Draft. A report submitted by LGL Ltd (9768 2nd St., Sidney BC V8L 3Y8) to Environmental Emergency Services Branch BC Environment Lands and Parks.

Fuller, I.A., T.C. Telfer, C.G. Moore, M. Wilkinson. 1991. The use of multivariate techniques in conservation assessment of rocky seashores. Aquat. Conserv. Mar. Fresh. Ecosyst. 1:103–122.

Fulton, J. 1973. Some aspects of the life history of *Calanus plumchrus* in the Strait of Georgia. J. Fish. Res. Board Can. 30:811–815.

Gardner, G.A. 1977. Analysis of zooplankton population fluctuations in the Strait of Georgia, British Columbia. J. Fish. Res. Board. Can. 34:1196–1206.

Gauch, H.G. 1982. Multivariate Analysis in Community Ecology. Cambridge Univ. Press, New York. 298 p.

Gilmartin, M. 1964. The primary production of a British Columbia Fjord. J. Fish. Res. Board Can. 21:505–538.

Gleason, H.A. 1917. The structure and development of the plant association. Bull. Torrey Botanical Club 43:463–81.

GLOBEC. 1988. Report of a workshop on Global Ocean Ecosystem Dynamics. May 1988. Joint Oceanographic Institutions Inc. 1755 Massachusetts Ave. NW Suite 800. ph: 202–232–3900 (same for all GLOBEC reports).

GLOBEC. 1991a. Initial science plan. Global ocean ecosystem dynamics. Report No. 1.

GLOBEC 1991b. Theory and modelling in Globec: A first step. Feb. 1991.

GLOBEC 1991c. Northwest Atlantic Program. GLOBEC Canada/US Meeting on NW Atlantic Fisheries and Climate. Report No.2.

GLOBEC. 1992. Northwest Atlantic Implementation Plan. Report No. 6. June 1992.

Golley, F. B. 1993. A History of the Ecosystem Concept in Ecology: More than the sum of the parts. Yale Univ. Press, New Haven & New York 254 p.

Gray, J.S. 1974. Animal-Sediment relationships. Oceanogr. Mar. Bio. Ann. Rev. 12:223–262.

Gray, J.S. 1981. The Ecology of Marine Sediments: An introduction to structure and function of benthic communities. Cambridge Univ. Press. Cambridge.

Gray, J.S., and H. Christie. 1983. Predicting long-term changes in benthic marine communities. Marine Ecology Progress Series 13:87–94.

Griffis, R.B., and K.W. Kimball. 1996. Ecosystem approaches to coastal and ocean stewardship. Ecol. App. 6:708–712.

Grumbine, R.E. 1994. What is ecosystem management? Cons. Biol. 8:1:27–38.

Grumbine, R.E. 1997. Reflections on "What is ecosystem management". Cons. Biol 11:1:41–47.

Haigh, R., and J.R. Taylor. 1990. Distribution of potentially harmful phytoplankton species in the northern Strait of Georgia, British Columbia. Can. J. Fish. Aquat. Sci. 47:2339–2350.

Haigh, R., and F.J.R. Taylor. 1991. Mosaicism of microplankton communities in the northern Strait of Georgia, British Columbia. Mar. Biol. 110:301–314.

Hallegraff, G.M. 1993. A review of harmful algal blooms and their apparent global increase. Phycologia 32:79–99.

Hansen, J.R., and A. Ingolfsson. 1993. Patterns in species composition of rocky shore communities in sub-arctic fjords of eastern Iceland. Mar. Biol. 117:469–481.

Harding, L.E., and H.E. Hirvonen. 1996. A marine ecosystem classification for Canada, pp.8–21. *In* Hay, D.E., R.D. Waters and T.A. Boxwell [eds.]. Proc., Marine Ecosystem Monitoring Network Workshop, Nanaimo, B.C., Mar. 28–30, 1995. Can. Tech. Rep. Fish. Aquat. Sci. 2108 160 p.

Harding, L.E., and E. McCullum. [eds.]. 1994. Biodiversity in British Columbia: Our changing environment. Ministry of Supply and Services. 426 p.

Harper, J.R. 1995. Physical processes overview for the west coast of Vancouver Island. Report to the Land Use Coordination Office, Victoria, B.C.

Harper, J.R., W.T. Austin, M. Morris, P.D. Reimer and R. Reitmeier. 1994. A biophysical inventory of the coastal resources of Gwaii Hanaas. Rep. prep. for the Can. Parks Serv. by Coastal and Oceans Research Inc., 10774 Derrick, Rd., Sidney, B.C. V8L 3R9 114 p.

Harper, J.R., J. Christian, W.E. Cross, R. Frith, G. Searing, D. Thompson. 1993. A classification of the marine regions of Canada. Final Report to Environment Canada. Vancouver, B.C.

Harper, J.R., G.A. Robilliard, and J. Lathrop. 1983. Marine Regions of Canada: Framework for Canada's System of National Marine Parks. Prep. for Parks Can. by Woodward-Clyde Consultants, 16 Bastion Square, Victoria, B.C. V8W 1H9.

Harrison, P.G. 1982a. Spatial and temporal patterns in abundance of two intertidal seagrasses, *Zostera americana* and *Zostera marina* L. Aquat. Bot. 12:305–320.

Harrison, P.G. 1982b. Comparative growth of *Zostera japonica* and *Zostera marina* under simulated intertidal and subtidal conditions. Aquat. Bot. 14:373–379.

Harrison, P.G. 1987. Natural expansion and experimental manipulation of seagrass *Zostera* spp. abundance and the response of infaunal invertebrates. Est. Coast. Shelf. Sci. 24:799–812.

Harrison, P. J., J.D. Fulton, G. Miller, C.D. Levings, F.J.R. Taylor, T.R. Parson, P.A. Thompson and D.W. Mitchell. 1984. A bibliography of the biological oceanography of the Strait of Georgia and adjacent inlets, with emphasis on ecological aspects. Can. Tech. Rep. Fish. Aquat. Sci. No. 1293. 140 p.

Harrison, P.J., J.D. Fulton, F.J.R. Taylor, and T.R. Parsons. 1983. Review of the biological oceanography of the Strait of Georgia: pelagic environment. Can. J. Fish. Aquat. Sci 40:1064–1094.

Harrison, P.J., D.L. Mackas, B.W. Frost, R.W. MacDonald and E.A. Crecelius. 1994. An assessment of nutrients, plankton and some pollutants in the water column of Juan de Fuca Strait, Strait of Georgia and Puget Sound, their transboundary transport, pp. 138–174. *In* Wilson, R.C.H., R.J. Beamish, F. Aitkens, and J. Bell [eds.]. Review of the marine environment and biota of Strait of Georgia, Puget Sound and Juan de Fuca Strait: Proc. BC/Wash. Symp. on Marine Environment, Jan 13/14, 1994. Can. Tech. Rep. Fish. Aquat. Sci. 1948.

Hawkes, M.W. 1994a. Conserving marine ecosystems: Are British Columbia's Marine Protected Areas adequate? Pp.393–410. *In* Harding, L.E., and E. McCullum [eds.]. Biodiversity in British Columbia: Our changing environment. Min. Supply & Services. 426 p.

Hawkes, M.W. 1994b. Benthic marine algal flora (seaweeds) of British Columbia: Diversity and conservation status, pp. 113–118. *In* Harding, L.E., and E. McCullum [eds.]. Biodiversity in British Columbia: Our changing environment. Min. Supply & Services. 426 p.

Hay, D.E., R.D. Waters, and T.A. Boxwell [eds.]. 1996. Proc. Marine Ecosystem Monitoring Network Workshop, Nanaimo, B.C. March 28–30. 1995. Can. Tech. Rep. Fish. Aquat. Sci. 2108. 160 p.

Hayden, B.P., and R. Dolan. 1976. Coastal marine fauna and marine climates of the Americas. Jour. Biogeography 3:71–81.

Hayden, B.P., R. Dolan, and G.C. Ray. 1982. A system of biophysical provinces in coastal and marine habitats for conservation purposes. Proc. World. Nat. Parks. Cong. Bali. Indonesia.

Hayden, B.P., G.C. Ray, and R. Dolan. 1984. Classification of coastal and marine environments. Environ. Cons. 11(3):199–207.

Hayward, T.L., and J. A. McGowan. 1979. Pattern and Structure in an oceanic zooplankton community. Amer. Zool. 19:1045–1055.

Healey, M.C. 1978. The distribution, abundance and feeding habits of juvenile Pacific salmon in Georgia Strait, British Columbia. Fish. Mar. Serv., Can. Tech. Rep. 788. 49 p.

Healey, M.C. 1979. Detritus and juvenile salmon production in the Nanaimo estuary. Production and feeding rates of juvenile chum salmon (*Onchorhyncus keta*). J. Fish. Res. Board Can. 36:488–496.

Heath, W.A. 1977. The ecology and harvesting of euphausiid in the Strait of Georgia. Ph.D. thesis. Univ. British Columbia, Vancouver, B.C. 187 p.

Hemple, G., and K. Sherman. 1993. Scientific and organizational aspects of large marine ecosystems research,. pp.18–23. *In* Sherman K., L. Alexander, and B. Gold [eds.]. Large Marine Ecosystems: Stress, Mitigation and Sustainability. Am. Assoc. Advanc. Sci. AAS Press, Washington, D.C. 376 p.

Hesse, R., W.C. Allee, and K.P. Schmitt. 1951. Ecological Animal Geography. 2nd ed. John Wiley & Sons, New York, N.Y. 715 p.

Heywood, V.H., and R.T. Watson [eds.]. 1995. Global Biodiversity Assessment. UN Environment Programme. Cambridge Univ. Press, Cambridge. 1140 p.

Hily, C. P. Potin, and J. Floc'h. 1992. Structure of subtidal algal assemblages on soft-bottom sediments: fauna/flora interactions and role of disturbances in the Bay of Brest, France. Mar. Ecol. Prog. Ser. 85:115–130.

Hiscock, K. 1995. Classification of benthic marine biotopes of the north-east Atlantic. Proc. BioMar - Life workshop held in Cambridge, Nov. 16–18 1994. Joint Nature Conservation Committee. 105 p.

Hiscock, K., and D.W. Connor. 1991. Benthic marine habitats and communities of Britain: The development of an MNCR classification. Peterborough, Joint Nature Conservation Committee, Report No. 6. 92 p.

Hiscock, K and R. Mitchell. 1980. The description and classification of sublittoral epibenthic ecosystems, pp.323–370. *In* J.H. Price, D.E.G. Irvine, W.F. Farnham [eds.]. The Shore Environment Vol. 2. Ecosystems.

Holdridge, L. 1967. Life zone ecology. Tropical Science Centre, San Jose, Costa Rica.

Howes, D., J. Harper, and E. Owens. 1994. British Columbia Physical Shore-zone Mapping System: Discussion Document. Rep. subm. to Resources Inventory Committee by the Coastal Task Force. avail. Secretariat, Resources Inventory Committee, 840 Cormorant St., Victoria, B.C. V8W 1R1.

Howes, D.E., M.A. Zacharias, and R.J. Harper. 1996. The marine Ecoregions of British Columbia. Report to the Resource Inventory Committee. Land Use Coordination Office, Victoria, B.C.

Hughes, J.M.R. 1995. The current status of European wetland inventories and classifications. Vegetatio 118(1–2):17–28.

Hume, T.M., and C.E. Herdendorf. 1988. A geomorphic classification of estuaries and its application to coastal resource management. Ocean Shoreline Management 11:249–274.

Hunter, M.D., and P.W. Price 1992. Playing chutes and ladders: heterogeneity and the relative roles of bottom up and top down forces in natural communities. Ecology 73:724–732.

Hunter, R.A., L.E. Jones, M.M. Wayne, and B.A. Pendergast. 1982. A biophysical estuarine mapping system for B.C. Proc. of a Technical Workshop to Discuss the Incorporation of Wildlife Information into Ecological Land Surveys. 21-24 March, 1982, Banff Alberta. Land/Wildlife Integration No.2. Ecological Land Classification Series, No. 17, 220 p.

Hutchins, L.W. 1947. The basis for temperature zonation in geographic distribution. Ecol. Mono. 17:325–35.

Hutchinson, A.H., and C.C. Lucas. 1931. Epithalassa of the Strait of Georgia. Can. J. Res. 5:231–284.

Jansson Bengt-Owe, 1972. Ecosystem approach to the Baltic problem. Bulletins from the Ecological Research Committee No. 16. Swedish National Research Council.

Jay, D.A., and C.A. Simenstad. 1994. Downstream effects of water withdrawal in a small, high-gradient basin: Erosion and deposition on the Skokomish River delta. Estuaries 17:702–715.

Jennings, M.D. 1995. Gap analysis today. A confluence of biology, ecology, and geography for management of biological resources. Wildlife Soc. Bull. 23:658–662.

Jerlov, N.G. 1977. Classification of sea water in terms of quanta irradience. J. Cons. CIEM 37(3)281–287.

Johnson, L.L., M.S. Myers, D. Goyette and R.F. Addison. 1994. Toxic chemicals and fish health in Puget Sound and the Strait of Georgia, pp. 304–329. *In* Wilson, R.C.H., R.J. Beamish, F. Aitkens, and J. Bell [eds.]. Review of the marine environment and biota of Strait of Georgia, Puget Sound and Juan de Fuca Strait: Proc. BC/Wash. Symp. on the Marine Environment, Jan 13/14 1994. Can. Tech. Rep. Fish. Aquat. Sci. 1948.

Joiris, C.R. 1992. Summer distribution and ecological role of seabirds and marine mammals in the Norwegian and Greenland seas (June 1988). Jour. Mar. Syst. 3:73–89.

Jones, N.S. 1950. Marine bottom communities. Bio. Rev. 25:283–313.

Jones and Stokes and Associates, Inc. 1981a. Ecological Characterization of the central and northern California coastal region. Vol.1. Basic Ecological Concepts. U.S. Fish and Wildlife Service, Office of Biological Services, and Bureau of Land Management, Pacific Outer Continental Shelf Office, Washington D.C. FWS/OBS - 80/45.

Jones and Stokes and Associates, Inc. 1981b. Ecological Characterization of the central and northern California coastal region. Vol. II. Regional characterization.. U.S. Fish and Wildlife service, Office of Biological Services, and Bureau of Land Management, Pacific Outer Continental Shelf Office, Washington D.C. FWS/OBS – 80/46.1.

Jones and Stokes and Associates, Inc. 1981c. Ecological Characterization of the central and northern California coastal region. Vol.III, Part 1. Habitats. U.S. Fish and Wildlife service, Office of Biological Services, and Bureau of Land Management, Pacific Outer Continental Shelf Office, Washington D.C. FWS/OBS – 80/47.1

Kichuki, T. 1966. An ecological study on animal communities of the *Zostera marina* belt in Tomioka Bay, Amakusa, Kyushu. Publ. Amakusa Mar. Biol. Lab. Kyushu Univ. 1:1–106.

Kichuki, T. 1980. Faunal relationships in temperate seagrass beds, pp.153–172. *In* Phillips, R.C., and C.P. McRoy [eds.]. Handbook of seagrass biology an ecosystem perspective. Garland STMP Press. New York, N.Y.

Kideys, A.E. 1994. Recent dramatic changes in the Black Sea ecosystem, the reason for the sharp decline in Turkish Anchovy fisheries. Jour. of Mar. Systems. 171–181.

Kirkegaard, E., and K. Richardson. 1994. Scientific criteria for the establishment of undisturbed areas in the North Sea for Scientific purposes. ICES Cooperative Research Report. No 203.21 p.

Klemas, V.V., J.E. Dobson, R.L. Ferguson and K.D. Haddad. 1993. A coastal land cover classification system for the NOAA coastwatch change analysis project. Jour. Coast. Res. 9:862–872.

Koblents-Mishke, I.O. 1983. An attempt to classify the marine pelagic ecosystems on the basis of primary production and its spatial variability. Oceanolog. Acad. Sci. USSR. 23:2:233–239.

Koutitonsky, V.G., and G.L. Bugden. 1991. The physical oceanography of the Gulf of St. Lawrence: A review with emphasis on the synoptic variability of motion, pp.57–90. *In* J.C. Therriault [ed.]. The Gulf of the St. Lawrence: small ocean or big estuary? Can. Spec. Publ. Fish. Aquat. Sci. 113.

Krajina, V.J. 1965. Biogeoclimatic zones and biocoenoses of British Columbia. Ecology of Western North America 1:1–17.

Krebs, C.J. 1994. Ecology the Experimental Analysis of Distribution and Abundance. 4th ed. Harper Collins. 801 p.

Kuznetsov, A.P. 1978. Trophic structure as a system and the symbolics of its classification. Oceanology Acad. Sci. USSR. 18:4:481–484.

Kuznetsov, A.P., V.P. Shuntov, and L.A. Borets. 1993. Food chains, physical dynamics, perturbations and biomass yields of the Sea of Okhotsk, pp. 69–78. *In* Sherman K., L. Alexander, and B. Gold [eds.]. Large Marine Ecosystems: Stress, Mitigation and Sustainability. Am. Assoc. Advance. Sci. AAS Press, Washington, D.C. 376 p.

Lambert, P. 1994. Biodiversity of marine invertebrates in British Columbia, pp. 57–69 *In* Harding, L.E., and E. McCullum [eds.]. Biodiversity in British Columbia: Our changing environment. Environ. Can., Can. Wildlife Serv., Vancouver, B.C.

Larson, R.J. 1987. Trophic ecology of planktonic gelatinous predators in Saanich Inlet, British Columbia: diets and prey selection. J. Plankton Res. 9(5):811–820.

Laws, R.M. 1985. The ecology of the southern ocean. Am. Scientist. 73:26–40.

LeBlond, P.H. 1983. The Strait of Georgia: functional anatomy of a coastal sea. Can. J. Fish. Aquat. Sci. 40:1033–1063.

Lee, J.C., Yoshida, B.L., and Bourne, N. 1982. Ecological coastal classification of Pacific Rim National Park. Unpub. rep. prep. by J.C. Lee and Associates (Nanaimo) for Parks Canada.

Legare, J.E.H. 1957. The qualitative and quantitative distribution of plankton in the Strait of Georgia in relation to certain oceanographic factors. J. Fish. Res. Board. Can. 14(4):521–552.

Leigh, E.G. Jr., R.T. Paine, J.F. Quinn, and T.H. Suchanek. 1987. Wave energy and intertidal productivity. Proc. Natl. Acad. Sci. USA. 84:1314–1318.

Levin, S.A. 1992. The problem of pattern and scale in ecology. Ecology 73(6):1943–1967.

Levings, C.D. 1980. Benthic biology of dissolved oxygen deficiency event in Howe Sound, B.C., pp. 515–522. *In* Freeland, H. D.M. Farmer and C.D. Levings [eds.]. Fjord Oceanography. Plenum Press, New York, N.Y.

Levings, C.D. 1991. Strategies for restoration and development of fish habitat in the Strait of Georgia-Puget Sound Inland Sea, Northeast Pacific Ocean. Mar. Poll. Bull. 23:417–422.

Levings, C.D., R.E. Foreman and V.J. Tunnicliffe. 1983. Review of the benthos of the Strait of Georgia and contiguous fjords. Can. J. Fish. Aquat. Sci. 40:1120–1141.

Levings, C.D., and R.M. Thom. 1994. Habitat changes in the Georgia Basin: Implications for resource management and restoration, pp.330–351. *In* Wilson, R.C.H., R.J. Beamish, F. Aitkens, and J. Bell [eds.]. Review of the marine environment and biota of Strait of Georgia, Puget Sound and Juan de Fuca Strait: Proc. BC/Wash. Symp. on Marine Environment, Jan 13/14 1994. Can. Tech. Rep. Fish. Aquat. Sci. 1948.

Lie, U. 1974. Distribution of benthic assemblages in Puget Sound, Washington, U.S.A. Marine Biology 26, pp. 203–223.

Liken, G.E. 1985. An experimental approach to the study of ecosystems. The Fifth Tansley Lecture. J. Ecology 73:381–396.

Lindeboom, H.J. 1995. Protected areas in the North Sea: an absolute need for future marine research. Helgol. Meereshunters. 49:591–602.

Linden, O. 1993. Oceanographic features of importance for coast marine biosphere reserves, pp.39–42 *In* Price, A., S. Humphrey [eds.]. Application of the biosphere reserve concept to coastal marine seas. Papers presented at the UNESCO/IUCN San Francisco Workshop 14–20 Aug. 1989. IUCN Gland.

Lindstrom, S.C., and R.E. Foreman. 1978. Seaweed associations of the Flat Top Islands, British Columbia: Comparison of community methods. Syesis 11:171–185.

Lobban, C.S., and P.J. Harrison. 1997. Seaweed ecology and physiology. Cambridge Univ. Press, Cambridge U.K. 366 p.

Longhurst, A.R. [ed.]. 1981. Analysis of Marine Ecosystems. Academic Press, New York, N.Y.

Luternauer, J.L., J.J. Clague, and C. H. Pharo. 1983. Substrates of the Strait of Georgia, British Columbia, Can. J. Fish. Aquat. Sci. 40:1026–1032.

Mackas, D.L. 1992. Seasonal cycle of zooplankton off southwestern British Columbia. 1979–1989. Can. J. Fish. Aquat. Sci. 49:903–921.

Mackas, D.L., K.L. Denman, and M.R. Abbott. 1985. Plankton patchiness: biology in the physics vernacular. Bull. Mar. Sci. 37:652–674.

Mackas, D.L., and J.D. Fulton. 1989. Distribution and aggregation of zooplankton in the Strait of Georgia and their potential availability to marine birds, pp. 19–25. *In* Vermeer, K., and R.W. Butler [eds.]. The ecology and status of marine and shoreline birds in the Strait of Georgia, British Columbia. Spec. Publ., Can. Wildl. Serv., Ottawa, Ont.

Mackas, D.L., and G.C. Louttit. 1988. Aggregations of the copepod *Neocalanus plumchrus* at the margin of the Fraser River plume in the Strait of Georgia. Bull. of Mar. Sci. 43(3):810–824.

Mackas, D.L, G.C. Louttit, and M.J. Austin. 1980. Spatial distribution of zooplankton and phytoplankton in British Columbian coastal waters. Can. J. Fish. Aquat. Sci. 37:1476–1487.

Mackas, D.L., and H.A. Sefton. 1982. Plankton species assemblages off southern Vancouver Island: geographic pattern and temporal variability. J. Mar. Res. 40:1173–1200.

Mahaffy, M.S., D.R. Nyswwander, K. Vermeer, T.R. Wahl, and P.E. Whitehead. 1994. Status trends and potential threats related to birds in the Strait of Georgia, Puget Sound and Juan de Fuca Strait, pp. 256–282. *In* Wilson, R.C.H., R.J. Beamish, F. Aitkens, and J. Bell [eds.]. Review of the marine environment and biota of Strait of Georgia, Puget Sound and Juan de Fuca Strait: Proc. BC/Wash. Symp. on Marine Environment, Jan 13/14 1994. Can. Tech. Rep. Fish. Aquat. Sci. 1948.

Major, J. 1951. A functional, factorial, approach to plant ecology. Ecology 32:392–412.

Mann, K.H. 1992. Physical influences on biological processes: How important are they? S. Afr. J. Mar. Sci. 12:107–121.

Mann, K,H., and J.R.N. Lazier. 1991. Dynamics of marine ecosystems: Biological - physical interactions in the oceans. Blackwell Sci. Pub. Boston MA. 466 p.

Marine Environmental Quality Advisory Group (MEQAG).1994. Marine Ecological Classification System for Canada. Environment Canada. Jan. 1994. 21 p.

Marliave, J.B. 1986. Lack of planktonic dispersal in rocky intertidal fish larvae. Trans. Am. Fish. Soc. 115:149–154.

Marliave, J.B., and M. Roth 1995. *Agarum* kelp beds as a nursery habitat of spot prawns, *Pandalus platyceros* Brandt 1852 (Decapoda, Caridea). Crustaceana 68:27–37.

Masse, H. 1972. Quantitative investigations of sand-bottom macrofauna along the Mediterranean north-west coast. Marine Biology 15:209–220.

Matthews, G.W.T. 1993. The Ramsar Convention; its history and development. Ramsar Convention Bureau, Gland Switzerland.

McFarlane, G.A., and R.J. Beamish. 1992. Climatic influence linking copepod production with strong year classes in sablefish, *Anoplopoma fimbria.* Can. J. Fish. Aquat. Sci. 49:743–753.

McFarlane, G.A., D.M. Ware, R.E. Thomson, D.L. Mackas, B. Hargreaves and C. Robinson. 1995. A review of the physical, biological and fisheries oceanography of a large marine ecosystem located of the West Coast of Vancouver Island and implications for management. Abstract, p.137. *In* Tang, Q and K. Sherman. [eds.]. The Large Marine Ecosystems of the Pacific Rim: A report of a symposium held in Quingdao, Peoples Republic of China, 8–11 Oct. 1994. A Marine Conservation and Development Report. IUCN, Gland, Switzerland. x + 168 p.

McGowan, J.A. 1974. The nature of oceanic ecosystems, pp. 9–28. *In* Miller C.B. [ed.]. The Biology of the Pacific Ocean. Oregon State Univ. Press, Corvallis, Ore.

McQuoid, M.R., and L.A. Hobson. 1997. Changes in diatom abundance and species composition in Saanich Inlet from frozen sediment cores and ODP169S hole 1034B. Abstract. 11th Northwest Algal Symposium, Univ. Victoria May 9–11 1997.

Meidinger, D., and J. Pojar. 1991. Ecosystems of British Columbia. Min. Forests, Victoria, B.C.

Mercier, F., and C. Mondor. 1995. Sea to sea to sea: Canada's National Marine Conservation Areas System plan. Parks Canada. Dep. Canadian Heritage, Parks Canada, Hull, P.Q. 106 p.

Merilees, W. 1985. The humpback whales of Georgia Strait. Waters, Jour. Van. Aqu. 8:1–24.

Mills, E.L. 1969. The community concept in marine zoology, with comments on continua and instability in some marine communities: A review. J. Fish. Res. Brd. Can. 26:1415–1428.

Mills, E.L. 1975. Benthic organisms and the structure of marine ecosystems. J. Fish. Res. Brd. Can. 32:1657–1663.

Michanek, G. 1979. Phytogeographic provinces and seaweed distribution. Bot. Mar. 22:375–391.

Mobius, K. 1877. Die Auster and die Austernwirthschaft. Verlag von Wiegandt, Hempel and Parey, Berlin. Trans. H.J. Rice. Published in Fish and Fisheries Annual Report of the Commission for the year 1880, 3:29:H:681–747.

Morris, M.C. 1996. Testing a Nearshore Biophysical Classification System. M.Sc. Thesis. Dept. Bot., Univ. British Columbia, Vancouver, B.C. 99 p.

Mumby, P.J., P.S. Raines, D.A. Raines, J.P. Gibson. 1995. Geographic information systems: a tool for integrated coastal zone management in Belize. Coastal - Management 23:111–121.

Natio, B.G. 1987. Newcastle Island Passage and Nanaimo Harbour Fish habitat Inventory. Can Manuscr. Rep. Fish. Aquat. Sci. 1947. 34 p.

National Research Council (NRC). 1994. Priorities for Coastal Ecosystem Science. National Academy Press. Washington, D.C.

National Research Council (NRC). 1996. The Bering Sea Ecosystem. National Academy Press, Washington, D.C.

Nature Conservancy. 1996. A classification for freshwater communities. Proc. of the Nature Conservancy's Aquatic Community Classification Workshop. Unpub rep. 13 p.

Nelson, T.A. 1997. Interannual variance in a subtidal eelgrass community. Aquat. Bot. 56:245–252.

Nemoto, T. 1959. Food of baleen whales with reference to whale movements. Sci. Rep. Whale. Res. Inst. No. 14:1–290.

Noon, B.R., and K.S. McKelvey. 1996. Management of the spotted owl: A case history in conservation biology. Annu. Rev. Ecol. Syst. 27:135–162.

Norse, E.A. 1993. Global marine biological diversity: A strategy for building conservation into decision making. Island Press, Washington, D.C. 383 p.

Norse, E.A. 1995. Maintaining the world's biological diversity. Bull of Mar. Sci. 57:10–13.

Nyblade, C.F. 1979. Five-year intertidal community change, San Juan Islands, 1974–1978 and the intertidal benthos of north Puget Sound Summer 1978. Appendix F. Baseline study program Washington State Dept. Ecology, Olympia, Wash.

Odum, H.T. 1967. Biological circuits and marine systems of Texas, pp. 99–157. *In* Olson, T.A., and F.J. Burgess [eds.]. Pollution and Marine Ecology. John Wiley and Sons.

Odum, E.P. 1968. Energy flow in ecosystems: A historical review. Am. Zool. 8:11–18.

Olesiuk, P.F., M.A. Bigg, G.M. Ellis, S.J. Crockford and R.J. Wigen. 1990. An assessment of feeding habits of harbour seals (*Phoca vitulina*) in the Strait of Georgia, British Columbia, based on scat analysis. Can Tech Rep. Fish. Aquat. Sci. No. 1730.

O'Neill, R.V., D.L. DeAngelis, J.B. Wade, and T.F. Allen. 1986. A hierarchical concept of ecosystems. Princeton Univ. Press. Princeton, N.J.

O'Reilly, J.E., C.E. Evans-Zetlin and D.A. Busch. 1987. Primary production, pp. 220–223. *In* Backus, R.H. [ed.]. Georges Bank. MIT Press. Cambridge, Mass.

Orians, G.H. 1993. Endangered at what level? Ecological Applications 3(2) 206–208.

Outram, D.N., and C. Haegele. 1972. Food of the Pacific Hake (*Merluccius productus*) on an offshore bank southwest of Vancouver Island, British Columbia. J. Fish. Res. Board Can. 29:1792–1795.

Oviatt, C., P. Doering, B. Nowicki, L. Reed, J. Cole, and J. Frithsen. 1995. An ecosystem-level experiment on nutrient limitation in coastal marine environments. Mar. Ecol. Prog. Ser. 116:171–179.

Paine, R. 1974. Intertidal community structure. Oecologia 15:93–120.

Paine, R.T. 1988. Food webs: road maps of interactions or grist for theoretical development. Ecology 69:1648–1654.

Paish, H. 1970. The Canadian marine environment as a national park theme: A reconnaissance study. Rep. by Howard Paish & Assoc. Ltd, Vancouver, B.C. to Dep. Indian and Northern Development, National Historic Parks Branch, Ottawa, Ont. 43 p.

Parks Canada. 1995. Sea to sea to sea: Canada's National Marine Conservation Areas System Plan. Parks Canada, Dep. Canadian Heritage, Ottawa, Ont.

Parks Canada. 1997. Charting the Course: towards a *Marine Conservation Act*. Discussion Paper. February 1997. Dep. Canadian Heritage, Ottawa, Ont.

Parsons, T.R. 1991. Trophic relationships in marine pelagic ecosystems, pp. 89–99. *In* J. Mauchline and T. Nemoto. Marine biology: Its accomplishment and future prospect. Elsevier, Oxford/New York.

Parsons, T.R. 1992a. The removal of marine predators by fisheries and their impact on trophic structure. Mar. Poll. Bull. 25(1–4):51–54.

Parsons, T.R. 1992b. Ecological relations, pp.561–570. *In* D.W. Hood, and S.T. Zimmerman. The Gulf of Alaska: Physical Environment and Biological Resources. NOAA, US Dept. Interior.

Parsons, T.R., L.J. Albright, and J. Parslow. 1980. Is the Strait of Georgia becoming more eutrophic? Can. J. Fish. Aquat. Sci. 37:1043–1047.

Parsons, T.R., R.J. LeBrasseur and W.E. Barraclough. 1970. Levels of production in the pelagic environment of the Strait of Georgia, British Columbia: a review. J. Fish. Res. Bd. Can. 27:1251–1264.

Parsons, T.R., J. Stronach, G.A. Borstad, G. Louttit, and R.I. Perry. 1981. Biological fronts in the Strait of Georgia, British Columbia and their relation to recent measurements of primary productivity. Mar. Ecol. Prog. Ser. 6:237–242.

Parsons, T.R., M. Takahashi, and B. Hargrave. 1984. Biological Oceanographic Processes. Permagon Press, New York, N.Y. 330 p.

Pauly, D, and V. Christensen. 1995. Primary production required to sustain global fisheries, Nature 374:255–257.

Petersen, C.G.J. 1913. Valuation in the sea: II. The animal communities of the sea-bottom and their importance for marine zoogeography. Report of the Danish Biological Station 21:1–44.

Peterson, E.B., and N.M. Peterson. 1991. A first approximation of principles and criteria to make Canada's protected area systems representative of the nation's ecological diversity. Canadian Council on Ecological Areas. Occasional Papers. 47 p.

Peterson, W.T., C.B. Miller and A. Hutchinson. 1979. Zonation and maintenance of copepod populations in the Oregon upwelling zone. Deep Sea Res. 26:467–494.

Phillips, R.C. 1984. The ecology of eelgrass meadows in the Pacific Northwest: A community profile. U.S. Fish. Wildl. Serv. FWS/OBS–84–24. 85 p.

Phillips, R.C., and C.P. McRoy [eds.]. 1980. Handbook of seagrass biology an ecosystem perspective. Garland STMP Press, New York, N.Y.

Pickard, G.L. 1961. Oceanographic features of inlets in the British Columbia mainland coast. Jour. Fish. Res. Brd. Can. 18:6:907–999.

Pielou, E.C. 1979. Biogeography. Wiley Interscience, New York, N.Y. 351 p.

Pielou, E.C. 1984. The Interpretation of Ecological data: A Primer on Classification and Ordination. Wiley, New York, N.Y.

Pielou, E.C. 1991. After the Ice Age: The return of life to glaciated North America. Univ. Chicago Press, Chicago. 366 p.

Pitcher, T.J. [ed.]. 1997. The design and Monitoring of Marine Reserves. Fisheries Centre Research Reports 1997. Vol 5, No. 1. Fisheries Centre, Univ. British Columbia, Vancouver, B.C. 47 p.

Pocklington, P., and M.J. Tremblay 1987. Faunal Zones in the NW Atlantic based on Polychaete distributions. Can. J. Zool. 65:391–402.

Polhemus, D.A., J. Maciolek and J. Ford. 1992. An ecosystem classification of inland waters for the tropical Pacific islands. Micronesoia 25:155–173.

Polovina, J.J., G.T. Mitchum, N.E. Graham, M.P. Craig, E. Demartini, and E. N. Flint. 1994. Physical and biological consequences of a climate event in the central North Pacific. Fish. Oceanogr. 3:1:15–21.

Pomeroy, L.R. 1989. Relationships of primary and secondary production in lakes and marine ecosystems, pp. 97–119. *In* Cole, J., G. Lovett, S. Findlay [eds.]. Comparative analyses of ecosystems: Patterns mechanisms and theories. Springer Verlag, New York, N.Y.

Pomeroy, L.R. 1974. The ocean's food web, a changing paradigm. Bioscience 24:9499–9504.

Posey, M.H. 1988. Community changes associated with the spread of an introduced seagrass, *Zostera japonica*. Ecology 69:974–983.

Pritchard, D.W. 1989. Estuarine classification: A help or a hindrance? pp. 1–38. *In* Neilson, B.J., A. Kuo and J. Brubaker [eds.]. Estuarine circulation.

Ray, G.C. 1976. Critical Marine Habitats. IUCN Publication 37, Gland Switzerland.

Ray, G.C. 1981. The role of large organisms, pp.397–413. *In* A.R. Longhurst [ed.]. Analysis of Marine Ecosystems. Academic Press. New York, N.Y.

Ray, C.G. 1988. Ecological diversity in coastal zones and oceans, pp. 36–50 *In* Wilson, E.O. [ed.]. Biodiversity. National Academy Press, Washington, D.C. 521 p.

Ray, G.C. 1991. Coastal-zone biodiversity patterns. BioScience 41:490–498.

Ray, G.C., J.R. Clark, N.M. Foster, P. Godfrey, B.P. Hayden, S.J. Leatherman, E. Odum, J.H. Sather, and W.P. Gregg. 1981. Interim guidelines for identification and selection of coastal biosphere reserves. US MAB report no. 6. Washington, D.C.

Ray, G.C., and J.F. Grassle. 1991. Marine Biological Diversity. BioScience 41:453–457.

Ray, G.C., and B.P. Hayden. 1992. Coastal zone ecotones, pp.403–420. *In* A. Hansen and F. di Castilla [eds.]. Landscape Boundaries. Springer Verlag, New York, N.Y.

Ray, G.C., and B.P. Hayden. 1993. Marine biogeographic provinces of the Bering, Chukchi and Beaufort Seas, pp. 175–184. *In* Sherman K., L. Alexander, and B. Gold [eds.]. Large Marine Ecosystems: Stress, Mitigation and Sustainability. American Association for the Advancement of Science. AAS Press, Washington DC. 376 p.

Ray, G.C., and M.G. McCormick-Ray. 1995. Critical habitats and representative systems in marine environments. Concepts and procedures, pp.23–40. *In* T. Argy [ed.]. The science of conservation in the coastal zone: New insights on how to design implement and monitor marine protected areas. IUCN, Gland, Switzerland.

Reid, J.L., E.R. Brinton, A. Fleminger, E.L. Venrick, and J.A. McGowan. 1978. Ocean circulation and marine life, pp. 65–130. *In* Charnock, H., and G. Deacon. Advances in Oceanography. Plenum Press. New York, N.Y.

Richardson, L.L. 1996. Remote sensing of algal bloom dynamics. BioScience 46:492–501.

Ricketts, E.F., J. Calvin and J.W. Hedgepeth. 1985. Between Pacific tides, 5th ed. Stanford Univ. Press, Stanford, Calif.

Ricklefs, R.E. 1990. Scaling patterns and process in marine ecosystems, pp. 169–178. *In* Sherman, K., L.M. Alexander and B.D. Gold [eds.]. Large Marine Ecosystems Patterns, Processes and Yields. AAAS Symp., AAAS Washington, D.C.

Robinson, C.L. 1994. The influence of ocean climate on coastal plankton and fish production. Fish. Ocean. 3:3:159–171.

Robinson, C.L.K., D.E. Hay, J. Booth, and J. Truscott. 1996. Standard methods for sampling resources and habitats in coastal subtidal regions of British Columbia. Part 2: Review of sampling with preliminary recommendations. Can Tech. Rep. Fish. Aquat. Sci. 2119. 119 p.

Robinson, C.L.K., and C.D. Levings. 1995. An overview of habitat classification systems, ecological models, and geographic information systems applied to shallow foreshore marine habitats. Can. Man. Rep. Fish. Aquat. Sci. 2322. 65 p.

Romaine, S.J., D.L. Mackas and M.C. Macaulay and D.J. Saxby. 1995. Comparisons of repeat acoustic surveys in Jervis Inlet, British Columbia: 1994–1995. *In* Harvesting krill: Ecological impact, assessments, products and markets. Nov 14–16. Fisheries Centre, Univ. British Columbia, Vancouver, B.C.

Roughgarden, J. S. Gaines, and H. Possingham. 1988. Recruitment dynamics in complex life cycles. Science 241:1460–1466.

Ryther, J.H. 1969. Photosynthesis and fish production in the sea. Science 166:72–76.

Salm, R.V., and J.R. Clark. 1984. Marine and coastal protected areas: A guide for planners and managers. I.U.C.N, Gland Switzerland.

Scagel, R.F. 1963. Distribution of attached marine algae in relation to oceanographic conditions in the northeast Pacific, pp. 37–50. *In* Dunbar M.J. [ed.]. Marine distributions. Royal Soc. of Canada Spec. Publ. No. 5 Univ. Toronto Press, Toronto, Ont.

Scagel, R.F., P.W. Gabrielson, D.J. Garbary, L. Golden, M.W. Hawkes, S.C. Lindstrom, J.C. Oliviera, and T.B. Widdowsen. 1989. Benthic marine algae of B.C., Southeast Alaska, and Oregon. Phycological Contribution No. 3. Dep. Bot, Univ. British Columbia, Vancouver, B.C. 535 p.

Schoch, C.G., and M.N. Dethier. 1996. Scaling up. The statistical linkage between organismal abundance and geomorphology rocky intertidal shorelines. Jour. Exp. Mar. Biol. Ecol. 201:1–2:37–72.

Scott, D.A., and T.A. Jones. 1995. Classification and inventory of wetlands. Vegetatio 118:1–2:3–16.

Schmitt, C., Schweigert J., and T.P. Quinn. 1994. Anthropogenic influences on fish populations of the Georgia Basin. I Salmonids. II. Marine fishes, pp.218–255. *In* Wilson, R.C.H., R.J. Beamish, F. Aitkens, and J. Bell [eds.]. 1994. Review of the marine environment and biota of Strait of Georgia, Puget Sound and Juan de Fuca Strait: Proc BC/Wash. Symp. on the Marine Environment, Jan 13–14, 1994. Can. Tech. Rep. Fish. Aquat. Sci. 1948.

Schiel, D.R., and M.S. Foster. 1986. The Structure of subtidal algal stands in temperate waters. Oceanography and Marine Biol. Annual Review 24:265–307.

Searing, G.F., and K.K. English. 1983. A comparative analysis of three natural areas of Canadian significance in Queen Charlotte Sound for their potential use as marine national parks. Report prepared for Parks Canada, by L.G.L. Ltd., 9768 Second Street, Sidney, B.C. V8L 3Y8. 92 p.

Searing, G.F., and H. R. Frith. 1995. British Columbia biological shore-zone mapping system. Unpub. rep. sub. to Land Use Coordination Office by L.G.L Ltd., 9768 Second Street, Sidney, B.C. V8L 3Y8.

Setchell, W.A. 1915. The law of temperature connected with the distribution of marine algae. Ann. Mo. Bot. Gard. 2:287–305.

Sewell, M., and J. C. Watson (1993). A "source" for asteroid larvae? Recruitment of *Pisaster ochraceus, Pycnopodia helianthoides* and *Dermasterias imbricata* in Nootka Sound British Columbia. Mar. Biol. Ecol. 117:287–398.

Shelford, V.E. 1935. Some marine biotic communities of the Pacific coast of North America. Part I. General survey of the communities - their extent and dynamics. The Major Communities. Eco. Mono. 5:249–234.

Shelford, V.E., and E.D. Towler. 1925. Animal communities of San Juan Channel and adjacent areas. Pub. Puget Sound Biol. Stn. 5:31–73.

Shepphard, C.R.C., K. Matheson, J.C. Bythell, P. Murphy, C.B. Myers, B. Blake. 1995. Habitat mapping in the Caribbean for management and conservation: Use and assessment of aerial photography. Aquat. Conserv. Mar. Freshwat. Ecosyst. 5:4:277–298.

Sherman, K. 1991. The large marine ecosystem concept: Research and management strategy for living marine resources. Ecological Applications 1(4):349–360.

Sherman, K. 1994. Sustainability, biomass yields and health of coastal ecosystems: an ecological perspective. Mar. Ecol. Prog. Ser. 112:277–301.

Sherman, K. 1995. Marine ecosystem sustainability. *In* Tang, Q and K. Sherman. [eds.]. The Large Marine Ecosystems of the Pacific Rim: Rep. of symp. held in Quingdao, People's Republic of China, 8–11 Oct. 1994. A Marine Conservation and Development Report. IUCN, Gland, Switzerland.

Sherman K., and L. Alexander. [eds.]. 1986. Variability and management of large marine ecosystems. AAAS Selected Symposium 99. Westview Press Inc. Boulder, Colo. 493 p.

Sherman, K.L., L.M. Alexander and B.D. Gold. 1990. Large marine ecosystems patterns processes and yields. American Association for the Advancement of Science. AAS Press, Washington DC. 242 p.

Sherman K., L. Alexander, and B. Gold [eds.]. 1993. Large Marine Ecosystems: Stress, Mitigation and Sustainability. American Association for the Advancement of Science. AAS Press, Washington DC. 376 p.

Sherman K., M. Grosslein, D. Mountain, D. Busch, J. O'Reilly, and R. Theroux. 1988. The continental shelf ecosystem off the northeast coast of the United States, pp. 279–337. *In* Postma H., and J.J. Zilstra [eds.]. Ecosystems of the World 27: Continental Shelves, Ch. 9. Elsevier, Amsterdam.

Shim, J.H. 1976. Distribution and taxonomy of planktonic marine diatoms in the Strait of Georgia. PhD thesis, Univ. British Columbia, Vancouver, B.C.

Short, H.L., and J.B. Hestbeck. 1995. National biotic resource inventories and gap analysis. BioScience 45:535–539.

Shrader-Frechette and E.D. McCoy 1993. Method in ecology: strategies for conservation. Cambridge Univ. Press, Cambridge.

Sibert, J. 1979. Detritus and juvenile salmon production in the Nanaimo Estuary: II Mieofauna available as food to juvenile chum salmon (*Onchonhyncus keta*). J. Fish. Res. Board Can. 36:497–503.

Sibert, J., T.J. Brown, M.C. Healey, B.A. Kask, and R.J. Naiman. 1977. Detritus-based food webs: exploitation by juvenile chum salmon (*Onchonhyncus keta*). Science 196:649–650.

Sibert, J., and P. Reimer. 1976. Textural analysis of the surficial sediments of the Nanaimo River Delta. Fish. Res. Board Can. MS Rep. 1405 21 p.

Simenstad, C.A., C.D. Tanner, R.M. Thom, and L. Conquest. 1991. Estuarine Habitat assessment protocol. EPA 910/0–91–037. Rep. to U.S. Environ. Protect. Agency, Region 10, Fish. Res. Inst., Univ. Washington, Seattle, Wash. 201 p.

Slocombe, D.S. 1993. Implementing ecosystem-based management. BioScience 43:612–622.

Smith, R.C., and K.S. Baker. 1982. Oceanographic chlorophyll concentrations determined by satellite Nimbus-7 Coastal Zone Colour scanner. Marine Biology 66:269–279.

Snelgrove, P.V.R., and C.A. Butman. 1994. Animal-sediment relationships revisited: Cause versus effect. Oceanography and Marine Biology Annual Review 32:111–177.

Sobel, J. 1993. Conserving biological diversity through marine protected areas: A global challenge. Oceanus Fall 1993:19–26.

Springer, A.M. C.P. McRoy, and M.V. Flint. 1996. The Bering Sea Green Belt: shelf edge processes and ecosystem production. Fish. Oceanogr. 5(¾):205–223.

St. John, M.A., J. Stevenson Macdonald, P.J. Harrison, R.J. Beamish, and E. Choromanski. 1992. The Fraser River plume: some preliminary observations on the distribution of juvenile salmon, herring and their prey. Fish. Oceanogr. 1:2:153–162.

Stauffer, R.C. 1937. Changes in the invertebrate community after disappearance of the eelgrass. Ecology 18:427–431.

Steele, J.H. 1974. The structure of marine ecosystems. Harvard Univ. Press, Cambridge, Mass.

Steele, J.H. 1985. A comparison of terrestrial and marine ecological systems. Nature 313:355–358.

Steele, J.H. 1991a. Marine functional diversity. BioScience 41:470–474.

Steele, J.H. 1991b. Ecological explanations in marine and terrestrial systems, pp.101–106. *In* T. Machline and T. Nemoto [eds.]. Marine Biology its accomplishments and future prospect. Elsevier, Amsterdam.

Stephenson, T.A., and A. Stephenson. 1972. Life between tidemarks on rocky shores. Freeman. San Francisco, Calif.

Stockner, J.G., D.D. Cliff, and D.B. Buchanan. 1977. Phytoplankton production and distribution in Howe Sound, British Columbia: A coastal marine embayment-fjord under stress. J. Fish Res. Board Can. 36:657–666.

Stockner, J.G., D.D. Cliff and K.R. Shortreed. 1979. Phytoplankton ecology of the Strait of Georgia, British Columbia. J. Fish. Res. Board Can. 36: 657–666.

Stockner, J.G., K.S. Shortreed, and E.A. MacIsaac. 1980. The benevolent Strait: A reply. Can. J Fish. Aquat. Sci. 1048–1054.

Stronach. J.A., J.O. Backhaus, T.S. Murty. 1993. An update on the numerical simulation of oceanographic processes in the waters between Vancouver Island and the Mainland: the C3 model. Oceanography and Marine Biology Annual Review 31:1–86.

Suchanek, T.H. 1994. Temperate coastal marine communities: Biodiversity and threats. Amer. Zool. 34:100–114.

Swinbanks, D.D. 1979. Environmental factors controlling floral zonation and distribution of burrowing and tube-dwelling organisms of Fraser-delta tidal flats, British Columbia. PhD thesis. Univ. British Columbia, Vancouver, B.C. 274 p.

Tanasichuk, R. 1995. The importance of euphausiids to a British Columbia coastal marine ecosystem. *In* Harvesting krill: ecological impact, assessments, products and markets. Nov. 14-16. Fisheries Centre, Univ. British Columbia, Vancouver, B.C.

Tanasichuk, R.W., D.M. Ware, W. Shaw and G.A. McFarlane. 1991. Variations in diet, daily ration and feeding periodicity of Pacific Hake (*Merluccius productus*) and spiny dogfish (*Squalus acanthias*) off of the lower west coast of Vancouver Island. Can. J. Fish. Aquat. Sci. 48:2118–2128.

Tang, Q and K. Sherman. 1995. The Large Marine Ecosystems of the Pacific Rim: Rep. of symp. in Quingdao, Peoples' Republic of China, 8–11 Oct. 1994. A Marine Conservation and Development Report. IUCN, Gland, Switzerland. x + 168 p.

Tansley, A.G. (1935) The use and abuse of vegetational concepts and terms. Ecology 16(3):284–307.

Taylor, M.E., and J.C. Roff. 1997. A classification system from marine conservation. Draft rep. to World Wildlife Fund, Ottawa, Ont.

Taylor, M.E., and J.C. Roff (in press). A classification system for marine conservation. Aquatic Conservation.

Taylor, F.R.J., and R.A. Horner. 1994. Red tides and other problems with harmful algal blooms in Pacific Northwest coastal waters, pp.75 –186. *In* Wilson, R.C.H., R.J. Beamish, F. Aitkens, and J. Bell [eds.]. Review of the marine environment and biota of Strait of Georgia, Puget Sound and Juan de Fuca Strait: Proc. BC/Wash. Symp. on Marine Environment, Jan 13-14, 1994. Can. Tech. Rep. Fish. Aquat. Sci. 1948.

Tegner, M.J., and P.K. Dayton. 1987. El Niño effects on Southern California kelp forests. Advances in Ecological Research 17:243–279.

Thayer, G.W., S.M. Adams, and M.W. LaCroix. 1975. Structural and functional aspects of a recently established *Zostera marina* community, pp. 518–540. *In* Cronin, L.E. [ed.]. Estuarine Research. Academic Press, New York, N.Y.

Thom, R.M., and R.G. Albright. 1990. Dynamics of benthic vegetation standing-stock, irradience and water properties in central Puget Sound. Mar. Biol. 104:129–141.

Thom, R.M., B. Miller, and M. Kennedy. 1995. Temporal patterns of grazers and vegetation in a temperate seagrass system. Aquat. Bot. 50:201–205.

Thomas, A.C., and W.J. Emery. 1986. Winter hydrography and plankton distribution on the southern Vancouver Island continental shelf. Can. J. Fish. Aquat. Sci. 43:1249–1258.

Thomson, R.E. 1981. Oceanography of the British Columbia coast. Can. Spec. Publ. Aquat. Sci. 56: 291 p.

Thomson, R. E. 1994. Physical oceanography of the Strait of Georgia-Puget Sound–Juan de Fuca Strait system, pp.36–100. *In* Wilson, R.C.H., R.J. Beamish, F. Aitkens, and J. Bell [eds.]. Review of the marine environment and biota of Strait of Georgia, Puget Sound and Juan de Fuca Strait: Proc. BC/Wash. Symp. on Marine Environment, Jan 13–14 1994. Can. Tech. Rep. Fish. Aquat. Sci. 1948.

Thorson, G. 1957. Bottom communities (sublittoral to shallow shelf), pp. 461–534. *In* Hedgepeth, J. [ed.]. Treatise on marine ecology and paleoecology. Mem. Geol. Soc. America Vol. 1 No. 67

Truscott, J. 1996. Availability of mapping for the nearshore areas of British Columbia, pp. 110–112. *In* Hay, D.E., R.D. Waters, and T.A. Boxwell [eds.]. Proc., Marine Ecosystem Monitoring Network Workshop, Nanaimo, B.C., March 28–30, 1995. Can. Tech. Rep. Fish. Aquat. Sci. 2108. 160 p.

Tully, J.P. A.J. Dodimead. 1957. Properties of the water in the Strait of Georgia, British Columbia, and influencing factors. J. Fish. Res. Board. Can. 14:241–319.

Tunnicliffe, V.1981. High species diversity and abundance of the epibenthic community of an oxygen deficient basin. Nature 294:354–356.

Turner, M.G., R.H. Gardner and R.V. O'Neill. 1995. Ecological dynamics at broad scales: Ecosystems and landscapes. Science and Biodiversity Policy. BioScience Supplement 1995: S-29-S-35.

Underwood, A.J. 1986. What is a community? pp. 351–367. *In* Raup, D.M., and D. Jablonski [eds.]. Patterns and processes in the history of life on earth. Springer-Verlag, Berlin.

Udvardy, M.D.F. 1975. A classification of the biogeographical provinces of the world. IUCN Occasional paper 18. IUCN Morges, Switzerland 49 p.

van den Hoek C. 1975. Phytogeographical provinces along the coasts of the northern Atlantic Ocean. Phycologia 14:317–30.

van den Hoek, C. 1982. Phytogeographic distribution groups of benthic marine algae in the North Atlantic Ocean: A review of experimental evidence from life history studies. Helgol. Meeresunters 35:153–214.

van den Hoek, C. 1984. World-wide latitudinal and longitudinal seaweed distribution patterns and there possible causes as illustrated by the distribution of the Rhodophyta genera. Helgol. Meeresunters 38:227–57.

Wahl, T.R, D.G. Ainley, A.H. Bennedict and A.R. Degange. 1989. Associations between seabirds and water-masses in the northern Pacific Ocean in summer. Mar. Biol. 103:1–11.

Wainwright, D.S., J. Harper, G.F. Searing and D. Howes. 1995. Ecological Classification within British Columbia's Marine Regions. Rep. to Land Use Coordination Office, Victoria, B.C.

Waldichuk, M. 1957. Physical oceanography of the Strait of Georgia, British Columbia. J. Fish Res. Board Can. 14:321–486.

Waldichuk, M. 1971. A review of the general oceanographic and related aspects of the Strait of Georgia. *In* National Marine Parks Straits of Georgia and Juan de Fuca. Rep. to Interdepartmental Task Force on National Marine Parks. Subm. by Task Force Technical Working Group.

Waldichuk. M. 1983. Pollution in the Strait of Georgia: a review. Can. J. Fish. Aquat. Sci. 40:1142–1167.

Ware, D.M., and G.A. McFarlane. 1989. Fisheries production domains in the Northeast Pacific Ocean, pp. 359–379. *In* R.J. Beamish and G.A. McFarlane [eds.]. Effects of ocean variability on recruitment and an evaluation of parameters used in stock assessment models. Can. Spec. Publ. Fish. Aquat. Sci. 108.

Ware, D.M., and R.E Thomson. 1991. Link between long-term variability in upwelling and fish production in the NE Pacific Ocean. Can. Jour. Fish. Aquat. Sci. 48:2296–2306.

Ward, P., K. Moore, and R. Kistritz. 1992. Wetlands of the Fraser lowland 1989: An inventory. Canadian Wildlife Service, Pacific and Yukon Region. Tech. Rep. Ser. No. 146.

Watson, J.C. 1993. The effects of sea otter (*Enhydra lutris*) foraging on shallow rocky communities off northwestern Vancouver Island, British Columbia. Ph.D. thesis, Univ. California at Santa Cruz. 169 p.

West, P., T.M. Fyles, B. King, and D.C. Peeler. 1994. The effects of human activity on the marine environment of the Georgia Basin: Present waste loadings and future trends. *In* Wilson, R.C.H., R.J. Beamish, F. Aitkens, and J. Bell [eds.]. 1994. Review of the marine environment and biota of Strait of Georgia, Puget Sound and Juan de Fuca Strait: Proc. BC/Wash. Symp. on Marine Environment, Jan 13–14, 1994. Can. Tech. Rep. Fish. Aquat. Sci. 1948.

Whittaker, R.H., S.A. Levin, and R.B. Roat. 1973. Niche, habitat and ecotope. Am. Nat. 107:321–338.

Wiken E. 1986. Terrestrial Ecozones of Canada. Environment Canada. Ecological Land Classification Series No. 19.

Williams, G.L. 1989. Coastal/Estuarine fish habitat description and assessment manual Part 1. Species/Habitat outlines. Fisheries and Oceans Unsolicited proposal program, Supply and Services Canada. 11 Laurier St. Hull, Que. K1A 0S5.

Williams, G.L. 1990. Coastal/Estuarine fish habitat description and assessment manual. Part II. Habitat Description Procedures. Fisheries and Oceans Unsolicited proposal program, Supply and Services Canada. 11 Laurier St. Hull, Que K1A 0S5.

Williams, G.L., J.R. Harper, and C. Durance. 1993. Coastal/Estuarine Fish Habitat Description Manual. Training Program Supplement. Fisheries and Oceans Canada. Habitat Management Division, 555 West Hastings Street, Vancouver BC V6B 5G3

Wilson, R.C.H., R.J. Beamish, F. Aitkens, and J. Bell [eds.]. 1994. Review of the marine environment and biota of Strait of Georgia, Puget Sound and Juan de Fuca Strait: Proc. BC/Wash. Symp. on Marine Environment, Jan 13–14, 1994. Can. Tech. Rep. Fish. Aquat. Sci. 1948. 348 p.

Yin, K., P.J. Harrison, and R.J. Beamish. 1997. Effects of a fluctuation in Fraser discharge on primary production in the central Strait of Georgia, British Columbia, Canada. Can. J. Fish. Aquat. Sci. 54:1015–1024.

Yin, K. P.J. Harrison, R.H. Goldblatt, and R.J. Beamish. 1996. Spring bloom in the central Strait of Georgia: Interactions of river discharge, winds and grazing. Mar. Ecol. Prog. Ser. 138:255–263.

Zacharias, M.A., and D.E. Howes. (In press). An analysis of marine protected areas in British Columbia using a marine ecological classification. Natural Areas J.

Zacharias, M.A., and D.E. Howes. (draft). The development and Verification of a Marine Ecological Classification: A case study in the Pacific Marine Region of Canada. Draft manuscript.

Zacharias, M.A., D.E. Howes, and C. Ogborne. (draft) A physical based marine classification system for the Georgia Basin. A methodology and field verification.

Zoltai, S.C., and D.H. Vitt. 1995. Canadian Wetlands: Environmental gradients and classification. Vegetatio 118:131–137.

Zurbrigg, E. 1996. Towards an Environment Canada strategy for coast and marine protected areas. Canadian Wildlife Service, Hull, P.Q. K1A 0H3.

WHAT DOES DFO HABITAT AND ENHANCEMENT BRANCH NEED TO IMPLEMENT AN ECOSYSTEM APPROACH?

Steve Samis
Fisheries and Oceans Canada
Habitat and Enhancement Branch
555 West Hastings St.
Vancouver, B.C. V6B 5G3

Two questions have been posed by the Workshop leaders for me to address:

1. What will the DFO Habitat and Enhancement Branch (HEB) gain from an ecosystem approach?
2. What does Habitat Enhancement Branch require to implement an ecosystem approach?

Both are valid questions and challenging to answer. In preparation, what follows is some background on the *Oceans Act* and the term "ecosystem approach":

- Promulgated in January 1997, the *Oceans Act* is early in its implementation phase. Pacific Region has a comparatively small piece of ocean, but it contains some of the key urban-growth areas of Canada, with extensive economic development underway in the coastal zone.
- Part I of the *Oceans Act* defines the oceans areas under Canada's jurisdiction.
- Part II provides some basic management tools.
- Part III consolidates oceans powers under DFO's Minister.

In more detail:

- Part I asserts federal authority over the following:
  - Territorial Sea. The first 19.2 km (12 miles) are sovereign territory: all laws apply;
  - Contiguous Zone. Sovereign rights exist over fiscal, immigration, sanitation, and customs matters. Canada can take action to prevent offences and the entry of offenders;
  - Exclusive Economic Zone. Sovereign rights exist to explore and exploit, conserve and manage, living and non-living natural resources; and
  - Continental Shelf. Sovereign rights exist to explore and exploit non-living and sedentary living resources.

- In Part II, the management tools are threefold:
  - Marine Environmental Quality (MEQ) standards and guidelines;
  - Integrated Management Plans [such as Integrated Coastal Zone Management (ICZM)]; and
  - Marine Protected Area (MPA) designation.

  Part II also refers to a national Oceans Strategy (to be developed), which is based on the following three principles;

  - sustainable development,
  - integrated management of activities, and
  - the precautionary approach.
- Part III consolidates powers for oceans and sets out the regulatory framework for MEQ and MPA designations.
- There are 11 occurrences of the word "ecosystem" in the *Oceans Act*, including:
  - The need to improve our understanding of ecosystems (five occurrences);
  - The need to manage ecosystems (two occurrences); and
  - Conducting scientific research and surveys to advance knowledge of ecosystems (three occurrences).

There is only one reference to an "ecosystem approach," which is in the fifth "Whereas" clause:

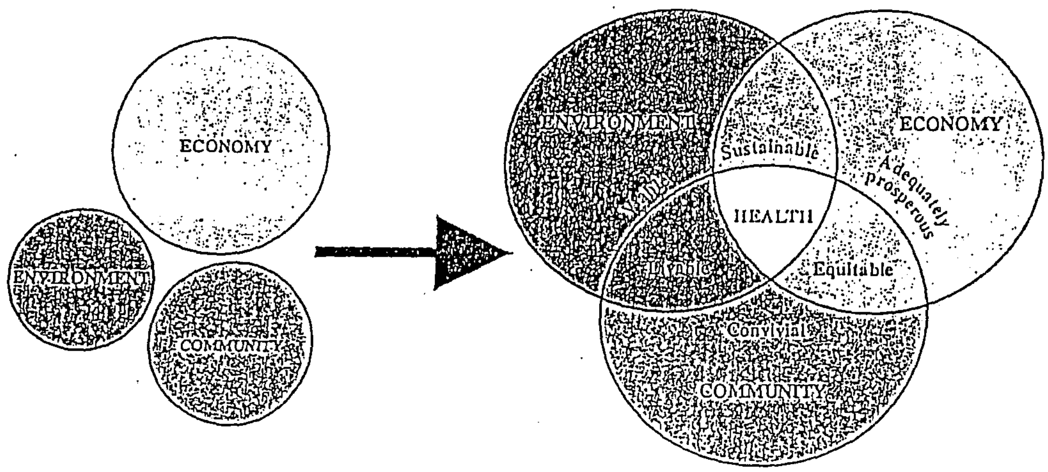
> WHEREAS Canada holds that conservation, based on an ecosystem approach, is of fundamental importance to maintaining biological diversity and productivity in the marine environment.

The 1992 Ecosystems Workshop may not have led us to the holy grail, but it did include some very thoughtful discussions. For example, the following is taken from an address by Stan Rowe (FRAP 1992):

> The public in its innocence has no difficulty accepting that an ecosystem can be a real spatial object: a complete watershed, a lake with everything that is in it, a tract of forest land including its interpenetrating soil and air, or a river system. Academics have been more wary. Trained as biologists, many have strenuously resisted adopting the idea that an ecosystem can be anything more than an abstract concept, a textbook diagram with arrows showing energy flowing and materials cycling from box to box, lacking spatial dimensions and structureless save for compositional numbers pinned on it. They understand ecosystems primarily as a learning device whose chief value is the reminder that all organisms require the support of peripheral things.

Professor Emeritus Stan Rowe
University of Saskatchewan. 1992

The Canadian Council of Ministers of Environment (CCME 1996) presented a concept of an ecosystem approach as three interlocking circles: economy, community, and environment. They stress the importance of understanding linkages among the components and redressing imbalances among them (Figure 1).



Traditional approach

Ecosystem approach

FIGURE 1. The shift from traditional to ecosystem-based decision making (modified from Hancock 1990).

Other points of interest from CCME (1996) are:

- To successfully manage the coastal zone, the people must be managed, not the environment;
- An ecosystem includes humans and the interactions between them and the environment;
- The environmental impact that human actions have within ecosystems is influenced by economic and social conditions;
- Ecosystem-based management represents a progression away from single-media or sectoral resource management approaches towards a more holistic approach;
- Ecosystem-based management means that different resources cannot be managed in isolation — multi-sector ecosystem users must cooperate; and
- Ecosystem boundaries should be defined pragmatically, based on the requirements of the task at hand.

Papers in support of DOE's Georgia Basin/Lower Fraser Ecosystem Initiative make similar linkages, and relate the issues back to sustainable development.

The Fraser River Estuary Management Plan (FREMP) and the Burrard Inlet Environmental Action Plan (BIEAP) Management Committees (FREMP/BIEAP 1997) have adopted the following as a working definition:

> [An ecosystem approach is] a geographically comprehensive approach to environmental planning and management which recognizes the interrelated nature of environmental media, and that humans are a key component of ecological systems; it places equal emphasis on concerns related to the environment, the economy and the community.

Some views and concerns on the Australian approach to coastal zone management from the Internet:

- The current style of governance is a major contributor to the continuing degradation of the coastal zone;
- The issue: fragmented, segregated management systems;
- The solution: integrated coastal area management; and
- Local area management is the practical unit of coastal zone management.

Valerie A. Brown (Australian National University)

See also related material at <www.erin.gov.au/portfolio/dest/Turning_Tide/tide3.html>

DFO's Habitat Council, particularly Otto Langer (pers. comm. 1997), provided some useful insights into implementation of an ecosystem approach:

- An ecosystem approach should be considered a way of thinking, not a process unto itself or a final product;
- We need to increase our ability to collect knowledge to make the ecosystem an understandable and functional unit;
- An ecosystem approach requires that cumulative effects be part of our daily thinking;
- Structural changes in bureaucracies are required to provide for integration across sectors;
- Because watersheds/Strait of Georgia contain processes that create habitats, an ecosystem approach has to be applied at a watershed/Strait level to have relevance to those processes;
- An ecosystem approach leads us to watershed protection and necessarily away from stream-by-stream restoration;
- Watershed protection can only occur through effective planning and implementation; not through traditional project-by-project referrals (an anti-ecosystem approach);
- As we move to more highly managed systems, mistakes become important, hence the need for the precautionary principle; and
- Define carefully what is wanted from this workshop if it is to make a difference.

To answer the second question, "What does HEB require to implement an ecosystem approach?" I will rely on DFO's national MEQ working group (chaired by Camille Mageau and mentored by Mike Bewers) for the following, in the context of considering specific developments or groups of developments in the coastal zone:

- What used to be there?
- What is there now?
- What condition is it in?
- What are the trends? and
- Is intervention now required?

Once those questions are satisfactorily addressed, the following question can be considered: Can additional development be accommodated in the study area, within the limits of national constraints and international commitments? For example:

- *Fisheries Act*;
- *CEPA*;
- The DFO Policy for the Management of Fish Habitat;
- The *Oceans Act* principles of sustainable development, integrated management of activities, and the precautionary principle; and
- UNCLOS, etc.

Some final comments on implementing an ecosystem approach. We require:

- Good performance indicators in the environment of how we are doing;
- Reliable criteria for evaluating the functioning of the ecosystem;
- Better reporting on the state of ecosystems;
- Knowledge of which systems are under stress so that we can intervene;
- Understanding of the kinds of stresses operating so that we can apply mitigation;
- Integration at a high level; and
- Understanding at the population/ecosystem level to make the necessary linkages back to the habitat impacts.

LITERATURE CITED

Fraser River Action Plan (FRAP) 1992. Towards an ecosystem approach in British Columbia: Results of a workshop on ecosystem goals and objectives, 7–9 Dec. 1992. ESSA Environmental and Social Systems Analysts Ltd. for Department of the Environment, B.C.

Ministry of Environment, Lands and Parks, and B.C. Ministry of Forests. FRAP publication 1993-16.

Canadian Council of Ministers of Environment (CCME). 1996. A framework for developing goals, objectives and indicators of ecosystem health: Tools for ecosystem-based management.

FREMP/BIEAP. 1997. Attachments to steering committee meeting agenda. Oct. 16, 1997.

Hancock, T. 1990. Towards healthy and sustainable communities: Health, environment and economy at the local level. A presentation at the 3rd colloquium on environmental health, Nov. 22, 1990, Quebec City, Que.

DISCUSSION

Jennifer Lash: When you talk about habitat, you talk about moving away from the stream-by-stream approach. My own little "bee in my bonnet" is that habitat is a lot more than streams. I think that's really important. When we're talking about integrated coastal-zone management, we're talking about the marine environment too. I'm sure you meant that, but it's something I'd like to emphasize.

Steve Samis: Good point. That was a freshwater example that I gave. I don't think we consider the marine environment to exclude streams. The coastal zone can include the coastal community and the coastal watershed. Where most of the habitat action and damage is occurring is on those small streams — for example, on Vancouver Island in terms of urban development and water withdrawal and highway construction — and therefore we cannot forget it. I may have overemphasized small streams at the expense of the marine, but that's where the habitat action is.

Jennifer Lash: I understand, and I agree that they all have to be connected. That's very important for us to remember.

My other question concerns the ecosystem approach. You talked about needing more knowledge before we're able to do this. How do you decide that there's enough knowledge so you can move ahead with things, and when do you start putting in interim protections that you allow to continue changing as we get more knowledge?

Steve Samis: I think we're managing on an ecosystem approach now and have been for several years. It depends on what part of the province you want to look at. Some of our estuary management programs have a fair amount of information behind them. Then there are other areas where we know very, very little. I think the message to be taken from that bullet is that we're looking to science to continue to develop marine research information, such that we can apply an ecosystem approach from a knowledgeable perspective. It's an ongoing process that never ends. There is a continuing need for research.

Jennifer Lash: I don't think we'll ever know everything.

Steve Samis: That's why we have the precautionary principle, so we err on the side of conservation when we don't have all the scientific information. That's obviously how we manage on a day-to-day basis. We haven't stopped the world because the *Oceans Act* came out. We're saying that we want to do it better.

Jennifer Lash: Thank you.

Bob Wilson: Steve, one of your overheads had a quote from Valerie Brown, in which she said that the practical basis for coastal area management was that unit which could be managed at a local level; in other words, local-area management. That's a bit of a different concept from the biological or the physical basis for ecological classification that we looked at in, for example, Jane Watson's report. That's a fairly traditional approach to ecosystem classification. Do you see this as a layer over top of those conventional methods of ecosystem classification, a replacement for it, a complement to it? How do these two things fit, in your mind?

Steve Samis: I think they fit in that managers may be forced to consider an ecosystem as including the upland area, the human population. For example, a manager who's sitting on a local resource management plan that includes a coastal area would have to consider the humans and their discharges as part of the ecosystem. They may wind up managing arbitrarily based on administrative boundaries, whereas the scientist is much more likely to look at the marine environment from a scientific perspective and provide that kind of information to the manager to help make those decisions. So it would be possible, if you wanted, to take Strait of Georgia and carve it up into regional districts. The boundaries go right out to the middle. They connect. There's no water left untouched, I'm told. We could use that approach, which would be purely administrative, but it may not serve our purposes in every case for every kind of review. So I guess that comes back to the pragmatism that we talked about at the outset in terms of setting our boundaries.

Bill Austin: I don't think I saw biological communities, which is fine, and I also didn't hear the word "wildlife." I don't know if that was by design or if we're considering that passé now. My concern is that it does tend to creep in when one is referring to habitats. When you mentioned CCME, it twigged me to remember that back in 1990 they defined wildlife very broadly to include everything, but the provincial *Wildlife Act* still defines it very narrowly: things that have fur and feathers. Does the *Oceans Act* address that at all? Is there any definition in there of wildlife? Or is there an update on the CCME position?

Steve Samis: Well, the *Oceans Act* is broader than just fish. It aims to set a level playing field amongst the clients that we have traditionally managed. In the past, under the *Fisheries Act*, the fisherman was the primary client. Now all clients are at an even level. That includes management of oceans for other values, including marine mammals and other kinds of wildlife. Yes, those are intended within the *Oceans Act.*

I may not have mentioned biological communities. They're definitely part of our thinking. They're very much a part of how we manage the habitat. If a sewage outfall is going into a particular bay, we would definitely want to know, from science and from others in our department, what the marine biological communities are about and whether they are already stressed or could take any further insults from a certain discharge. We'd want to look at the oceanography. We'd want to know the flushing rate. We'd want to know the types of habitats in the area. That's very much part of what we do.

Craig Stevens: Your presentation highlights a key point for me. Ultimately the *Oceans Act* is going to require DFO to take up a largely public health role — and not public health in the traditional sense of the word. But when we start including social and economic factors, we are in fact getting closer to the definition that the World Health Organization presents for health, which is allowing people the resources to satisfy their needs for living. In a way, this entire systems-management is ultimately having a human-community input. When we start talking about intersectoral and interdisciplinary work, it's going to be essential to implement this successfully to facilitate linkages between the traditional public health people and people now who are becoming environmental managers with an ecosystem approach.

Steve Samis: No argument there.

John Pringle: We do have three area managers here: Chris Dragseth, DFO's South Coast area; Dick Carson, Fraser River; and Don Radford, North Coast. We have a little time. Is there anything you would like to add to Steve's presentation? Rick Higgins, as well, is head of the South Coast office.

Rick Higgins: I am Head at the present time. We're waiting, as Steve said. However, the cheques keep coming, so I'm happy.

John Pringle: Is there anything you would like to add to Steve's presentation?

Dick Carson: There is one point I'd like to add. I was greatly heartened by your presentation, Steve. I was quite concerned coming into the workshop as an area manager and not a technical person. My past experience and my reflection on this subject is that it has been approached very much from a scientific standpoint. It's really encouraging to see the socioeconomic part being factored in more and more. It has to be a dimension. It's obviously something that we are going to struggle hugely with, to move along with it, but it's a big dimension and it's one that we have to recognize. That's what the public is demanding of us now and expecting of us. Probably one of the predominant factors with the new *Oceans Act* is that we've got to recognize that our definition of an ecosystem has to have a human dimension. I want to compliment you on bringing that part out very strongly in your presentation.

Steve Samis: Thank you, Dick.

Norm Lemmen: Can I follow up on that? I see something that we should be very aware of. I'm an ex-area-manager, so maybe this is seeing things with both hats on. This new policy is very clearly a change in direction for the federal government. In the past we had only the no-net-loss policy, which we all saw — at least I did — as people learning to live within an ecosystem. Now our federal policy is very clearly a policy that says that we are permitted to change that ecosystem to balance the needs we have. In other words, people are now part of that ecosystem, so it can be manipulated to meet our needs, as opposed to us learning to live within an existing ecosystem. Now, it's a very subtle change in policy, but in my mind that means that the federal government is giving us, as managers, licence to basically write off or provide less protection to habitat and species and stocks than we used to.

Steve Samis: I disagree, Norm. I'm glad you brought it up, because that question is near and dear to my heart. That's why I put the federal constraints on the overhead. I wanted to make it very clear that the *Fisheries Act* is in no way diminished by the *Oceans Act*, and neither is the fish habitat policy or any of the other federal regulations, policies, and acts. Those are the national constraints when you go into integrated coastal-zone management. When you sit down with the mayor and council and you want to talk about the development of a coastal zone, those are the ground rules. They haven't changed.

What it says is: If there are, in the ocean, greater economic benefits that can be derived by relocating industry, by cleaning up industry, by encouraging or discouraging industry, all those things are on the table. Part of what the *Oceans Act* talks about is enhancing the economic benefits to Canadians. That doesn't take away from the *Fisheries Act*. So if you're a *Fisheries*

Act manager and you're at the table and somebody wants to come in with a major development, you say: "Fine, but here are the federal constraints, and they haven't changed. Now, let's do it in a more effective and planned way." Everybody gets an opportunity to speak, and we can find out whether that industry could be better accommodated in a different bay or in a different way. Those federal constraints haven't changed.

Chris Dragseth: There is some additional background to what Steve has outlined. People should be aware that one of the biggest obstacles or challenges to implementation of the *Oceans Act* is going to be pulling together into this process all the various governments, government agencies, ministries, departments, stakeholders, etc. As additional background to what Steve has outlined, people should be aware that DFO is in the process of establishing an Oceans Directorate for the Pacific Region. That Directorate will report to the Regional Director General, Donna Petrachenko. That will be up and running by the end of November. In fact, the competition for the Director's position is this week. That group will be the focus for DFO as far as the coordination of the *Oceans Act* implementation, but the actual implementation will be done by the various branches within Pacific Region.

THE PACIFIC MARINE ECOZONE OF CANADA

Lee Harding
Canadian Wildlife Service
Pacific Wildlife Research Centre
Delta, B.C.

1.0 INTRODUCTION

A number of ecosystem classifications have been developed for Canada (Rowe 1977; Wiken 1986; Ecoregions Working Group 1989) but these either have not included the marine environment, or have not adequately represented the variety of marine ecosystems in Canada. For example, the Marine Regions of Canada, a classification system developed in 1983 (Harper et al.) following extensive consultations with marine scientists across the country and examination of world literature, was only a two-dimensional representation, and did not represent ecosystems at more than one scale. Provincial systems, such as those of British Columbia (Demarchi et al. 1989) and Nova Scotia (Davis 1994), adequately represented marine ecosystems in their regions, but lacked a national or international context. In 1992, the Interdepartmental Committee on Oceans (ICO) Marine Environmental Quality Working Group directed the Marine Environmental Quality Advisory Group (MEQAG) to develop a hierarchical marine ecological classification system for Canada. This paper presents the results of that work. Its primary purpose is to provide a spatial framework for monitoring and reporting on the health of Canada's marine ecosystems; however, it is expected that this system will serve many other ecosystem planning, conservation, and protection uses as well.

2.0 METHODS

Coastal and Ocean Resources Inc. (CORI) of Sidney, B.C., was contracted to develop an ecological classification system for Canada's marine areas. The documentation for the Marine Regions of Canada, as developed by Canadian Parks Service (Harper et al. 1983), was reviewed. This included an extensive series of physical (oceanography, coastal environment, and physiography) and biological (marine birds, marine mammals, fish, and invertebrates) theme maps derived from the literature and from consultation with a broad spectrum of marine scientists across Canada. Classification systems proposed by Mondor et al. (1991) and Croom et al. (1992) for the Canadian portions of the Atlantic (including Arctic) and Pacific oceans, which were based in part on the earlier Parks Canada work and in part on a global marine environmental classification scheme developed for IUCN (Hayden et al. 1984), were also reviewed.

Based on this earlier work and information on global marine classification systems from the open literature, CORI developed a base-case proposal for discussion purposes. In association with LGL Ltd., and coordinated by MEQAG, CORI then held a series of seven regional workshops soliciting input and feedback from approximately 70 marine scientists and science managers across Canada. At these workshops, participants considered appropriate diagnostic parameters and boundaries for various spatial ecological units of the three coasts of Canada.

CORI's proposal (Harper et al. 1993) was presented to the Marine Environmental Quality Advisory Group, whose members represented Environment Canada's Conservation and Protection Service, the State of Environment Reporting Service, and Canadian Parks Service (now in Heritage Canada). Their reviews resulted in a revision of CORI's proposed criteria used to delineate the top level division (i.e., ecozones), more emphasis being placed on physiography (ocean basins and archipelagos) than on seasonal and pack ice. After these revisions, the classification system was discussed further within MEQAG and with some other advisors, resulting in modifications to the Pacific Ecozone to more closely match the marine portions of the provincial ecological system. These changes, while deviating somewhat from a strictly hierarchical rule-based system developed by CORI (Harper et al. 1993), was felt to be a practical approach to integrating federal and provincial systems. This paper outlines the system accepted by the Marine Environmental Quality Advisory Group, and approved in March 1994 by the Interdepartmental Committee on Oceans (chaired by DFO) Marine Environmental Quality Working Group (co-chaired by DFO and Environment Canada).

3.0 RESULTS

A four-level classification has been developed. The highest level, **ecozone**, meshes fairly well with Hayden et al.'s (1994) global classification of ocean and coastal marine environments. At sub-ecozone levels, this classification system builds on the earlier two-dimension marine bioregion classification prepared for Parks Canada. The levels or orders of the system are intended to be compatible with, if not an extension of, the ecological classification system developed for Canada's land (Wiken 1986). Marine **ecoprovinces** are broad divisions of ecozones relevant to national and provincial environmental planning and management. Marine **ecoregions** are subdivisions of ecoprovinces intended to be useful for regional- to provincial-scale planning and management. The lowest level, **ecodistrict**, is local- to regional-scale marine ecosystems, and is intended to be the basic unit of coastal zone management. Angel (1994) and others have shown that physical and ecological complexity increases — i.e., uniformity decreases — inshore. This complexity is expressed in this classification system, in which the lower levels of the hierarchical structure tend to be more finely divided, particularly inshore and among islands and other features of physical diversity.

In this system, marine ecological units are determined by physical variables such as shoreline configuration, bathymetry, currents, and water column properties (including both physical properties such as temperature and chemical properties such as salinity and conductivity), and by processes such as mixing. The criteria selected are those with important ecological implications at the appropriate scales. These physical criteria pose constraints on which biota can live there, and on how they interact with each other and with their environment. In developing the criteria, we work from global-scale delineation criteria down through continental/ocean basin criteria to oceanic mixing criteria. We apply these criteria nationally so that the hierarchy remains consistent from region to region and each regional or subregional boundary is explicitly defined by one or more criteria. Inset boxes in the following section contain definitions, criteria, ecological implications, and boundary conditions for the Marine Ecozone, Marine Ecoprovince, Marine Ecoregion, and Marine Ecodistrict subdivisions.

3.1 Marine Ecozones

Marine Ecozone - an area of the earth's surface with global-scale influence on marine ecosystems.

Criteria: Ocean basins, inter-basin archipelagos, and presence/absence of permanent or seasonal ice are used to delineate these ecozones.

Ecological significance of marine ecozones:

- major influence on global climate patterns
- major component of global heat exchange between the atmosphere and ocean
- intercontinental oceanic circulation
- character of ice (pack, landfast, seasonal, drifting, or absent) a major factor controlling the use and productivity of marine biota
- restrictions between ocean basins indirectly controls global patterns of biota.

Boundary conditions: Continental margins; inter-basin straits, and archipelagos.

Oceanic Basins and Archipelagos

This criterion distinguishes oceanic waters associated with each of the major ocean basins and reflects the geologic and evolutionary history of the basins (inset below). Angel (1994) described how tectonic plate movements, long-term climatic changes, and sea level changes have driven speciation and extinction events. Continents have drifted, seabeds have spread, connections between land masses have opened and closed, and global circulation patterns have been altered. For example, in Canada the Beaufort Sea has at times during the Pleistocene Period been closed to the Pacific, but now is not; the Great Lakes have, during the Holocene Period (10 000 years before present until now), been at times freshwater, and at other times marine; and the eastern coastline has a complex freshwater/saltwater history owing to sea level changes (Pielou 1991). As well, global extinction events, such as those at the end of the Cambrian, Permian, and Tertiary Periods, created evolutionary bottlenecks where only the lucky species survived (Gould 1989). Therefore, the biological assemblages — and consequently the ecosystems — that exist today are the result of geologic and evolutionary history, with perhaps a strong element of serendipity.

Water Masses

Angel (1994) showed how water mass chemical properties such as dissolved nitrate, phosphate, and silicate are unique chemical signatures of ocean basins and reflect their gyral patterns. Angel (1994) also showed that the global oceans turn over at time scales of less than a millennium; hence, in the absence of any abiotic and biotic limitations to their ranges, marine organisms would rapidly become ubiquitous. That they are not is clear evidence for such limitations. It has become clear, through the work of Haury et al. (1978) and others, that basin-scale variability, both in terms of biomass distribution and assemblage type, is predominantly determined by the thermohaline circulation patterns which are largely driven by planetary forcing. Van der Spoel and Heyman (1983), synthesizing information on relationship between water masses — and hence gyral circulation of ocean basins — and zooplankton assemblages, derived the main biogeographic zones of the pelagic realm. Likewise, in the periphery of oceanic basins, i.e., the coastal zone, Briggs (1975, referenced in Angel 1994) described regions throughout which the fauna were largely similar and bounded by zones of rapid faunal change. Therefore, ocean basins and their associated coastal zones can be a primary criterion in defining marine ecosystems at a continental scale.

Climate

In defining ecozones based on ocean basins and archipelagos, the influence of climate patterns and their effect on water mass, and hence on biological communities, was considered. The Arctic Ocean is dominated by polar easterlies, permanent (pack and landfast, or shelf) and seasonal ice, and cold-water formation. The Atlantic Ocean circulation is driven by the same global wind patterns as the Pacific (west wind drift) but has unique water properties and circulation patterns, at least in the Canadian context, where oceanic currents are altered by continental boundaries. These water mass properties and circulation patterns have unique oceanic-scale effects on the biological communities and further qualify them for separation at the ecozone level.

Pack Ice

Permanent ice is included as a first-order criterion because of the profound and continental-scale effect it has on development of ecosystems. A permanent cap of ice covers the north polar sea, rotating in a counter-clockwise gyre owing to the Coriolis effect. It does not melt, although open leads develop at all seasons. Productivity is low because of the severe inhibition of light. Salinity is low and the water column highly stratified, owing to the freezing of freshwater expelling saline water downward, and the absence of wind-driven mixing; water mass exchange with other oceans does, however, occur. The few kinds of life that have adapted to this extreme environment also make it unique at the ecozone level.

Seasonal and Shelf Ice

The seasonal ice cover, characteristic of Arctic Archipelago and Northwest Atlantic Ecozones, and to a lesser extent the intrusion of drifting icebergs as occurs on the Atlantic coast, exert a major influence on water column properties, penetration of light, and distribution of biota. Many species have developed specific adaptations to survive in regions of recurring ice cover, and one biological community, the epontic (on the underside of ice), is unique to these zones. As ice melts in spring, the biota and nutrients on and in the under-ice surface are dispersed into the water column, initiating a sequence of primary and secondary production that follows the retreating ice edge. This annual phenomenon does not occur on permanent pack ice that covers the Arctic Basin, or on ice-free zones. In northern portions of the Arctic Archipelago Marine Ecozone, the ice between the islands becomes landfast and rarely or never melts, but is not part of the pack ice of the Arctic Basin.

3.2 Marine Ecoprovinces

Marine Ecoprovince - a portion of a Marine Ecozone characterized by major faunal assemblages, meso-scale ocean processes, and climate-driven ecological features.

Criteria: Meso-scale surface current patterns and continental margins are used to delineate marine ecozones.

Ecological significance of marine ecoprovinces:

- interaction between ocean current systems, or between oceanic and continental systems
- an indicator of meso-scale water masses
- an indicator of meso-scale biotic assemblages and productivity
- a meso-scale indicator of biological recruitment potential.

Boundary conditions: transition between oceanic currents or water masses, between oceanic and continental or shelf bathymetry, or between ecological systems dominated by coastal processes, and those not.

Oceanic Surface Circulation

Circulation patterns are strongly controlled by global wind patterns and, as such, Dietrich's (1963) classification implicitly incorporates climate criteria. Hayden et al. (1984) further subdivide Dietrich's Marine Realms into oceanic realms and coastal regions on the basis of physical and chemical properties, including salinity, temperature, and seasonal movement of water and air masses. They note that zoogeographic classifications closely reflect these major oceanic "realms." Surface circulation patterns indirectly control water temperature, upwelling and downwelling locations (hence nutrient regimes), and consequently primary and secondary productivity. The International Union for the Conservation of Nature (IUCN) has adopted the classification of Hayden et al. (1984) as a basis for protected area planning. We use regional or meso-scale ocean currents in combination with more detailed information on physical, chemical, and biological properties of water masses to discriminate three ecoprovinces in the Pacific Marine Ecozone, two in the Arctic Marine Ecozone, two in the Northwest Arctic Marine Ecozone, and four in the Atlantic Marine Ecozone.

Continental Margins

Continental margins are considered not only in terms of the continental shelf/water depth effect, but more importantly in terms of the proximity to freshwater sources from land. Freshwater produces changes in near-coast currents (e.g., coastal buoyancy currents), unique water masses, stratification, and nutrient sources. The shallow depth of shelves as compared to ocean basins controls the gross differences in benthic species and, to some extent, fish utilization. As a result of proximity to land, marine mammal and sea bird distributions are markedly different along the continental margins as compared to oceanic areas.

3.3 Marine Ecoregions

Marine Ecoregion - a part of a marine ecoprovince characterized by continental shelf-scale regions that reflect regional variations in salinity, marine flora and fauna, and productivity.

Criteria: Semi-enclosed marginal seas with significant freshwater input and marine-shelf areas delineate these marine ecoregions. There are seasonal variations in nutrient sources and common water mass properties and biotic assemblages among the ecodistricts that comprise the eroregion, driven by the same or similar processes.

Ecological significanceof these criteria:

- lower salinities in marginal seas due to terrestrial freshwater input and restricted marine water exchange
- estuarine-like stratification and circulation conditions in marginal seas and surrounding areas
- generally higher productivity in marginal seas due to terrestrial nutrient input and estuarine-like mixing processes
- estuarine-like biological assemblages (marginal seas) and transitional marine assemblages (marine shelf)
- biota generally require some feature tied to, or influenced by, terrestrial systems.

Boundary conditions: Extent of bathymetric features, such as coastline, continental shelf, continental slope, that constrain or interact with water mass movements, influence ecosystems and generate the processes characteristic of the region.

Marginal Seas

Marginal seas are defined as areas with a significant freshwater input; they may be semi-enclosed, such as Hudson Bay, or open shelf areas such as the Beaufort Sea. The distinguishing features are that the area has significantly reduced surface salinities, strong stratification, and an associated estuarine-like circulation system. These areas usually have high biological productivity associated with the nutrient source and circulation system.

3.4 Marine Ecodistricts

Marine Ecodistrict - a portion of a marine ecoregion characterized by unique areas of oceanic mixing processes and associated biotic communities.

Criteria: Mixing processes and stratification are used to delineate marine ecodistricts.

Ecological significance of these criteria:

- stratification resulting from combinations of mixing energy and water density variations
- well-mixed areas usually have a greater abundance of nutrients
- an indirect indicator of biological productivity where well-mixed areas usually have higher productivity than well-stratified areas.

Boundary conditions: Oceanographic, bathymetric, or topographic (land margin) restrictions on circulation that drive the mixing or water column structure and associated biological assemblages used to define the ecodistrict.

Mixing Processes

Mixing provides an index of the stratification and/or tidal mixing. Strong stratification prevails where mixing is weak and there is freshwater input (e.g., fjords), whereas areas of strong tidal currents are often vertically homogeneous or very weakly stratified (e.g., Bay of Fundy). Upwelling is included under this category as it is a special case of mixing. Mixing has important biological implications in that nutrients are usually distributed throughout the water column in well-mixed areas. Conversely, areas of strong stratification may experience nutrient depletion in some layers (e.g., fjords). Upwelling areas, including polynya in the Arctic, are usually associated with high productivity due to nutrient enrichment.

4.0 APPLYING THE CLASSIFICATION SYSTEM TO CANADA'S MARINE ENVIRONMENT

Five marine ecozones have been delineated: one in the Pacific Region, two in the Arctic Region, and two in the Atlantic Region. Dietrich's (1963) classification of the Northeast Pacific Ocean Realm corresponds with our Pacific Marine Ecozone. Our Pacific Marine Ecozone is also compatible with Croom et al.'s (1992) West Coast Fjords Province proposed to IUCN, except that we include Juan de Fuca Strait, whereas they consider it part of the more southerly Oregonian Province.

Application in the Pacific Marine Ecozone

The first-order subdivision involves the application of the "ocean basin" and "water mass" criteria and results in the delineation of one Marine Ecozone on Canada's Pacific coast (Table 1). The Bering Strait currently restricts water exchange between the Arctic and Pacific oceans to only waters above 50 metres. This restriction has contributed to the development of unique water properties in the Pacific Ocean where temperatures and salinities are higher than in the Arctic Ocean. Seasonal ice at the northern boundary in the Bering Sea and in the Sea of Okhotsk further alters water column properties and influences biota. Based on zoogeography and temperature regime, this ecozone may be considered as a boreal transition zone between the polar waters of the Arctic and the temperate waters of the Pacific Ocean in mid-latitudes (Thomson 1981). Between the southern tip of Vancouver Island and Dixon Entrance, ocean surface temperature declines approximately 3°C and reflects a steadily changing environment with progression northward. At any one latitude within this ecozone, oceanic water temperatures range approximately 7°C seasonally, which is reflected by differences in the characteristics of the biological community.

During glacial periods of the Pleistocene, Arctic and Pacific oceans were completely isolated by Beringia (Pielou 1991), allowing speciation to proceed separately in both oceans (Angel 1994). Consequently, while these environmental differences and evolutionary history are reflected in the differing ocean plankton species composition of the Arctic and Pacific Oceans (Hemleben et al. 1988), they are similar enough that Van Der Spoel and Heyman (1983) considered the northern Pacific and the southern Beaufort Sea a single biogeographic zone, based on zooplankton assemblages. On the other hand, Van Der Spoel and Heyman (1983) also documented breakpoints in species composition of coastal communities at the Bering Strait, at the Aleutian Peninsula, and at about the B.C.-Alaska border. Therefore, the differentiation between Arctic and Pacific ecozones based on physiography is also reflected in a transitional flora and fauna.

Marine mammals unique to the ecozone within Canada include Steller and California sea lions, sea otters, northern fur seals, giant and Stejnegers beaked whales, northern right-whales, dolphins, Pacific pilot whales, Dall's porpoises, and grey whales. Five species of anadromous salmon (Genus: *Oncorhynchus),* Pacific herring, halibut, and other groundfish form the backbone of the commercial fishery. This ecozone provides habitat within Canada for 4525 known species of marine invertebrates, including over 300 endemics, representing about 3.5% of the world's known invertebrates, and perhaps another 2000 species yet to be discovered (Lambert 1994; Tunnicliffe 1993). There are about 645 species and subspecies of benthic marine macroalgae (Hawkes 1994).

Breeding bird populations unique to the ecozone within Canada include fork-tailed petrels, Brandt's and Pelagic Cormorants, Pigeon Guillemot, Marbled and Ancient Murrelets, Cassin's and Rhinoceros Auklets, and Tufted and Horned Puffins; 74% of the world population of Ancient Murrelets and 80% of the world's Cassin's Auklet population breed in British Columbia (Campbell et al 1990).

Tables 1 to 4 summarize the general physiographic, oceanographic, and biological characteristics of subdivisions in the Pacific ecozone.

TABLE 1. Characteristics of the Pacific Marine Ecozone

Marine Ecozone	Physiographic Characteristics	Oceanographic Characteristics	Biological Characteristics
Pacific	Pacific Ocean Basin includes spreading ridges, transform faults, and plate subduction zone; moderately wide shelf and partial separation from Arctic Ecozone.	Pacific Ocean water masses classified as boreal transition zone; general eastward-setting oceanic current (Subarctic Current) with divergence point off the shelf.	Unique oceanic plankton community; many species of fish and marine invertebrates, many with planktonic larvae unique to the Pacific Ocean; marine mammals and birds have less ocean-specific mobility.

TABLE 2. Characteristics of the Pacific Marine Ecoprovinces

Marine Ecoprovinces	Physiographic Characteristics	Oceanographic Characteristics	Biological Characteristics
Northeast Pacific	Includes abyssal plain, continental rise, and continental slope; a major transform fault occurs along the west margin and a seamount chain trends NW/SE.	Eastward-flowing Subarctic Current bifurcates at coast with northerly- flowing Alaskan Current; current flow generally northward throughout year.	Boreal plankton community; summer feeding ground for Pacific salmon stocks; abundance of pomfret, Pacific saury, albacore tuna, & jack mackerel in summer; marine mammals plentiful; important seabird colonies including alcids, auklets, & petrels.
Transitional Pacific	Includes abyssal plain, continental rise and continental slope; also includes spreading ridges, geothermal vents, transform faults, triple junction, and plate subduction zone.	Area of variable currents; southerly areas may be affected by southward-flowing California Current in summer but remainder of area characterized by weak and variable currents; Davidson Current along shelf edge flows north in winter, south in summer.	Transition zone between southerly, temperate and northerly, boreal plankton communities; mixing of oceanic and coastal plankton communities adjacent to the coastal shelf; geothermal vent biota; feeding grounds for southern fish stocks; marine mammals moderately abundant; seabird breeding grounds for auklets, puffins, & petrels.
Pacific Shelf/Fjords	From shelf edge landward; most water depths less than 300 m except areas of Queen Charlotte Sound and some of the deeper mainland fjords; coastline highly crenellated, rocky and with moderate relief.	Strongly influenced by freshwater runoff that reduces salinity of shelf waters, increases turbidity, drives coastal boundary currents, and creates an "estuarine-like" circulation and stratification.	Strong coastal, estuarine signature in plankton community; high occurrence of planktonic larvae for coastal fish & invertebrates in summer; feeding grounds for southerly fish stocks in summer; commercially important shellfish; abundant marine mammal populations; important breeding grounds for seabirds & waterfowl, e.g., alcids & auklets.

TABLE 3. Characteristics of the Pacific Marine Ecoregions

Marine Ecoregions	Physiographic Characteristics	Oceanographic Characteristics	Biological Characteristics
Abyssal Plain	Spreading ridges, geothermal vents, transform faults, triple junction and plate subduction zone.	Variable currents as described in Table 4.	Transition and mixing zone as described in Table 4; vent biota.
Continental Slope	The continental shelf drops off sharply near the shelf break at 200 m.	The continental slope between the 200 m and 2000 m depth contours defines general division between oceanic and physical processes characterized by upwelling.	Mixture of neritic and oceanic plankton communities; rich fishing grounds for salmon, herring, and groundfish; feeding areas for large populations of seabirds.
Pacific Shelf	Generally shallow, gently sloping shelf (<200 m), except Queen Charlotte Sound which is slightly deeper with a series of banks and channels; numerous fjords and islands.	Characterized by transitional "estuarine" and "marine" water masses and associated currents; open Pacific wave exposure; generally northerly currents in winter, southerly currents in summer.	Strong coastal signature of neritic plankton species; high primary productivity; rich benthic community; feeding grounds for temperate fish, mammals, and marine birds.
Georgia Basin	Large strait characterized by numerous channels; fjords and islands; adjacent coastal lowlands.	Enclosed basin with large freshwater input (including Fraser River); high turbidity; generally well stratified with "estuarine-like" circulation patterns.	Neritic, estuarine plankton species; productive and protected habitats for juvenile fish and invertebrates; some productive benthic invertebrate areas; marine mammals such as seals are abundant; feeding area for marine birds (shorebirds, waterfowl, and seabirds).

TABLE 4. Characteristics of the Pacific Marine Ecodistricts

Marine Ecodistricts	Physiographic Characteristics	Oceanographic Characteristics	Biological Characteristics
North Coast Fjords	Interconnected fjords with outer sills and deep troughs, bounded by islands; soft bottom except rocky sills and sides.	Strong freshwater input at fjord heads, highly stratified, hypoxia at depth.	Low productivity owing to turbid water, except for marsh plants in estuaries; and attached invertebrate communities in areas of strong tidal flow; impoverished benthos; seabird wintering areas.
Dixon Entrance	Across-shelf trough with depths mostly <300 m; surrounded by low-lying coastal plains (Hecate Depression).	Strong freshwater influence from mainland river runoff drives northwestward- flowing, coastal buoyancy- driven current and "estuarine-like" circulation.	Mixture of neritic and subpolar plankton species; migratory corridor for Pacific salmon; some productive and protected areas for juvenile fish and invertebrate development.
Hecate Strait	Very shallow strait dominated by coarse bottom sediments; surrounding coastal lowlands.	Semi-protected waters with strong tidal currents that promote mixing; dominantly "marine" waters.	Neritic plankton communities with some oceanic intrusion; nursery area for salmon and herring; abundant benthic invertebrate stocks; feeding grounds for marine mammals and birds.
Queen Charlotte Sound	Wide, deep shelf characterized by several large banks and inter-bank channels.	Ocean wave exposures with depths mostly >200 m and dominated by oceanic water intrusions.	Mixture of neritic and oceanic plankton communities; northern limit for many temperate fish species; lower benthic invertebrate production.
Queen Charlotte Strait	Deep, narrow fjords cutting into high coastal relief.	Protected waters with restricted circulation and often strongly stratified.	Unique species assemblages in benthic and plankton communities.
Johnstone Strait	Narrow, constricted channels.	Protected coastal waters with strong currents; well mixed, poorly stratified.	Migratory corridor for anadromous fish; diverse species assemblage of benthic fish; rich sessile, hard substrate invertebrate community.

Marine Ecodistricts	Physiographic Characteristics	Oceanographic Characteristics	Biological Characteristics
Vancouver Island Shelf	Narrow, gently sloping shelf.	Open coast with oceanic wave exposures; north- ward, coast-hugging, buoyancy-driven current due to freshwater influence; seasonal upwelling at outer margin.	Highly productive with neritic plankton community; northern limit for hake, sardine, northern anchovy, Pacific mackerel; rich fishing, grounds for benthic fish and invertebrates.
Strait of Georgia	Broad shallow basin surrounded by coastal low- lands (Georgia Depression).	Protected coastal waters with significant freshwater input, high turbidity, and seasonally stratified; very warm in summer.	Neritic plankton community; nursery area for Pacific salmon, herring; abundant shellfish habitat.
Juan de Fuca Strait	Deep trough; a major structural feature accentuated by glacial scour.	Semi-protected coastal waters with strong "estuarine-like" outflow current (coast-hugging, buoyancy-driven current to north); major water exchange conduit with "inland sea."	Mixture of neritic and oceanic plankton species; migratory corridor for anadromous fish; moderately productive.

LITERATURE CITED

Angel, M.V. 1994. Spatial distribution of marine organisms: Patterns and processes. *In* P.J. Edwards, R.M. May and N.R. Webb (eds.), Large scale ecology and conservation biology. Blackwell Scientific Publ., Oxford.

Campbell, R.W., N.K. Dawe, I. McTaggart-Cowan, J.M. Cooper, G.W. Kaiser, and M.C.E. McNall. 1990. The birds of British Columbia, Vol. 1: Nonpasserines. Royal B.C. Museum and Canadian Wildlife Service, Victoria, B.C.

Croom, M.M., R.J. Wolotira, and W. Henwood. 1992. Proposed biogeographic subdivision of the Northeast Pacific marine realm. Unpublished report submitted to IUCN, Lauzanne, Switzerland.

Davis, D. 1994. A systems approach to the identification of marine protected areas. Presented at Ecosystem Monitoring and Protected Areas, the Second International Conference on Science and Management of Protected Areas, Halifax, May 16-20, 1994.

Demarchi, D.A., R.D. March, A.P. Harcombe, and E.C. Lea. 1989. The Environment. *In* R.W. Campbell, N.K. Dawe, I. McTaggart-Cowan, J.M. Cooper, G.W. Kaiser, M.C.E. McNall. Birds of British Columbia, Vol. 1: Nonpasserines. Royal B.C. Museum and Environment Canada, Victoria, B.C.

Dietrich, D. 1963. General oceanography: An introduction. Interscience Publishers, N.Y.

Dunbar, M.J. 1951. Eastern Arctic waters. Bull. Fish. Res. Bd. Canada, No. 88.

Dunbar, M.J., 1985. The Arctic marine ecosystem. *In* F.R. Englehardt (ed.), Petroleum effects in the Arctic environment. Elsevier Applied Science Publishers, London and New York.

Dunbar, M.J., and D.M. Moore. 1980. Marine life and its environment in the Canadian Eastern Arctic: A biogeographic study. Marine Science Center Manuscript No. 33. McGill University, Montreal, Que.

Ecoregions Working Group. 1989. Ecoclimatic regions of Canada, first approximation. Ecological Land Classification Series, No. 23. Environment Canada, Ottawa, Ont.

Gould, S.J. 1989. Wonderful life: The Burgess Shale and the nature of history. Norton Co., New York, N.Y.

Haber, E. and A. Whittock. 1995. Benthic marine algae of the Canadian Arctic: Taxonomy, diversity, rarity and centres of species diversity. Canadian Wildlife Service and Canadian Museum of Nature, Ottawa, Ont.

Harper, J.R., G.A. Robilliard, and J. Lathrop, 1983. Marine regions of Canada: Framework for Canada's system of national marine parks. Contract Report by Woodward-Clyde Consultants, Victoria, for Parks Canada, Ottawa, Ont.

Harper, J.R., J. Christian, W. Cross, R. Frith, G. Searing and D. Thomson. 1993. A classification of the marine regions of Canada. Contract Report by Coastal and Ocean Resources Inc. to Environment Canada, North Vancouver, B.C.

Haury, L.R., J.A. McGowan, and P.H. Wiebe. 1978. Patterns and processes in the time-space scales of plankton distributions, pp. 277-328. *In* I. Steele (ed.), Spatial patterns in plankton communities. Plenum, N.Y.

Hawkes, M.W., 1994. Benthic marine algal flora (seaweeds) of British Columbia: Diversity and conservation status. *In* L.E. Harding and E. McCullum (eds.), Biodiversity in British Columbia: Our changing environment. Environment Canada, Vancouver, B.C.

Hayden, B.P, G.C. Ray, and R. Dolan. 1984. Classification of coastal and marine environments. Environmental Conservation 11(3):199-207.

Hemleben, C., M. Spendler, and O.R. Anderson. 1988. Modern planktonic foraminifers. Springer-Verlag, N.Y.

Lambert, P. 1994. Biodiversity of marine invertebrates in British Columbia. *In* L.E. Harding and E. McCullum (eds.), Biodiversity in British Columbia: Our changing environment. Environment Canada, Vancouver, B.C.

Mondor, C.A., F.M. Mercier, and M.M. Croom. 1991. Proposed subdivision of the northwest Atlantic marine realm for planning a global system of marine protected areas. Unpublished report submitted to IUCN, Lauzanne, Switzerland.

Pielou, E.C. 1991. After the ice age: The return of life to glaciated North America. Univ. Chicago Press, Chicago, Ill.

Rowe, J. S. 1977. The forest regions of Canada. Ministry of Supply and Services, Ottawa, Ont.

Thomson, R.E. 1981. Oceanography of the British Columbia coast. Department of Fisheries and Oceans, Can. Spec. Publ. Fish Aquat. Sci. 56.

Tunnicliffe, C. 1993. The marine biota of British Columbia. *In* M.A. Fenger, E.H. Miller, J.E. Johnson and E.J.R. Williams (eds.). Our living legacy: Proceedings of a symposium on biological diversity. Royal British Columbia Museum, Victoria, B.C.

Van Der Spoel, S. and R.P. Heyman. 1983. A comparative atlas of zooplankton: Biological patterns in the oceans. Springer-Verlag, New York, N.Y.

Wiken, E. 1986. Terrestrial ecozones of Canada. Environment Canada, Ecological Land Classification Series, No. 19.

Wilson, R. and R. Addison [eds.]. 1984. Health of the northwest Atlantic. Department of the Environment, Department of Fisheries and Oceans, Department of Energy, Mines and Resources.

DISCUSSION

Jon Sector: John, will you briefly explain the rationale for putting the coastal fjords in three different classifications?

John Harper: I may throw that one partially back to Lee. We originally had the coastal fjords as one complete eco-section, recognizing that the function and the ecology of a fjord was pretty similar, all the way from Jervis Inlet to Portland Canal.

I don't know whether I used the term, but there are backroom boys involved in these things. You put things in, and they come back and they're different. You can't find any documentation on why it's changed. I'm sure Lee Harding has quite a few grey hairs related to that. The State-of-the-Environment people are very concerned with lines. They want to match up lines from their terrestrial classifications with the marine classifications, so they move boundaries around with that objective. Their objective is to match those lines; it's not ecological integrity. So it changed. I'm not sure why the South Coast Fjords got deleted. That happened after my involvement.

Lee Harding: This gets into the area of the arbitrary nature of the process, which I mentioned. You've made a strong argument that once you establish the criteria, there shouldn't be anything else arbitrary; you just put the data and the criteria in, and it falls out that way.

It isn't that straightforward, to my way of thinking and to my colleagues' way of thinking. For one thing, if you follow that process slavishly — not to be pejorative — and take it to the nth degree, you end up in one region of Canada having two eco-districts, and in another region you might have a hundred. A hundred is unmanageable for the managers in that region. They say, "No, that's just too many. It won't work for us."

You said that people argue about the boundaries. I don't believe, from my perspective, that people argue about the boundaries so much as the assignment of one area to a level of hierarchy. All the scientists who participated in the process would agree on the degree of heterogeneity or homogeneity of the particular region they were looking at. It was the assignment of this particular level that was introduced. It was a judgment call. There was some juggling, if you will, at those levels, even though the criteria they were using to define the regions were the same and were applied consistently.

There were some other arbitrary natures. I mentioned the Demarchi zoning method. I can't defend it any more than you can or are willing to, and I'm not going to try. It's there for some reason that may be obvious to some and not obvious to others. If it doesn't come out in the next analysis or edition or review or whatever, that's the way it comes out.

Did I answer the question?

John Sector: In a word, no. The question I asked has been answered, but I guess I asked the question wrongly. The real question is not why or what is the rationale for the bureaucracy in the process. The real question in my mind is: Are the south coast fjords, which are part of your Georgia Basin classification ecologically, and from a land and water use point-of-view, more like the mid-coast fjords and the north coast fjords than they are like the Strait of Georgia? Why are those attached to the Strait of Georgia and not in a fjord classification? It's a physiographic and ecological question I'm asking, not a process question.

Don Howes: It's spatial; area and size become a function of what you include at what level. Lee was talking about that. The way I look at it, you've got the Georgia Basin, and if I'm breaking that down into "subunits" or "ecounits," that may be the first cut. There may be a reason for that. If they were larger, they might fit into a hierarchy. You could look at the west side of Vancouver Island. Why are some of the inland waters not separated? Well, they will fall out at the next level of the classification. There's this size and spatial distribution that comes into play in defining it and where it fits in the hierarchy. I think that's what Lee was trying to say.

Colin Levings: That really is a question to be answered in the session about time and space scales.

THE DEVELOPMENT OF AN ECOSYSTEM CLASSIFICATION USING AN ECOSYSTEM-BASED APPROACH

Mark A. Zacharias, Don. E. Howes
BC Land Use Coordination Office
PO Box 9426 Stn. Prov. Govt.
Victoria, B.C. V8W 9V1

John R. Harper
Coastal and Ocean Resources Inc.
9865 West Saanich Road
Sidney B.C. V8L 1S3

1.0 INTRODUCTION

Experience in terrestrial environments has demonstrated that the management, conservation, and preservation of individual species is difficult from both ecological and political standpoints (Edwards 1996; Scott et al. 1993). Species-based approaches as a means for conservation have been criticized for several reasons. These include their inability to address species of concern in a timely manner, their expense, and their bias towards "charismatic megafauna" (Jennings 1995; Scott et al. 1993).

In response to these concerns, a number of inventory and analysis tools have been developed for the conservation of ecosystems (Cherrill et al. 1995; Conroy and Noon 1996; Edwards 1996; Jennings 1995; Merrill et al. 1995; Scott et al. 1993). These tools are collectively known as "ecosystem approaches," and include ecosystem classification, landscape ecology, and gap analysis (Caicco et al. 1995; Davis and Reiners 1996; Short and Hestbeck 1995). Ecosystem approaches are implemented by mapping biological and physical data over large areas to identify "representative" and "distinct" areas, as well as gaps in the habitat ranges of species of concern so that mitigation strategies for their conservation can be developed (Scott et al. 1993).

Although the ecosystem approach has been accepted as part of the terrestrial conservation ethic, there has been less effort at developing methodologies to supplement the single-species approach in marine systems (Brunkhorst and Bridgewater 1995; Canada 1994; Cowardin et al. 1979; Davis 1995; Dethier 1992; Harding and Hirvonen 1996; Harper et al. 1993; Howes et al. 1996; Ray 1976; Salm and Clarke 1984; Taylor and Roff 1997). This deficiency was recognized as early as the 1950s, when many authors predicted the worldwide collapse of fisheries as a result of an inadequate understanding of population ecology, food webs, and habitat requirements (Carson 1963; Hardin 1966; Ray 1976). The lack of an ecosystem approach for marine conservation has also recently been noted by Norse (1993), Thorne-Miller and Catena (1991), and the National Research Council (1995). These authors conclude that traditional approaches to marine conservation are often inadequate, and that new techniques — including ecosystem approaches — must be developed (Norse 1993; Thorne-Miller and Catena 1991; National Research Council 1995).

There has been progress in the development of marine ecosystem classifications in recent years, but these endeavors still lag behind terrestrial efforts (Brunkhorst and Bridgewater 1995; Canada 1994; Cowardin et al. 1979; Dethier 1992; Harding and Hirvonen 1996; Harper et al. 1993; Howes et al. 1996; Ray 1976; Salm and Clarke 1984; Taylor and Roff 1997). The Province of British Columbia has been active in the development of terrestrial and marine ecosystem approaches for coastal zone management, marine protected area site identification, and oil spill countermeasures mapping. This paper reviews the development of ecosystem-based approaches for the Canadian portions of the northeast Pacific, and how they have been applied to coastal issues.

2.0 THE PHYSICAL BASIS FOR THE ECOSYSTEM APPROACH

Terrestrial ecosystem mapping was developed out of a requirement to identify current and historical boundaries of communities, and the abiotic conditions that support them (Cherrill et al. 1995; Conroy and Noon 1996; Edwards 1996; Jennings 1995; Merrill et al. 1995; Scott et al. 1993). In doing so, it was found that a knowledge of climate, vegetation, soils, and other abiotic properties could be used to predict the occurrence of higher vertebrate species. This knowledge was particularly useful in environments where these species were depleted as a result of human activities (Caicco et al. 1995; Davis and Reiners 1996; Short and Hestbeck 1995). The majority of primary producers in terrestrial environments are large — often homogenous — vascular species readily identified by the human eye, and are amenable to small-scale mapping techniques such as airborne and satellite remote sensing (Scott et al. 1993). Consequently, vegetation can be used in the prediction of vertebrate species (bottom up) or physical characteristics such as soils or climate (top down), and form the basis of terrestrial ecosystem mapping (Scott et al. 1993).

Marine environments, however, are very different. With the exception of the macroalgae in photic environments, primary producers consist of phytoplankton (often bacteria) whose numbers of species are still being estimated, and are subjected to constant transport (Norse 1993). The secondary consumers depending on these phytoplankton are just as diverse and poorly understood, and the cryptic nature of marine food webs continues upward through the large vertebrates (Mann and Lazier 1996; Thorne-Miller and Catena 1991). Our knowledge of the life histories of some of the most studied marine vertebrates is still poorer than almost all terrestrial vertebrate species (National Research Council 1995).

Our lack of biological knowledge is compounded by the pronounced effect of human activities on marine environments. Almost all data collected in marine environments have been affected by anthropogenic activities (Norse 1993). Considerable amounts of marine data are obtained from fishery catch statistics, where the act of observation (fishing) changes community composition and biomass. The northeast Pacific is also being studied subsequent to the removal of important herbivores and predators, including the Stellar's sea cow (*Hydrodamalis gigas*) and sea otter (*Enhydra lutris*) (Vermeij 1993). Many populations of non-harvested marine species are thought to have declined, but there is little empirical evidence to support this position (Thorne-Miller and Catena 1991). Consequently, the use of non-harvested species to describe the "natural state" of ecosystems may be erroneous.

In the northeast Pacific, humans, plants, and animals arrived simultaneously with the retreat of glaciation. Therefore there is no natural state in the absence of anthropogenic activities that conservation strategies strive to reproduce. In parts of the coastal northeast Pacific, indigenous peoples far outnumbered current populations, and harvested certain marine species in greater numbers than are presently harvested (British Columbia 1992; Cannings and Cannings 1996).

There is also considerable debate on the importance of biological versus physical determinants in marine systems (Dayton 1995; Mann and Lazier 1996; National Research Council 1995). Until recently, many authors supported the generalization that physical mechanisms and processes are more important than biological processes in defining community and trophic structure, and that pelagic systems are more physically influenced, while benthic environments are biologically accommodated (Etter and Grassel 1992; Ricklefs 1987; Thorne-Miller and Catena 1991). There are, however, new studies suggesting that physical processes define most aspects of the marine environment, and are more important in benthic systems than originally thought (Harris 1994; Meyers 1994; Roughgarden et al. 1994). The importance of the physical determining the biological becomes more noticeable as the scale of observation becomes smaller. The importance of small scale (large area) perturbations can be seen in what Harris (1994) terms the "horizontal" or within species, and the "vertical" or trophic structure. Physical processes are also more limiting on smaller rather than larger organisms, as smaller species are more affected by viscosity and inertia problems in a liquid medium (Angel 1994; Mann and Lazier 1996). Current theory also suggests that the greater the severity of the physical environment, the greater its effect on biological processes (Mann and Lazier 1996; Roughgarden et al. 1994).

In summary, the above observations suggest that physical and chemical processes control the biotic character of marine systems to a much greater extent than terrestrial environments. Human activities have also altered the biological composition of marine systems to the extent that their natural state is often difficult to characterize. In light of these considerations, British Columbia has chosen to base the development of an ecosystem approach on physical and chemical considerations rather than biological processes.

3.0 APPLICATIONS OF AN ECOSYSTEM APPROACH TO THE DEVELOPMENT OF THE BC MARINE ECOLOGICAL CLASSIFICATION

British Columbia currently has several marine and coastal programs underway and/or completed that are based on ecosystem approaches. The most comprehensive is the British Columbia Marine Ecological Classification (BCMEC) system. The classification is hierarchical and consists of four nested divisions based on physical properties, and a fifth division based on current, depth, bottom substrate, bottom relief, and wave exposure. The fifth division — the ecounit — was created at a considerably larger scale (1:250 000), and is the first example of a large-scale marine classification applied over a large area (453 000 km^2) (Harper et al. 1993; Howes et al. 1996; Zacharias and Howes 1998; Zacharias et al. [1998]). Ecounits were developed to evaluate the boundaries and homogeneity of the four larger divisions, as well as for the application to coastal management and marine protected areas planning. The ecounits represent work in progress, and are continually being updated as additional physical and chemical datasets become available. Salinity and temperature are currently being added to the ecounits. A detailed description of the classification can be found in Howes et al. (1996), and Zacharias et al. [1998] and plots of the various divisions are shown in Figures 1 and 2.

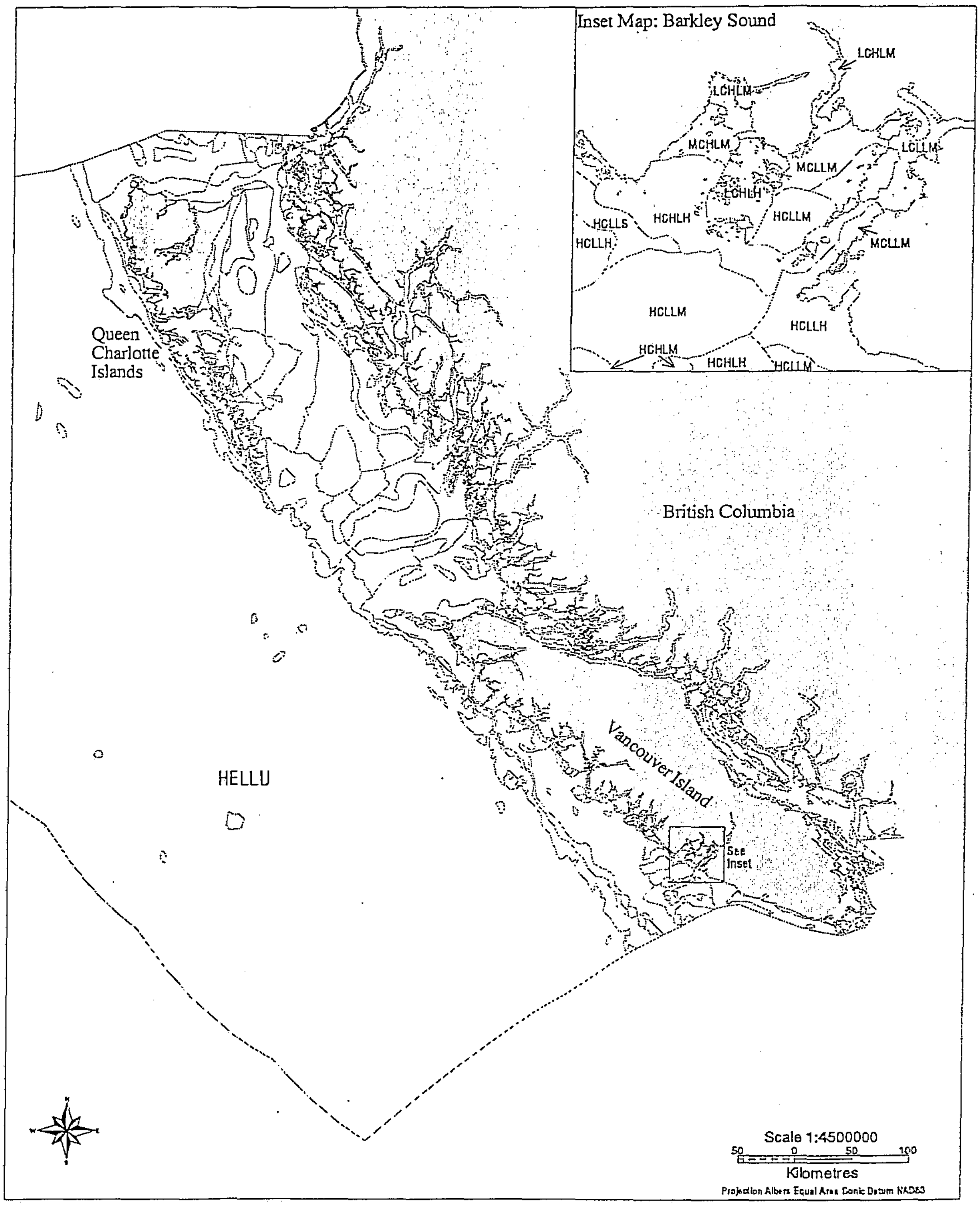


FIGURE 1. Marine Ecozones, Ecoregions, Ecoprovinces, and Ecosections of the B.C. Marine Ecosystem Classification.

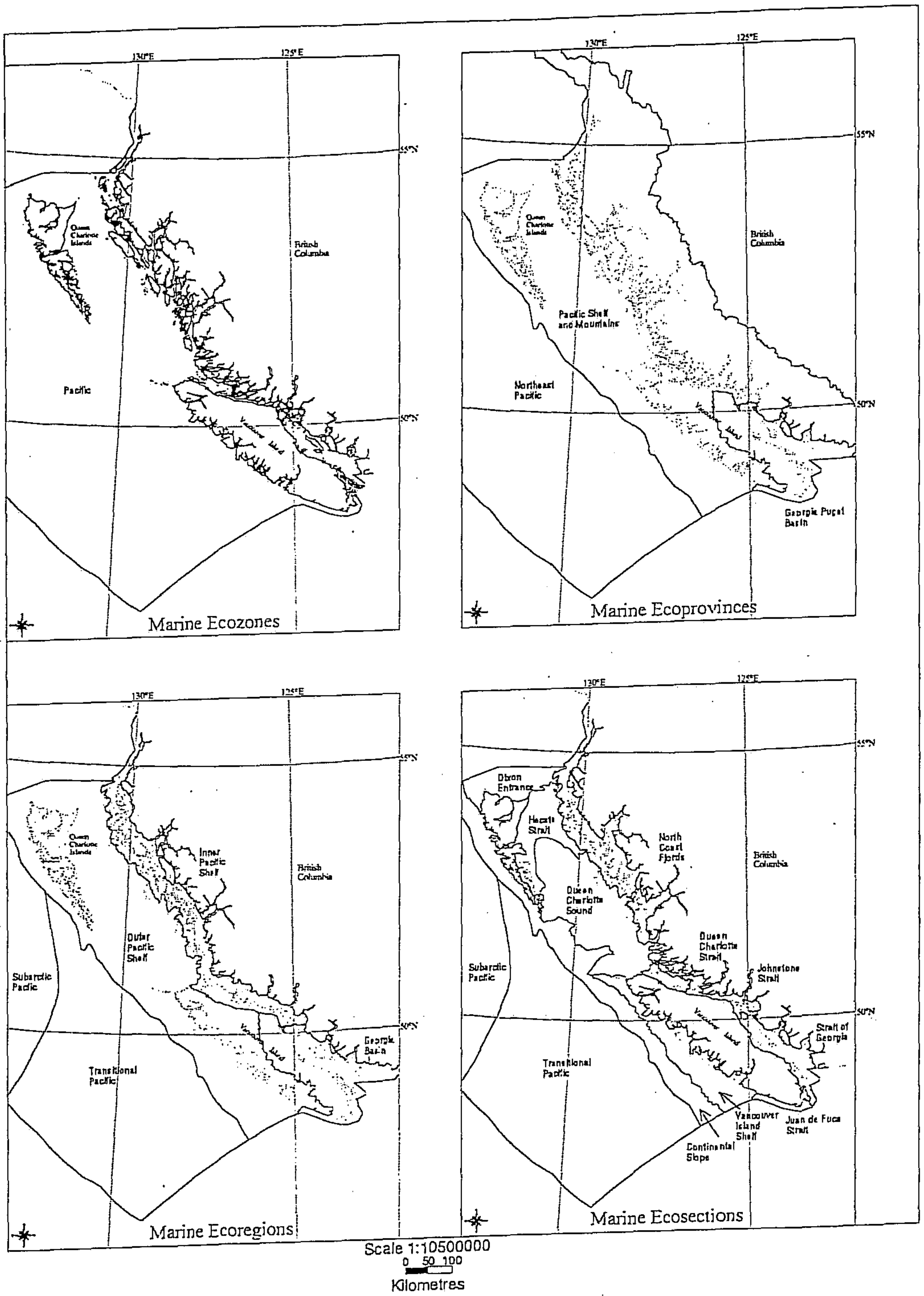


FIGURE 2. Marine Ecounits of the B.C. Marine Ecosystem Classification. The scale of the ecounits is 1:250 000. A legend is not shown because there are 65 possible combinations of current, depth, wave exposure, relief, and substrate for the 619 Ecounits.

4.0 APPLICATION OF THE BCMEC

The BCMEC was used to assess marine protected areas in British Columbia. Protected areas were assessed as a percentage of total marine area and shoreline length for each ecosection and ecounit. Results indicate that 1.25% of British Columbia's marine areas have some degree of protection. If the abyssal (> 1000 m) regions are excluded, this number rises to 4.22%. For British Columbia's 29 489 km of shoreline, 14.36% is protected in some way (Zacharias and Howes 1998). Results also indicate that high exposure, high current, and hard substrate environments have greater representation than other areas. In addition to assessing the amount of marine protected area within each ecosection and ecounit theme, the BCMEC is being used in the establishment of marine reserves using a representative ecosystems approach, and the development of a GAP analysis methodology for marine environments.

The BCMEC is a tool for identifying ecological boundaries in order to assess the representativeness of the current system of protected areas. The knowledge that one type of environment is more protected than another is not sufficient for proper marine planning. Each type of habitat or environment must be assessed in light of the ecological, economic, and social significance of that area compared to other areas. Nowhere is this more apparent than in the Strait of Georgia ecosection, which is not only under-represented with respect to other ecosections, but has global significance as habitat for migratory birds and many other species (British Columbia 1993b). The Strait of Georgia ecosection also supports one of the most rapidly growing human populations in the developed world.

The long-term objective of the BCMEC is to establish the ecological links between the physical characteristics of the marine environment and the habitat requirements of the species that inhabit these environments. While there is still much work to be accomplished, there is evidence that the ecosystem-based approach presented in this paper is a step towards this objective. Incorporation of additional physical, chemical, and biological data is underway, and will improve the ecounit level of the BCMEC to a point where broad-based inferences about community composition and habitat type can be made.

LITERATURE CITED

Angel, M.V. 1994. Long-term, large-scale patterns in marine pelagic systems. *In* P.S. Giller [ed.]. Aquatic Ecology. Proc. BES symposium, Cork, 1992. Blackwell Scientific, New York, N.Y.

British Columbia. 1992. The aboriginal peoples of British Columbia: a profile. Ministry of Aboriginal Affairs, Victoria, B.C.

Brunckhorst, D.J. and P.B. Bridgewater. 1995. Marine bioregional planning: A strategic framework for identifying marine reserve networks, and planning sustainable use and management. *In* N. Shackel and M. Woolaston [eds.] MPA and Sustainable Fisheries. Science and Management of Protected Areas Association, Ottawa, Ont.

Caicco, S.L., J.M. Scott, B. Butterfield, and B. Csuti. 1995. A gap analysis of the management status of the vegetation of Idaho (U.S.A). Conservation Biology 9:495–511.

Canada. 1994. A marine ecological classification system for Canada. Marine Environmental Quality Advisory Group, Ottawa, Ont.

Cannings, R. and S. Cannings. 1996. British Columbia: A natural history. Douglas and McIntyre Ltd., Vancouver, B.C.

Carson, R. 1963. The sea around us. Oxford University Press, Oxford, UK.

Cherrill, A.J., C. McClean, K. Tucker, S.P. Rushton, and R. Sanderson. 1995. Predicting the distributions of plant species at the regional scale: A hierarchical matrix model. Landscape Ecology 10:197–207.

Conroy, M.J. and B.R. Noon. 1996. Mapping species richness for conservation of biological diversity: Conceptual and methodological issues. Ecological Applications 6:763–773.

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. Fish and Wildlife Service, U.S. Department of the Interior. FWS/OBS-79/31.

Davis, D.S. 1995. A systems approach to the identification of marine protected areas. *In* N. Shackel and M. Woolaston [eds.]. MPA and Sustainable Fisheries. Science and Management of Protected Areas Association. Ottawa, Ont.

Davis, F. and W.A. Reiners. 1996. The nature of GAP analysis. Bioscience 46:390–390.

Dayton, P.K. 1995. Scaling, disturbance, and dynamics: stability of benthic marine communities. *In* T. Agardy [ed.]. The science of conservation in the coastal zone: New insights into how to design, implement, and monitor Marine Protected Areas. IUCN, Gland, Switzerland.

Dethier, M.N. 1992. Classifying marine and estuarine natural communities: An alternative to the Cowardin system. Natural Areas Journal 12(2):90–99.

Edwards, T.C. 1996. Data defensibility and GAP analysis. Bioscience 46:75–77.

Etter, R.J. and J.F. Grassle. 1992. Patterns of species diversity in the deep sea as a function of sediment particle size diversity. Nature 360:576–578.

Hardin, G. 1966. The tragedy of the commons. Science 162:1243–1248.

Harding, L. and H. Hirvonen. 1996. Marine ecological classification for Canada. Preliminary report to Environment Canada. Vancouver, B.C.

Harris, G. P. 1994. Pattern, process and prediction in aquatic ecology. A limnological view of some general ecological problems. Freshwater Biology 32(1):143–160.

Harper, J.R., J. Christian, W.E. Cross, R. Frith, G.F. Searing, and D. Thompson. 1993. A classification of the marine regions of Canada. Environment Canada, Ottawa, Ont.

Howes, D.E., M.A. Zacharias, and J.R. Harper. 1996. The marine ecoregions of British Columbia. Resource Inventory Committee. Victoria, B.C.

Jennings, M.D. 1995. Gap analysis today: A confluence of biology, ecology, and geography for management of biological resources. Wildlife Society Bulletin 23:658–662.

Mann, K.H. and J.R.N. Lazier. 1996. Dynamics of marine ecosystems: Biological – physical interactions in the oceans. Blackwell Science, London, UK.

Merrill, T.R.G. Wright, and J.M. Scott. 1995. Using ecological criteria to evaluate wilderness planning options in Idaho. Environmental Management 19:815–825.

Myers, A.A. 1994. Biogeographic patterns in shallow-water marine systems and the controlling processes at different scales. *In* P.S. Giller [ed.]. Aquatic Ecology. Proc. BES symposium, Cork, 1992. Blackwell Scientific, New York, N.Y.

National Research Council. 1995. Understanding marine biodiversity. National Academy Press, Washington, D.C.

Norse, E.A. 1993. Global marine biological diversity: Strategy for building conservation into decision making. Island Press, Washington, D.C.

Ray, G.C. 1976. Critical marine habitats. IUCN Publication 37. Gland, Switzerland.

Ricklefs, R.E. 1987. Community diversity: Relative roles of local and regional processes. Science 235: 167-171.

Roughgarden, J., T. Pennington, and S. Alexander. 1994. Dynamics of the rocky intertidal zone with remarks on generalization in ecology. Philosophical Trans. Roy. Soc. London. B 343(1303):79–85.

Scott, J.M., F. Davis, B. Csuti, R. Noss, B. Butterfield, C. Groves, H. Anderson, S. Caicco, F. D'Erchia, T.C. Edwards Jr., J. Ulliman, and R.G. Wright. 1993. Gap analysis: A geographic approach to protection of biological diversity. Wildlife Monographs 123:1–41.

Salm, R.V. and J.R. Clark. 1984. Marine and coastal protected areas: A guide for planners and managers. State Printing, Columbia, S.C.

Short, H.L. and J.B. Hestbeck. 1995. National biotic resource inventories and GAP analysis. Bioscience 45:535–539.

Taylor, M.E. and J.C. Roff. 1997. A classification system for marine conservation. Draft report to the World Wildlife Fund, Ottawa, Ont.

Thorne-Miller, J. and J.G. Catena. 1991. Living Ocean: Understanding and protecting marine biodiversity. Island Press, Washington, D.C.

Vermeij, G.J. 1993. Biogeography of recently extinct marine species: Implications for conservation. Conservation Biology 7:391–397.

Zacharias, M.A. and D.E. Howes. 1998. An analysis of marine protected areas in British Columbia using a marine ecological classification. Natural Areas Journal 18(1).

Zacharias, M.A., D.E. Howes and J.R.H. Harper. [1998]. The British Columbia marine ecosystem classification: rationale, development, and verification. Coastal Management (in press).

DISCUSSION

Jennifer Lash: This may come up in the presentations later today in terms of identifying sites for marine protected areas. You talked about using ecounits—or was it ecosections, which are still quite large areas. As you know from the marine environment, areas such as nursery grounds and spawning areas are quite small isolated areas. Quite often they're not identified through the current parameters used in identifying systems. How can we ensure that we are getting representation in terms of conservation of biodiversity and more than just conservation of the actual physical habitat?

Don Howes: Using ecounits, going back, was done about three years ago, and it was just basically a dartboard. The MPA stuff we've done is from an ecosection level, just to see how we're doing within the ecosection. I think we need to get to these types in units. Once we get to the types in units — and I think we're pretty close to doing that in the intertidal; we're within a couple of months — that's one start. I think that's the real answer to your question. You need that lower level of the ecological classification.

Jennifer Lash: So what we really need is some more subtidal data telling us what's down there.

Don Howes: Yes, we've got the picture now. We brought a lot of information from the GSC. We have the bottom substrates. Vegetation is a little tougher. There's no doubt that there are gaps in what we're going to try to do over the next three to six months, but I'm more inclined to go and try to do it — to do something. You can always tear it down and build it up again.

Jennifer Lash: As long as we're aware that there are gaps.

Don Howes: But you could wait forever for information, and you're never going to have enough.

Jennifer Lash: Exactly.

Steve Samis: I was relating your talk, Don, to Lee Harding's. You both had coloured maps of the coast, but I wasn't clear whether yours and Lee's were complementary, supportive, or in disagreement.

Don Howes: They're actually supportive, other than the North Coast fjords, which was, I believe, in one of the earlier drafts. Was it not, John? I don't know the history behind why the North Coast fjords changed. There would be subtle differences in the boundary lines.

John Harper: It's the same, Don.

Don Howes: Oh, it's the same! Basically, when John and Lee did their first approach, they used 1:1 000 000 data, I believe. We brought in five themes with various sub-attributes at 1:250 000. We felt that was better resolution for the next generation of boundaries. They're basically in agreement.

Mark Zacharias: Just a quick note. We have done a preliminary gap analysis with eco-sections and ecounits with marine protected areas. I'm just using legislative mechanisms that are in place. This is coming out in January in the *Natural Areas Journal*. It's the small units and the larger units. We also have a paper in *Coastal Management* — hopefully coming out soon — which discusses the whole creation of the ecounits, but more importantly how they're used to verify the larger ecosections. If anyone needs copies of that, let me know.

A BIOPHYSICAL HABITAT CLASSIFICATION FOR INTERTIDAL ENVIRONMENTS IN THE STRAIT OF GEORGIA

Mark A. Zacharias, Don E. Howes, and Carol Ogborne
Land Use Coordination Office
Province of British Columbia
836 Yates St.
Victoria, B.C. V8V 3Z4

Mary Morris
Archipelago Marine Research Ltd.
2nd Floor, 525 Head Street
Victoria, B.C. V9A 5S1

1.0 INTRODUCTION

Considerable research effort has been directed toward the study of intertidal communities, and the physical and chemical processes that support them. Some of the more notable research on the "bottom-up" include papers by Menge (1992), Menge et al. (1983), Paine and Levin (1982), Raimondi (1988), Schoch and Dethier (1996), and Underwood and Jernakoff (1984). These studies, however, tend to be experimental in nature, where the scales of study ranged from centimetres to kilometres. More recently, several systematic inventory programs have been established to collect abiotic data over large areas. These new datasets facilitate the development of large-scale shoreline habitat classifications, which can then be used in coastal planning, marine protected areas, and oilspill countermeasures and sensitivity mapping.

This paper presents a habitat classification methodology in the Strait of Georgia, an area which is representative of the physical characteristics as well as biotic communities that comprise intertidal habitats. The input data used in the classification were collected according to published resource inventory methodologies, which are currently being applied to the collection of intertidal data throughout British Columbia's 29 500 km of shoreline. The approach presented here used a combination of two methodologies, the Two Way Indicator Species Analysis (TWINSPAN) for clustering site by species data, and regression tree models using abiotic data as predictors.

2.0 STUDY AREA AND METHODS

The study area for this research is the Strait of Georgia (the Strait), consisting of 4107 km of shoreline of the Canadian portions of the Georgia–Puget Basin (the Basin). British Columbia and Washington State have representatives sitting on a joint habitat loss working group, but before any meaningful discussion on habitat loss can be initiated, methods to quantify the types and amount of habitat that currently exist must be created. This information can subsequently be used to form a baseline dataset for long-term monitoring, and to estimate the historical habitat capability of the Strait.

This research was separated into two components. The first task was to collect baseline biotic and abiotic data through a combination of fieldwork and modelling. These data were then used to develop a biophysical habitat classification. A detailed description of each step is outlined below.

3.0 COLLECTION OF BASELINE BIOPHYSICAL DATA

The basis of this analysis was the B.C. Physical Shorezone Mapping System, which provides for the systematic recording of shoreline morphology, shore-zone substrate, and wave exposure characteristics (Howes et al. 1993). This system subdivides the shoreline into along-shore units and across-shore components, and is based on aerial video and field reconnaissance surveys. The system classifies the shoreline into 34 "coastal classes" and 16 "representative types" using a four-component classification based on substrate, sediment, width, and slope (described in Table 1). These coastal classes and representative types were then attached to a 1:40 000-scale digital shoreline coverage, in which each homogenous section of coastline became what is termed a "shore unit." There are 2509 shore units in the Strait of Georgia. Most of the intertidal length of the Strait is composed of rock cliffs (26%); when intertidal area is considered, estuaries and wetlands make up approximately 34% of the total (Figure 1). A large proportion of the intertidal length and area is composed of sand and gravel flats (11% and 17% respectively), and anthropogenic (artificial) shorelines represent about 6% of the Strait.

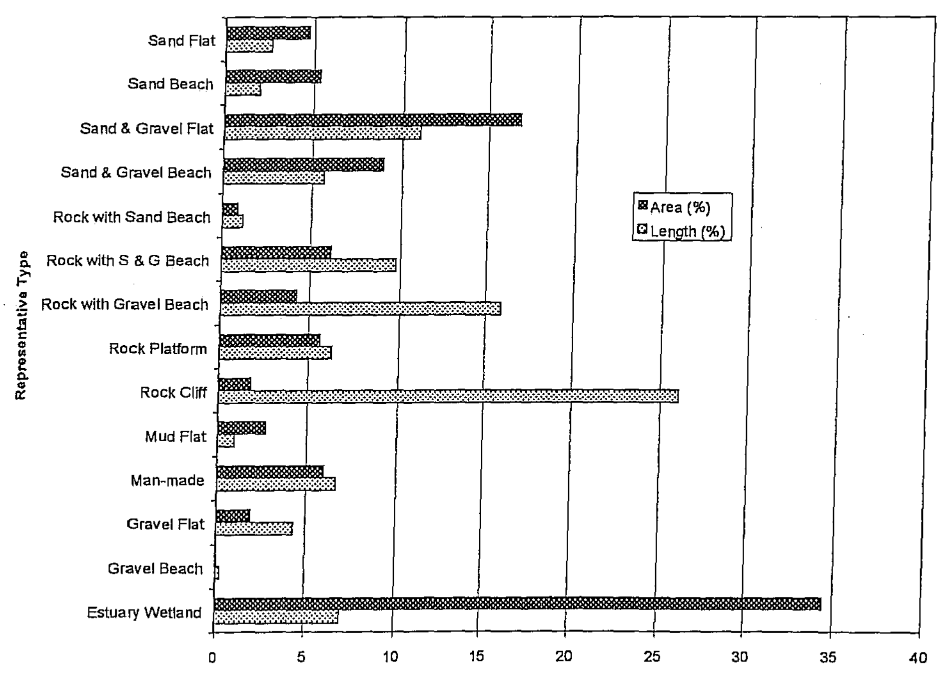


FIGURE 1. Proportion of intertidal length and area, Strait of Georgia, by representative type.

TABLE 1.The British Columbia physical shoreline mapping system

Substrate	Sediment	Width	Slope	Coastal Class	No	Representative Type	No
			Steep	n/a			
		Wide (>30 m)	Inclined (5-20)	Rock ramp, wide	1	Rock platform	2
Rock	n/a		Flat (<5)	Rock platform, wide	2	Rock platform	2
			Steep (>20)	Rock cliff	3	Rock cliff	3
		Narrow (<30 m)	Inclined (5-20)	Rock ramp, narrow	4	Rock cliff	3
			Flat (<5)	Rock platform, narrow	5	Rock platform	2
			Steep (>20)	n/a			
		Wide (>30 m)	Inclined (5-20)	Ramp with gravel beach, wide	6	Rock with gravel	4
	Gravel		Flat (<5)	Platform with gravel beach, wide	7	Rock with gravel	4
			Steep (>20)	Cliff with gravel beach	8	Rock with gravel	4
		Narrow (<30 m)	Inclined (5-20)	Ramp with gravel beach	9	Rock with gravel	4
			Flat (<5)	Platform with gravel beach	10	Rock with gravel	4
			Steep (>20)	n/a			
		Wide (>30 m)	Inclined (5-20)	Ramp w gravel & sand beach, wide	11	Rock with sand and gravel	5
Rock and Sediment	Sand & Gravel		Flat (<5)	Platform with G&S beach, wide	12	Rock with sand and gravel	5
			Steep (>20)	Cliff with gravel/sand beach	13	Rock with sand and gravel	5
		Narrow (<30 m)	Inclined (5-20)	Ramp with gravel/sand beach	14	Rock with sand and gravel	5
			Flat (<5)	Platform with gravel/sand beach	15	Rock with sand and gravel	5
			Steep (>20)	n/a			
		Wide (>30 m)	Inclined (5-20)	Ramp with sand beach, wide	16	Rock with sand	6
	Sand		Flat (<5)	Platform with sand beach, wide	17	Rock with sand	6
			Steep (>20)	Cliff with sand beach	18	Rock with sand	6
		Narrow (<30 m)	Inclined (5-20)	Ramp with sand beach, narrow	19	Rock with sand	6
			Flat (<5)	Platform with sand beach, narrow	20	Rock with sand	6
		Wide (>30 m)	Flat (<5)	Gravel flat, wide	21	Gravel flat	15
	Gravel		Steep (>20)	n/a			
		Narrow (< 30 m)	Inclined (5-20)	Gravel beach, narrow	22	Gravel beach	7
			Flat (<5)	Gravel flat or fan	23	Gravel beach	7
			Steep (>20)	n/a			
		Wide (> 30 m)	Inclined (5-20)	n/a			
Sediment	Sand & Gravel		Flat (<5)	Sand & gravel flat or fan	24	Sand and gravel flat	14
			Steep (>20)	n/a			
		Narrow (< 30 m)	Inclined (5-20)	Sand and gravel beach, narrow	25	Sand and gravel beach	8
			Flat (<5)	Sand & gravel flat or fan	26	Sand and gravel beach	8
			Steep (>20)	n/a			
		Wide (> 30 m)	Inclined (5-20)	Sand beach	27	Sand beach	9
	Sand/mud		Flat (<5)	Sand flat	28	Sand flat	10
			Flat (<5)	Mudflat	29	Mud flat	11
			Steep (>20)	n/a			
		Narrow (<3 0 m)	Inclined (5-20)	Sand beach	30	Sand beach	9
			Flat (<5)	n/a			
	Organics - Fines	n/a	n/a	Estuaries	31	Estuary, marsh or lagoon	12
	Artificial	n/a	n/a	Artificial, permeable	32	Anthropogenic	13
			n/a	Artificial, impermeable	33	Anthropogenic	13
	Channel			Channel	34	Channel	16

Current, salinity, and temperature data from the C3 three-dimensional baroclinic model were incorporated into each shoreunit. C3 is a model used to calculate currents, salinity, and temperature based on tides, wind transport, freshwater inputs, oceanic effects, currents, and water levels (Seaconsult 1996; Stronach et al. 1993). C3 is the most recent of a series of models developed for the Georgia Basin, and is based on a rewritten version of the GF8 model developed by the Department of Fisheries and Oceans (Crean et al. 1988a, 1988b; Stronach et al. 1993). Applications of the C3 include modelling sediment and contaminant transport, pollution, tsunami or storm surge events, and primary productivity (Seaconsult 1996; Stronach et al. 1993).

For this study, the C3 model was run to create monthly means for salinity, temperature, and currents in the Strait. As the Fraser River discharge drives many of the physical, chemical, and biological processes in the Georgia Basin, the model was run using years of historical minimum (1980), mean (1977), and maximum (1976) Fraser River discharges. Output from the C3 includes temperature (°C), salinity in parts per thousand (ppt), current speed in the positive grid x direction (cms^{-1}), and current speed in the positive grid y direction (cms^{-1}) (Seaconsult 1996). The grid for the simulation reported here had a 2000 X 2000 m spacing in the horizontal, and a non-uniform 20-layer vertical spacing through the first 10 m of the water column to resolve the near-surface vertical gradients associated with freshwater river plumes, insolation, and phytoplankton growth and decay (Seaconsult 1996; Stronach et al. 1993).

These modified shoreunits, however, were insufficient to describe the species, assemblages, and communities found in these environments. Previous studies have shown that the incorporation of other abiotic properties, including depth, slope, aspect, freshwater inputs, dessication, shade, and availability of nutrients may be used to successfully predict intertidal biological composition (Carefoot 1977; Denny et al. 1985; Dethier 1988; Harper 1995; Johansen 1972; Lewis 1964; Menge et al. 1983; Paine and Levin 1981; Schoch and Dethier 1996; Seapy and Littler 1978; Underwood and Jernakoff 1984). Although we have a reasonably comprehensive physical dataset, we do not have systematic data for the above properties, and as a result it was necessary to incorporate biological data with the abiotic data to create the intertidal habitat classification.

In contrast to the abiotic datasets discussed above, there is no systematic and synoptic biological sampling program in place in the Strait. The biological data available are often specific to a particular project, and collected in such a way that is difficult to relate to other studies. Consequently, in the summers of 1996/7 we collected species abundance data for 104 species at 87 sites throughout the Strait. Species were catalogued as rare, few, common, or abundant. Only macrobiota and fauna were catalogued to minimize sampling effort and disturbance to the sampled sites (i.e., no rock turning).

4.0 CREATING A HABITAT CLASSIFICATION

To attach biological community structure to the shorelines of the Strait, a methodology had to be designed that incorporated both the systematic physical data (shore units, salinity, temperature, currents, and fetch) and the infrequent species sample stations. One of the objectives of this methodology was the creation of a biological community model that could be applied to the remainder of the unsampled shorelines in the Strait. The habitat classification presented here uses the Two Way INdicator SPecies ANalysis (TWINSPAN) to define species associations and subsequent community types, which were then used as the response variables in a regression tree model based on shoreline morphology, fetch, salinity, temperature, and current velocity (Gaugh 1995; Venebles and Ripley 1995). A detailed description of the methodology is described below.

Site-by-species data were clustered using the TWINSPAN software with sites clustered by similarity of species type and presence or absence. Although species abundance data were collected, these data were reduced to presence/absence codes to allow for the fact that the various samplers may have quantified the number of organisms differently. Eight TWINSPAN clusters were generated using the third TWINSPAN hierarchy. The resulting TWINSPAN clusters were then used as response variables in an exploratory technique — regression tree modelling — to classify the various shoreline physical properties into homogenous classes. Tree-based techniques were selected for this study because the input datasets consist of both continuous data (temperature, salinity, currents, and fetch) and categorical data (shoreline morphology). The technique can also be used to generate a set of predictive binary rules that can be applied to other datasets. This method is an improvement on many clustering techniques, because the tree is generated using regression techniques that are independent of scale, and each cluster is defined by an easily interpreted set of rules that can be applied to any location in our study area. In addition, for each tree node or branch, the proportion of variance explained by the model can be easily determined (Gaugh 1995; Venables and Ripley 1995). The tree models are based on a recursive partitioning approach, which uses a set of predictor variables (x) to generate a single response variable (y). In this research, the predictor variables include the physical data, and the response variables are the TWINSPAN community codes.

While initial results were generated using this methodology, a problem with the TWINSPAN software has since been discovered (1997). We are currently repeating the analysis using an updated version of the TWINSPAN software. Results should be available in 1998.

5.0 SUMMARY

There have been many shoreline inventory programs throughout the world, but very few systems are structured to systematically assess a large area for gaps and conservation priorities. This approach to shoreline conservation is feasible, and may provide an indication of how gap analysis may be applied in the nearshore, coastal, and offshore environments.

LITERATURE CITED

Carefoot, T. 1977. Pacific seashores. Univ. Washington Press, Seattle, Wash.

Crean, P. B, T.S. Murty, and J.A. Stronach. 1988a. Mathematical modeling of tides and estuarine circulation. Springer-Verlag, New York, N.Y.

Crean, P.B, T.S. Murty, and J.A. Stronach 1988b. Numerical simulations of oceanographic processes in the waters between Vancouver Island and the mainland. Oceanography and Marine Biology: Annual Review 26:11–42.

Denny, M.W., T.L. Daniel, and M.A.R. Keohl. 1985. Mechanical limits to size in wave-swept organisms. Ecological Monographs 55:69–102.

Dethier, M.N. 1988. A survey of intertidal communities of the Pacific coast area of Olympic National Park, Washington. Report submitted to the National Parks Service.

Gaugh, H.G. 1995. Multivariate analysis in community ecology. Cambridge University Press.

Harper, J.R. 1995. Physical processes overview for the west coast of Vancouver Island. Report to the Land Use Coordination Office, Victoria, B.C.

Howes, D.E., J.R. Harper, and E. Owens. 1993. British Columbia physical shore-zone mapping system. British Columbia Resource Inventory Committee, Victoria, B.C.

Johansen, H.W. 1972. Effects of elevation change on benthic algae in Prince William Sound, pp. 35–68. *In* K.B. Krauskopf [ed.]. The great Alaska earthquake of 1964. National Academy of Sciences, Washington, D.C.

Lewis, J.R. 1964. The ecology of rocky shores. England University Press, London, U.K.

Menge, B.A. 1992. Community regulation: Under what conditions are bottom-up factors important on rocky shores. Ecology 73:755–765.

Menge, B.A., L.R. Ashkenas, and A. Matson. 1983. Use of artificial holes in studying community development in cryptic marine habitats in a tropical intertidal region. Marine Biology 77:129–142.

Paine, R.T. and S.A. Levin, 1981. Intertidal landscapes: Disturbance and the dynamics of pattern. Ecological Monographs 51:145–178.

Raimondi, P.T. 1988. Rock type affects settlement, recruitment, and zonation of the barnacle *Chthamalus anispoma* Pilsbury. Journal of Experimental Marine Biology and Ecology 123:253–267.

Schoch, G.C. and M.N. Dethier. 1996. Scaling up: The statistical linkage between organismal abundance and geomorphology on rocky intertidal shorelines. Journal of Experimental Marine Biology and Ecology 201:37–72.

Seaconsult Marine Research. 1996. C3 model output documentation and users guide. Seaconsult Marine Research Ltd., Vancouver, B.C.

Stronach, J.A, J.O. Backhaus, and T.S. Murty. 1993. An update on the numerical simulation of oceanographic processes in the waters between Vancouver Island and the Mainland: the C3 model. Oceanography and Marine Biology Annual Review 31:1–86.

Seapy, R.R. and M.M. Littler. 1978. The distribution, abundance, community structure, and primary productivity of macroorganisms from two central California rocky intertidal habitats. Pacific Science 32:293–314.

Underwood, A.J. and P. Jernakoff. 1984. The effects of tidal height, wave exposure, seasonality and rock pools on grazing and the distribution of intertidal macroalgae in New South Wales. Journal of Experimental Marine Biology and Ecology 75:71–96.

Venables, W.N. and B.C. Ripley. 1995. Modern applied statistics in Splus. Springer-Verlag, New York, N.Y.

Zacharias, M.A. and D.E. Howes. 1998. An analysis of marine protected areas in British Columbia using a marine ecological classification. Natural Areas Journal 18(1).

DISCUSSION

Bill Austin: On the salinity, can you tweak the data so you can show the differences between the low salinity in the summer related to the Fraser River, and during the winter, inside? Can you differentiate between silt and salinity in terms of the actual effect?

Mark Zacharias: For part A, yes. Our salinity comes out of the C-3 or GF-8 model as monthly averages. In the slide I showed, you can see that certain species are key to certain salinity and/or temperatures part of the year, particularly with recruitment strategies. What you saw in the 'tree' here is that it just happened on temperature in May; it didn't need salinity for this particular run. If we go further down the hierarchy, yes, it would be important. Our model didn't use salinity because we didn't have perfect sampling throughout the Strait. Some areas were better sampled than others.

Rob Russell: Can you tell me whether these classification systems apply primarily to intertidal areas or whether they're also applicable to the deeper areas further out in the Strait.

Mark Zacharias: The one we've been working on is strictly intertidal. As soon as in our sampling program we saw intertidal species — or species known to be intertidal — we stopped. Maybe Don wants to talk about some of the subtidal work we've been working on.

Don Howes: Briefly, we've been working on a couple of things. Through the RIC Committee two years ago, in 1996, Jackie [Booth] worked with the team and looked at a lot of the information and datasets in the near-shore. Recently we're working on, and are in the process of developing, a near-shore classification. We're doing some testing with different techniques we hope will reduce our costs for collecting that information. It's still evolving.

As far as other datasets go, we have collected pieces, elements, of the near-shore zone. For example, kelp, bottom substrate, etc. So it's something that we're evolving. Hopefully at the end of this fiscal year this work will be done, and we'll be writing it up as a RIC Report.

Glen Jamieson: I have a question concerning your classification of the intertidal. It's not designed to be attacking in any sense, but I think it just shows the complexity of what's involved here.

One of the definitions of the intertidal is that it's affected by air factors, environmental factors, as well as by the marine. From a clam perspective, some of the winter temperatures from outflow winds and so on — the cold can be very lethal to some animals. I'm wondering how you considered, in the intertidal, the effects of meteorological data.

Mary Morris: The occurrence of the species, whether they're there or not, is an index of the physical parameters at that site. What we did here is two separate analyses. The species presence/absence was taken as the clustering and the indication for the species grouping, and then we attached it to the physical ones. So I would say that winter conditions at sites are indirectly indexed by presence/absence of the things that we saw on the beach. Does that answer your question?

Glen Jamieson: Yes, thank you.

ECOSYSTEM CLASSIFICATION OF THE STRAIT OF GEORGIA: PHYSICAL OCEANOGRAPHIC DELINEATION

Richard E. Thomson
Institute of Ocean Sciences
9860 West Saanich Road
Sidney, B.C. V8L 4B2

The purpose of this talk is to delineate the principal ecosystem regimes of the Strait of Georgia based on its physical oceanographic characteristics, with specific focus on water mass properties and oceanic forcing mechanisms.

1.0 OVERVIEW OF THE REGION

The Georgia-Fuca System, comprising the Strait of Georgia, Puget Sound, and Juan de Fuca Strait, is part of an extensive estuarine regime situated between southern Vancouver Island and the mainland coasts of British Columbia and Washington State (Figure 1). Much of the waterway occupies submerged portions of the Georgia Depression whose formation began some 150 million years ago as part of a general downfolding of the earth's crust along the Pacific coast that followed commencement of the latest era of continental drift. The present configuration reflects the regional restructuring that took place during a series of ice ages throughout the Quaternary period.

At the peak of the last ice age, 15 000 to 20 000 years ago, glaciation extended as far south as Seattle and regional sea levels were about 100 m higher than they are today. Puget Sound, the largest of the multitude of fjords left behind by the retreating coastal glaciers is located 135 km from the Pacific Ocean and is the southern-most glacially-carved fjord-like estuary on the west coast of North America. The Strait of Georgia and Juan de Fuca Strait are true channels in that they are open at both ends and communicate with the open North Pacific.

For simplicity, we can view the region as a set of interconnecting boxes which receive runoff from the Fraser, Skagit, and other coastal rivers (Figure 2). The runoff mixes with the underlying oceanic water (much of the mixing taking place at the shallow sills separating the boxes in Figure 2) to produce a classic estuarine circulation with outflow of brackish water in the upper layer and inflow of saline water in the lower layer (Figure 3). Most of the exchange is through Juan de Fuca Strait, but a fraction also is through the northern channels.

2.0 WATER MASS ANALYSIS

Helland-Hansen in 1918 was the first to suggest the utility of plotting water temperature (T) against salinity (S). He found that these "T-S diagrams" were similar over large areas of the ocean and remained constant in time at many locations. An early application of the T-S diagram was the testing and editing of newly acquired hydrographic bottle data. When compared with existing T-S curves for a particular region, T-S curves from newly collected data quickly highlighted erroneous samples which could then be corrected or eliminated. Similar characteristic diagrams were developed for other ocean properties, such as dissolved oxygen and temperature. Many of these, however, were not conservative and could not be expected to exhibit the constancy of the T-S relationship.

Since this is a short talk, I have concentrated only on the summer data, using what is still the best basin-scale survey data for the Strait of Georgia system: that collected by Patrick Crean and Allard Ages for each month in 1968 from the entrance of Juan de Fuca Strait to the northern end of the Strait of Georgia (Figures 4 and 5). Based on the summer Temperature–Salinity (T-S; Figure 6) and Oxygen–Salinity (O-S; Figure 7) distributions for this region, there are a number of distinct regimes:

• Juan de Fuca Strait (JdF), extending from the Pacific entrance to southern end of Haro and Rosario straits;

• Haro Strait and Rosario Strait (HS), which have very similar T-S characteristics (with the much shallower Rosario Strait having a much smaller cross-section than Haro Strait);

• The southern Strait of Georgia, where there is vigorous flow exchange and mixing between the southern channels and the main body of the Strait;

• The central Strait of Georgia, extending northward to the southern end of Texada Island (this regime receives the main volume of fresh water from the Fraser River runoff);

• The northern Strait of Georgia, occupying the northern portion of the Strait but excluding the eastern side of Vancouver Island where the water properties are strongly affected by the southward density "jet" entering through Seymour Narrows on the flood;

• Johnstone Strait, whose water property structure has much in common with Juan de Fuca Strait;

• The major inlets such as Howe Sound (Figure 8), Burrard Inlet, and points north. The inlets have separate oceanic regimes where surface outflow of riverine water strongly affects the water property structure.

The T-S and O-S diagrams also show considerable cross-channel structure (Figures 9 and 10) especially at the northern and southern extremes of the Strait of Georgia, where dense currents are flowing into the intermediate and deep portions of the basin. The most dense water enters the deep portion of the Strait of Georgia in late summer (Figure 11, bottom panel), and is associated with upwelling on the outer coast.

T-S and O-S structures for winter and for other seasons are different from those for summer, particularly in the upper 50 m of the water column. There also are differences at depth, as dense water can intrude deeper and farther into the Strait in late summer than in other seasons. Not only is there a three-dimensional spatial structure to the water properties, there is also a temporal component to the water mass structure.

3.0 AN ENERGETICS CLASSIFICATION SCHEME

Another way of classifying the Strait of Georgia is through the dynamic processes that affect the currents and water mass formation. This scheme distinguishes between strong tidal channels (Figure 12) such as Active Pass, Porlier Pass, and Boundary Passage, and more quiescent flow regions, such as the northern portion of the Strait of Georgia and Boundary Bay in the south.

Oceanographic variability within these interconnecting basins is driven by regional forcing mechanisms that are strongly coupled to oceanic processes occurring over the continental margins of British Columbia and Washington State. The two principal components of the circulation within the waterway are: buoyancy- (freshwater) driven estuarine circulation and tidal currents. These components of the flow are then modified spatially and temporally by other factors including:

- Regional winds (time scales of hours to seasons to decades);
- Coastline and bottom topographic effects (e.g., topographic "steering," coastal backeddying);
- Bottom and internal friction (bottom drag and eddy viscosity);
- Inertial forces (non-linear "jets," tidal rectification, shear-induced mixing); and
- External factors related to up-strait propagation of oceanic "events" originating over the outer continental margin (e.g., intrusive density currents, internal Kelvin waves, wind-induced upwelling).

Each mechanism affects a component of the circulation, which in turn affects the water properties and other oceanographic aspects. To understand how the system works, we need to examine the individual components.

4.0 BUOYANCY (FRESHWATER) FLUXES

The primary estuarine circulation consists of outflow of relatively low-salinity water in the upper layer and inflow of relatively high-salinity water in the lower layer. Outflow at the top; inflow at the bottom (Figure 3). In the Georgia-Fuca System the nominal surface flow is out of Puget Sound, out of Juan de Fuca Strait, and out of the Strait of Georgia — at both ends. Roughly 85–95% of the flow volume is through Haro and Rosario straits with the remaining flow through Johnstone Strait.

The first-order mechanisms that can affect the basic strength of the estuarine circulation are:

- The amounts of runoff from the major rivers (mainly the Fraser River) which enter mostly in late spring, with a secondary bulge in late fall (see inset, Figure 3); and
- The intensity, duration, and distribution of vertical mixing and proximity to shallow sills.
- Secondary changes to the basic estuarine flow pattern are then brought about by winds and offshore water property structure (Figure 2).

5.0 THE TIDE-GENERATING FORCE

Superimposed on the quasi-steady estuarine circulation are time-varying motions dominated by the tidal motions having 2 ebbs and 2 floods per day of (generally) unequal height and current strength. In the Georgia-Fuca system, this spring-neap cycle in the tidal currents has an important impact on the oceanic exchange processes. Of particular importance is the fact that tidal currents supply the mechanical energy to mix away the stratification of the upper water column provided by the river runoff. That is, mechanical mixing by the tidal currents versus potential energy stored in the density structure (Figure 13). This leads to *hydraulic control* of both flushing of brackish water from the surface and intrusion of deep water along the bottom. The surface water easily escapes the Strait during sub-critical flow periods when there is little vertical mixing in the passes and is more strongly retained in the Strait during super-critical flow periods when vertical mixing is most intense.

6.0 SURFACE WIND STRESS

The surface winds play an important role in modifying the relationship between the tidal currents and the estuarine flow. In particular, summer northwesterlies (Figure 2) help drive the fresh water southward into the Strait of Georgia and eventually seaward via Juan de Fuca Strait (Figure 14). This also facilitates the flux of brackish water out of and dense water into the Strait. Strong southerly winds along the outer Washington coast in late fall and early spring (Figure 2) are responsible for reversal of the estuarine flow structure in Juan de Fuca Strait. This is either in the form of a density intrusive internal wave or an internal Kelvin wave generated along the outer coast and then propagating inward along the channel.

7.0 SUMMARY

Based on the observed water property structure and dynamics of the region, the Strait of Georgia-Puget Sound system can be divided into several oceanic domains (Figure 15) beginning with the quasi-oceanic regimes of Juan de Fuca Strait in the south and Johnstone Strait in the north. Haro Strait and Rosario Strait are combined into a separate oceanographic regime, as is Discovery Passage to the north. The Strait of Georgia is divided into distinct southern, central, and northern oceanographic domains. The coastal inlets are delineated as separate oceanographic regimes based on their low surface salinities and high stratification.

LITERATURE CITED

Crean, P.B. and A. Ages. 1971. Oceanographic records from twelve cruises in the Strait of Georgia and Juan de Fuca Strait, 1968. Vol. 1-5, Dept. Energy, Mines and Resources, Marine Sciences Branch, Victoria, B.C. 389 p.

Foreman, M.G.G., R.A. Walters, R.F. Henry, C.P. Keller, and A.G. Dolling. 1995. A tidal model for eastern Juan de Fuca Strait and the southern Strait of Georgia. J. Geophys. Res., C1, 100: 721-740.

Hellend-Hansen, B. 1918. Nogen hydrografiske metoder. Forh. Skand. Naturforskeres, 16, Kristania.

Thomson, R.E. 1994. Physical oceanography of the Strait of Georgia–Puget Sound–Juan de Fuca Strait System, pp. 36–100. *In* R. Wilson, R. Beamish, F. Aitkens, and J. Bell [eds.]. Review of the marine environment and biota of Strait of Georgia, Puget Sound and Juan de Fuca Strait. Cdn. Tech. Report of Fish. Aquat. Sci., 1948.

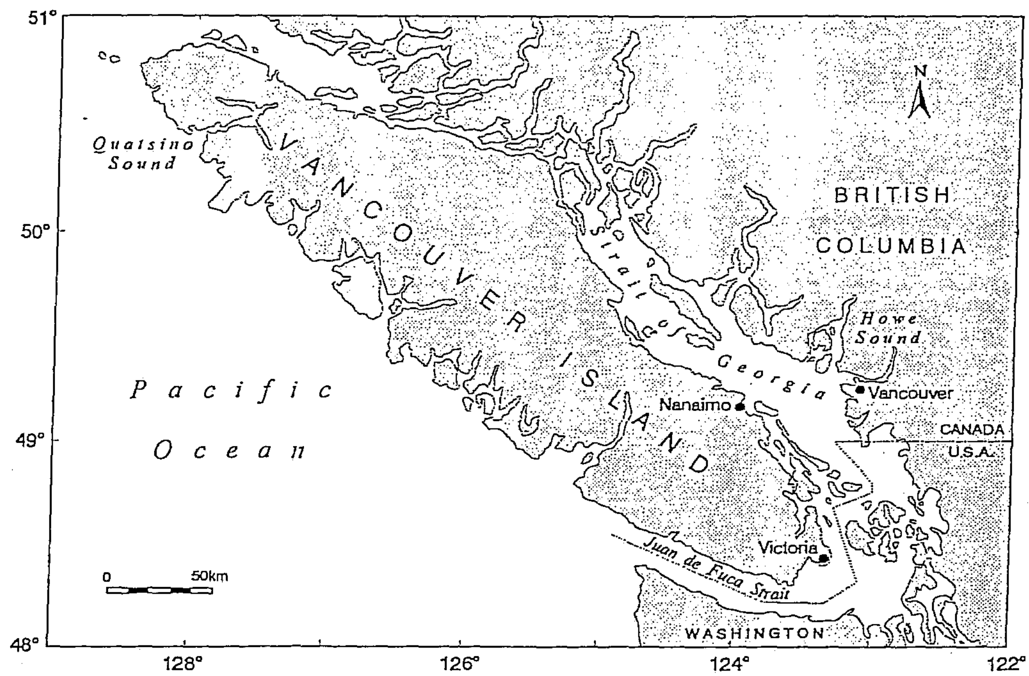


FIGURE 1. Map of the southern Georgia Basin showing the locations of the major oceanic basins.

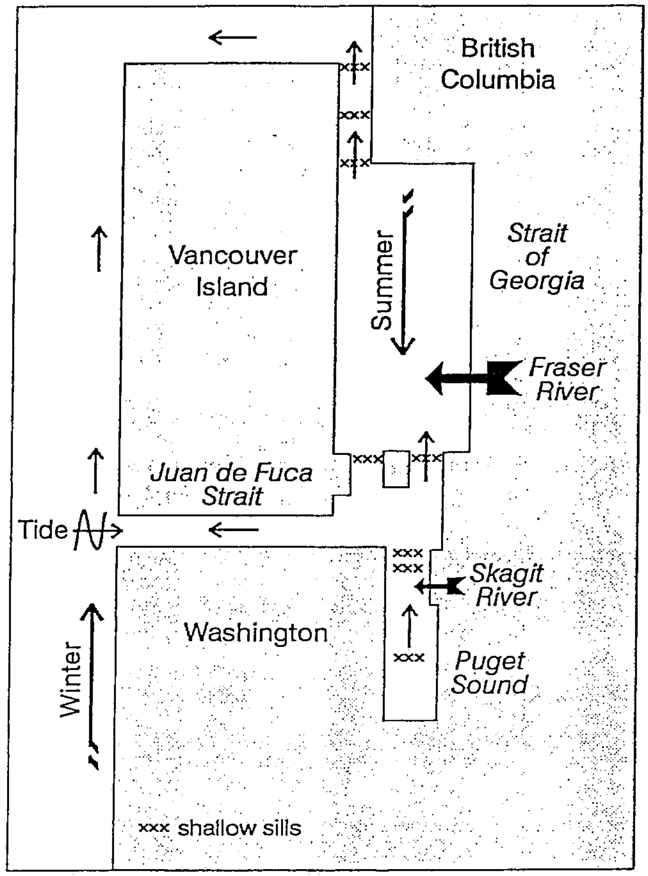


FIGURE 2. Schematic diagram of the Georgia Basin showing locations of the major sills, direction of surface flow, and locations of major riverine input. The large arrows with the broken tails denote surface winds.

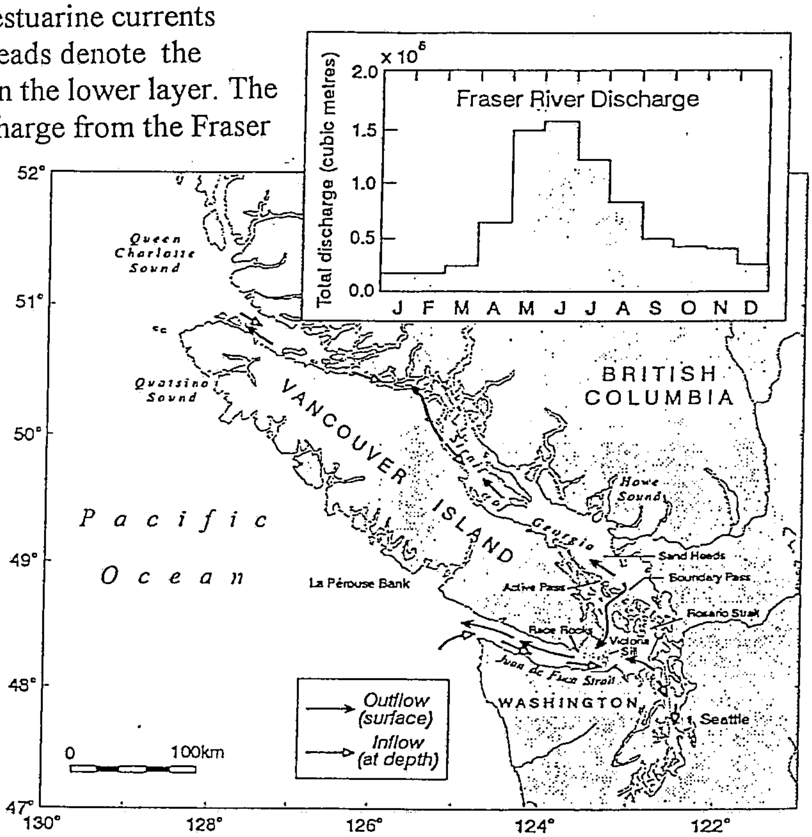


FIGURE 3. Freshwater-driven estuarine currents within the three main basins of the inner coastal waters. Solid arrowheads denote direction of the estuarine currents within the upper layer, open arrowheads denote the directions of the estuarine currents in the lower layer. The insert shows the monthly mean discharge from the Fraser River in units of 10^8 m^3/second.

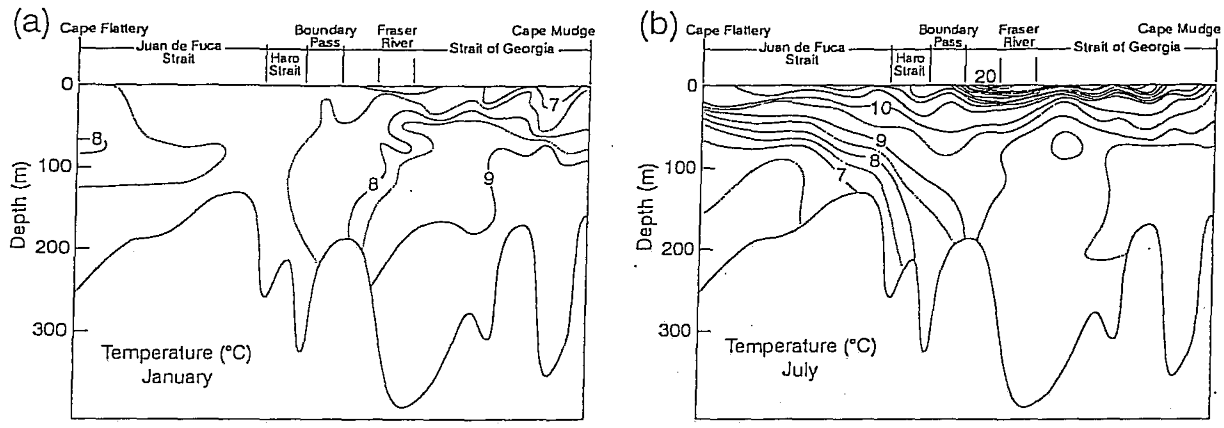


FIGURE 4. Temperatures for January (a) and July (b) for 1968 from Cape Flattery to Cape Mudge (modified after Crean and Ages 1971).

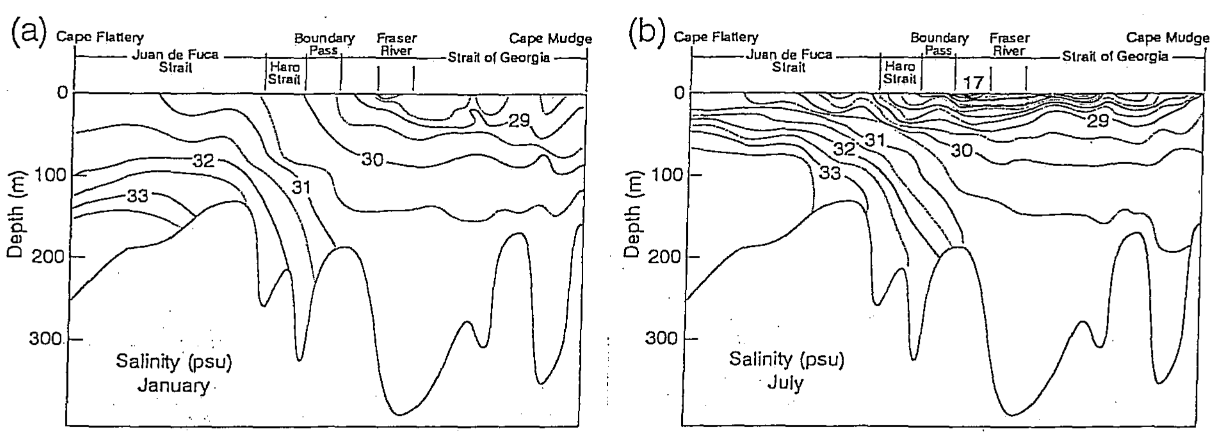


FIGURE 5. Salinity (in practical salinity units, psu) for January (a) and July (b) for 1968 from Cape Flattery to Cape Mudge (modified after Crean and Ages 1971).

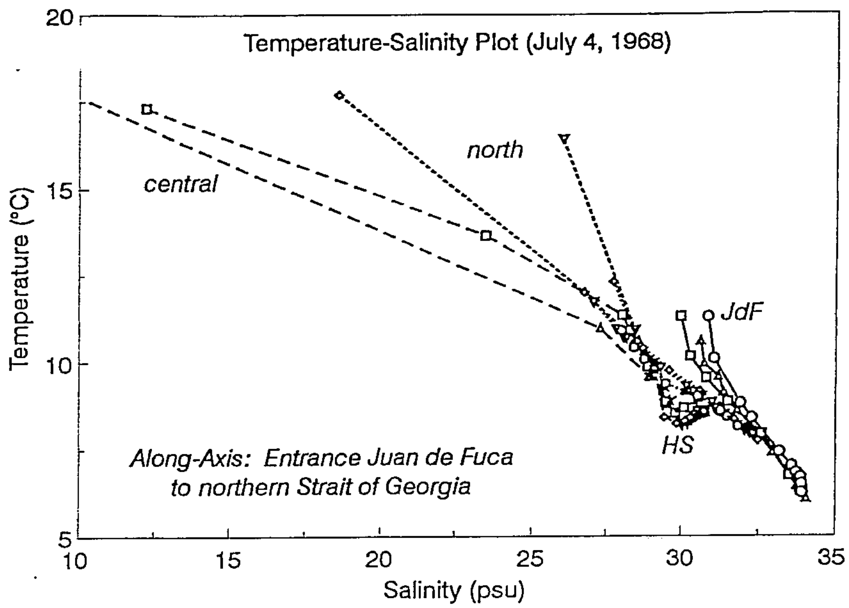


FIGURE 6. Temperature versus Salinity plots for data collected July 4, 1968, along the axis of the inner coastal waters from Cape Flattery in Juan de Fuca Strait to Cape Mudge in the Strait of Georgia (data from Crean and Ages 1971). JdF = Juan de Fuca Strait; HS = Haro Strait; north and south refer to northern and southern Strait of Georgia.

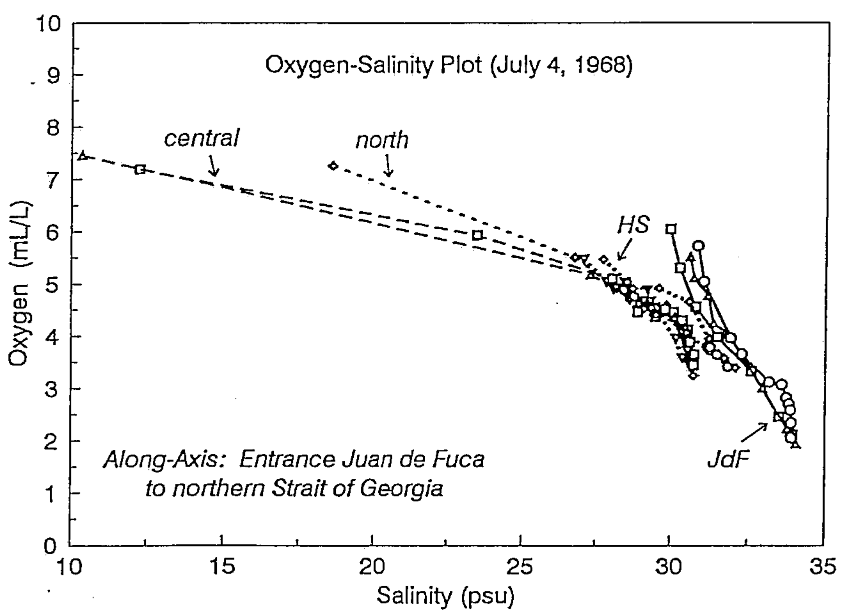


FIGURE 7. Oxygen versus Salinity plots for data collected July 4, 1968, along the axis of the inner coastal waters from Cape Flattery in Juan de Fuca Strait to Cape Mudge in the Strait of Georgia (data from Crean and Ages 1971). JdF = Juan de Fuca Strait; HS = Haro Strait; north and south refer to northern and southern Strait of Georgia.

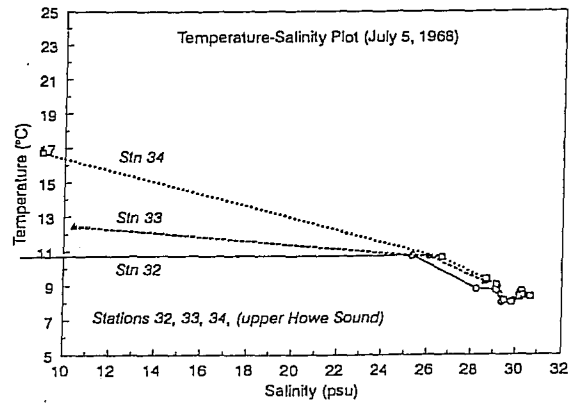


FIGURE 8. Temperature versus Salinity plots for data collected in July 5, 1968, along the axis of upper Howe Sound (data from Crean and Ages 1971).

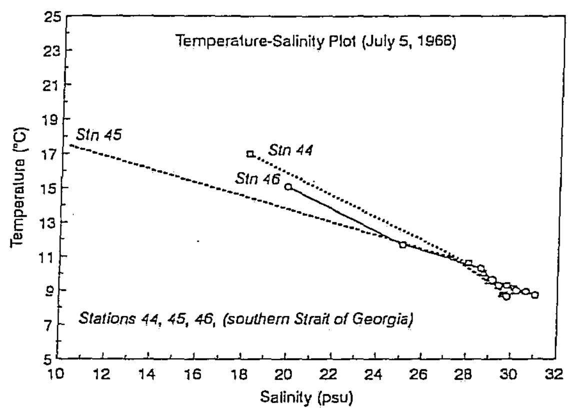


FIGURE 9. Temperature versus Salinity plots for data collected in July 5, 1968, across the southern portion of the Strait of Georgia (data from Crean and Ages 1971).

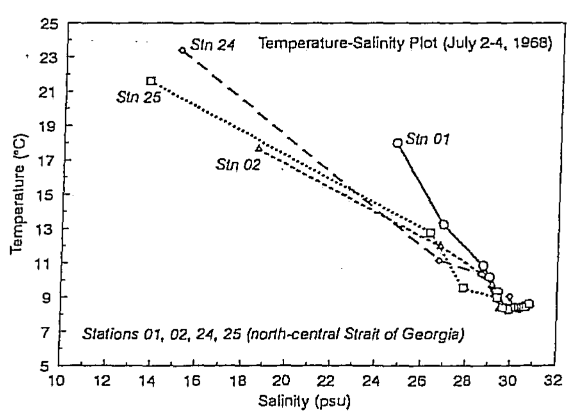


FIGURE 10. Temperature versus Salinity plots for data collected between July 2–4, 1968, across the north-central portion of the Strait of Georgia (data from Crean and Ages 1971).

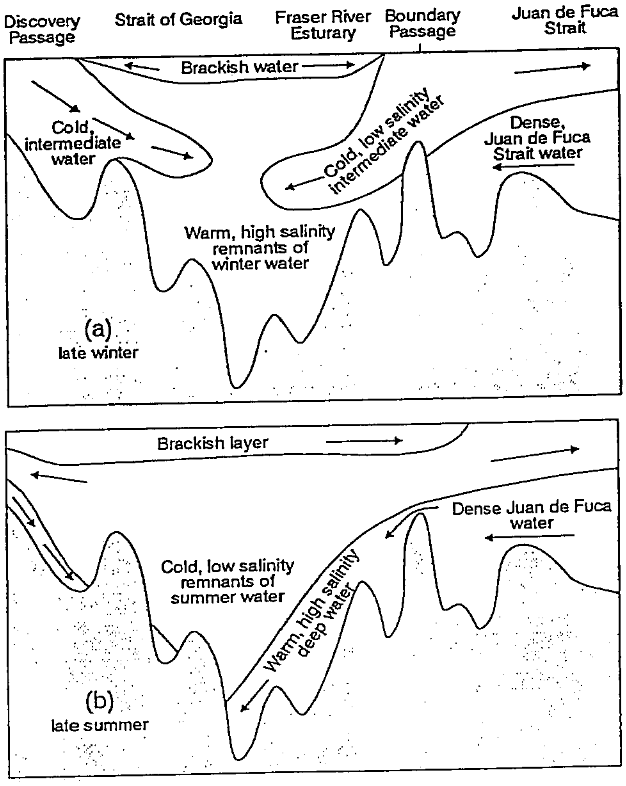


FIGURE 11. Water mass formation in the Strait of Georgia in (a) winter and (b) summer. Arrows denote direction of intrusions (from Thomson 1994).

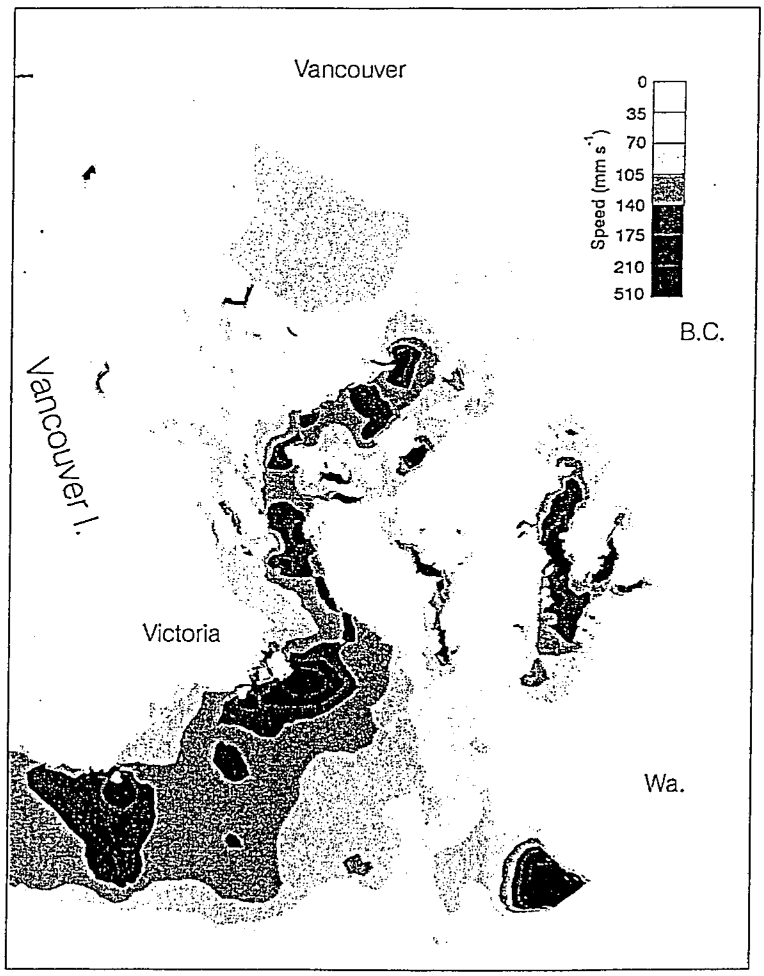


FIGURE 12. Tidal current speeds in mm/second during spring tides from the numerical model of Foreman et al. (1995).

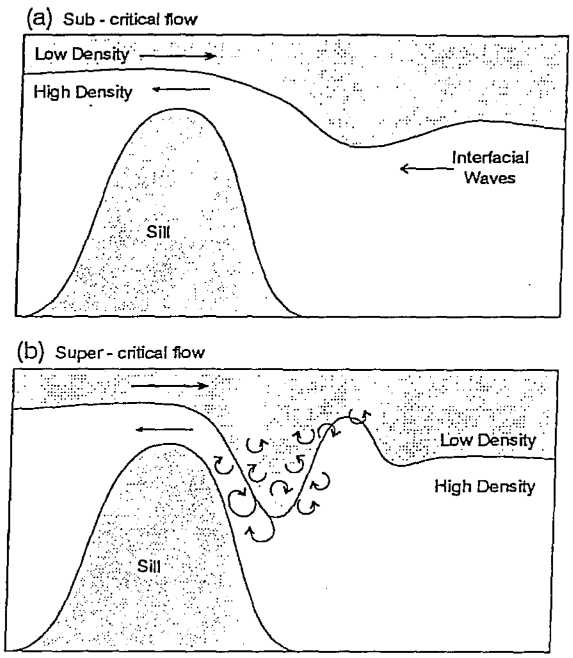


FIGURE 13. Schematic diagram of mixing-controlled estuarine exchange of deep and shallow water over sills. (a) Neap tides. The exchange of surface brackish water and deeper high density water proceeds unhindered; (b) Spring tides. In this case, turbulent mixing reduces the exchange of deep and shallow waters (from Thomson 1994).

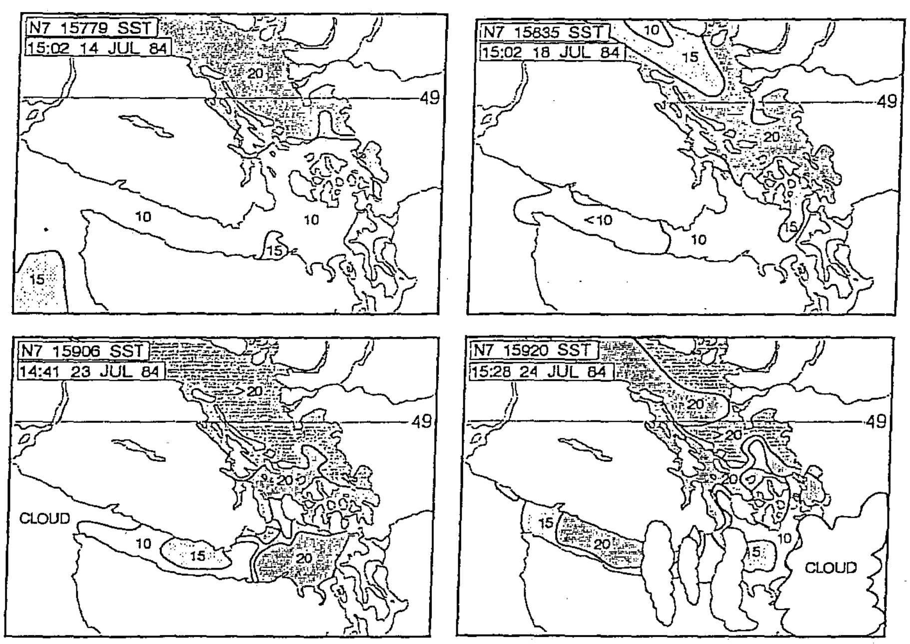


FIGURE 14. Surface water temperatures (in °C) extracted from a series of NOAA-7 satellite images for July 1984 (modified after Thomson 1994).

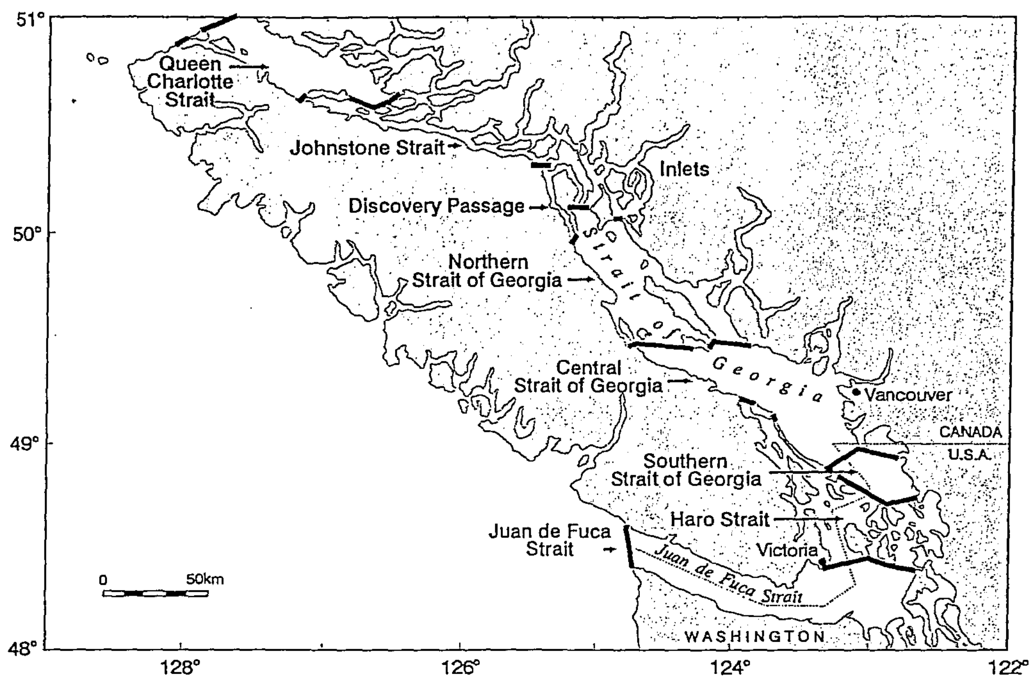


FIGURE 15. Delineated water property domains for the Georgia Basin based on the temperature–salinity and oxygen–salinity plots of Figures 6–10. Thick lines denote the boundaries of the water mass regions having different oceanic characteristics.

ECOSYSTEM DELINEATION IN THE GEORGIA BASIN BASED ON NUTRIENTS, CHLOROPHYLL, PHYTOPLANKTON SPECIES AND PRIMARY PRODUCTIVITY

Paul J. Harrison and Kedong Yin
Department of Earth and Ocean Sciences
University of British Columbia
Vancouver, B.C.
V6T 1Z4

1.0 INTRODUCTION

Georgia Basin is a diverse inland sea which is primarily composed of the Strait of Georgia and Puget Sound and their associated inlets. Puget Sound and the south end of the Strait of Georgia is connected to the Pacific Ocean through Juan de Fuca Strait and the north end of the Strait of Georgia is connected to the Pacific via the narrow Johnstone Strait and Discovery Passage (Figure 1). This paper will focus primarily on the Strait of Georgia.

The physical oceanography and water masses of the Strait of Georgia have been reviewed by Thomson (this volume). The physical characteristics are a major driving force influencing ecosystem delineation in the Strait. The biological oceanography has been reviewed previously by Parsons et al. (1970) and Harrison et al. (1983), and the reader should consult these reviews for further details that are not covered in this brief report. Nitrogenous nutrient sources and sinks have been reviewed recently for the Georgia Basin (Mackas and Harrison 1997). An extensive bibliography also exists on the biological oceanography of the Strait of Georgia (Harrison et al. 1984).

In this paper, the discussion of the ecosystem delineation of the Strait will be based on nutrients, chlorophyll, phytoplankton species, and primary productivity. The main basin of the Strait will be discussed as three regions: 1) the northern, 2) central, and 3) southern strait (Figure 1).

2.0 NORTHERN STRAIT OF GEORGIA

An arbitrary geographical boundary for the northern Strait is from the southern end of Texada Island northwards (Figure 1). This area of the Strait has not been well studied and the few earlier studies (Cattell 1969; Shim 1976; Stockner et al. 1979) only sampled one transect down the middle of the Strait. A recent comprehensive study by Haigh and Taylor (1991) employed a grid of stations which covered the area from east to west. The following paragraph summarizes the results of their one-year study in 1986.

The phytoplankton ecology of the northern Strait is strongly influenced by seasonality. Haigh and Taylor (1991) did not observe the spring diatom bloom in 1986, perhaps due to wind

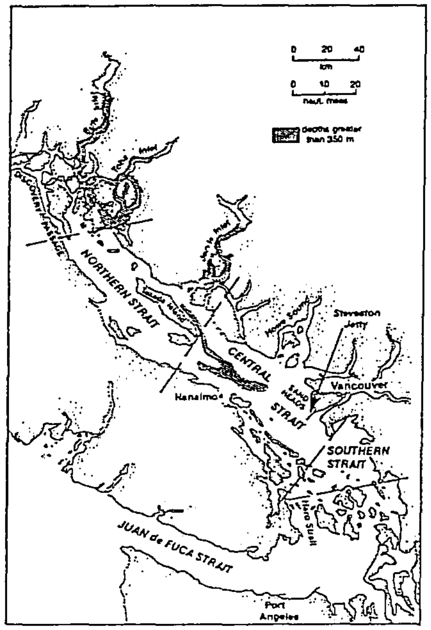


FIGURE 1. Map of the Strait of Georgia and its arbitrary division into the northern, central and southern Straits (from Waldichuk 1957)

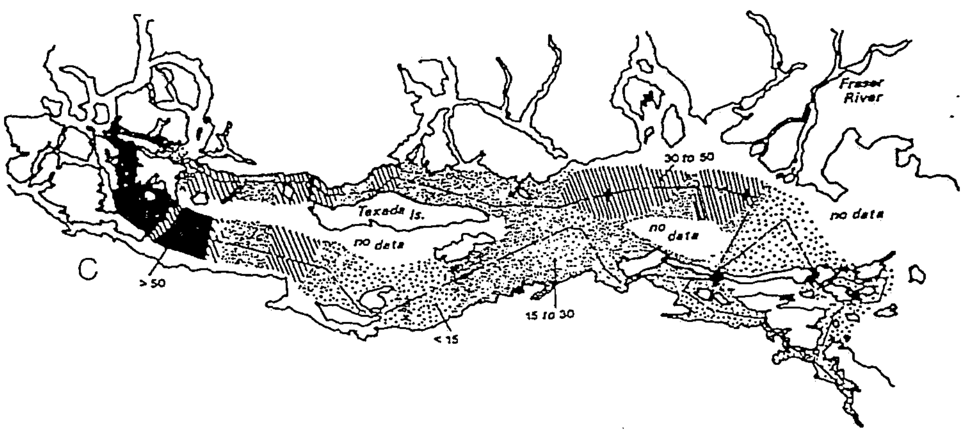


FIGURE 2. Chlorophyl *a* (μgL^{-1}) distribution in the Strait of Georgia during a ship survey on July 28 - August 2, 1980, derived from *in vivo* fluorescence. (from Parsons et al. 1981).

mixing and grazing. The potential absence of the spring bloom needs to be resolved in future studies. March and April were characterized by low chlorophyl (<3 µg L^{-1}) and consisted of flagellates, especially *Heterosigma*. Surface nitrate was above limiting concentrations. In August, chlorophyl was dominated by diatoms, especially *Chaetoceros* sp., *Skeletonema,* and *Rhizosolenia,* which formed a sub-surface maximum at 10 to 15 m. Surface chlorophyl was low and dominated by nanoflagellates. Nitrate was absent from the upper 5 to 15 m with the northwest area having the deepest nitracline (Price et al. 1985, Cochlan et al. 1991a). In September the west-side chlorophyl maximum was dominated by *Rhizosolenia,* the middle of the Strait by *Chaetoceros,* and the eastern side by *Chrysochromulia* and cryptomonads. The nitracline became shallower (5-10 m) but was deeper on the west than on the east side.

To summarize, Haigh and Taylor's (1991) observations and the scant previous studies, the following synthesis provides an overview of the northern Strait. The classic spring bloom appears to be absent or delayed (it is possible that Haigh and Taylor missed it between late April and late June when they did not sample). Haigh (1988) observed the spring bloom in April in the adjacent Malaspina complex of inlets but the increased exposure to wind mixing in the northern Strait could have delayed the spring bloom. The dominance by diatoms was not observed until August when surface nutrients were exhausted. During this season (with decreased winds and increased stratification due to an increase in surface temperatures), the differences between the east and west sides of the Strait are most obvious. The west side is more productive because of a narrow tidal jet observed on flood tides which brings colder nutrient-rich water into this area as a result of tidal mixing through Discovery Passage. The eastern side is more stratified (especially in late May, June, and early July due to the northward movement of the Fraser River plume along the east side of the Strait due to the Coriolis force) and dominated by flagellates. Parsons et al. (1981) also observed high chlorophyl which they attributed to diatom biomass associated with the tidally active northern Discovery Passage (Figure 2).

3.0 CENTRAL STRAIT OF GEORGIA

The central Strait is arbitrarily defined as the area from the south end of Texada Island to a line drawn from Point Roberts to Saanich Peninsula (Waldichuk 1957). It is also complex, especially due to the seasonal influence of the Fraser River plume. The plume reaches a peak in size in June and the actual distribution is influenced by a flood or ebb tide, and by wind velocity and especially wind direction. The plume can move south into Juan de Fuca Strait, west to the Gulf Islands and north, mainly along the east side. It is 1–4 m deep and increases stratification by inhibiting wind mixing. Hence, some studies have focussed on a comparison within and beyond the plume (Parsons et al. 1969; Stockner et al. 1979; Clifford et al 1989, 1990, 1991; Harrison et al. 1991).

The plume has a salinity range from a few parts per thousand to 20‰, temperatures that are a few degrees colder than surface water of the Strait (except in summer), very high light extinction coefficients (0.1 to nearly 1 m^{-1}), a unique nutrient signal (SiO_4^{-4} about 60 µM), and very low chlorophyl and primary productivity (Harrison et al. 1991, Yin et al. 1997a). When the plume is well developed in June , it is dark (<0.1% light depth) under the plume, but there are layers of relatively high chlorophyl (Cochlan et al. 1991b) and zooplankton which are presumably formed outside the plume, but are sucked back under the plume during the ebb tides (St. John et al. 1992). There are higher than expected juvenile and adult fish under the plume, including lamprey (St. John et al. 1992; Beamish and Neville 1995). Therefore the plume area could be considered a separate ecosystem. However, it varies a great deal seasonally and the maximum difference in size and chemical and biological parameters occurs in June. The third largest mechanism (after wind and tidal mixing) for transporting deep nutrient inputs into the surface layer of the Strait is the entrainment of the nitrate-rich salt-wedge water directly into the base of the Fraser River outflow (Figure 3). The rate of nitrate entrainment varies with the contact area and shear between the river/riverine plume and Strait of Georgia deep water (Yin et al. 1995a). However, it is consistently higher (2 to 12-fold) than the direct river-borne input (Yin et al. 1995 a,b,c).

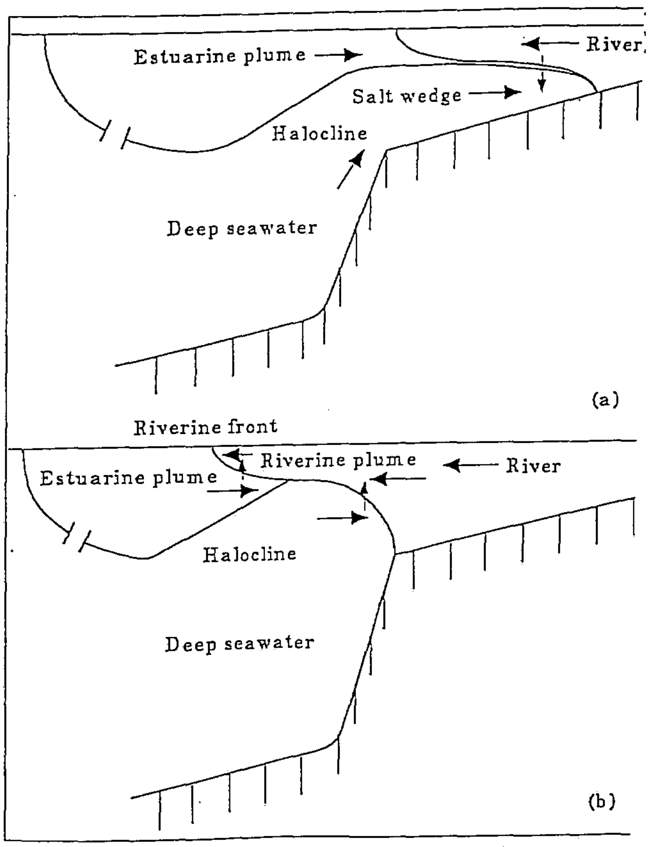


FIGURE 3. Vertical profile of the mouth of the Fraser River, showing the position of the river, riverine plume, estuarine plume and salt wedge during the flood and ebb tides. The main entrainment takes place at the interface between the deep water and the riverine plume during an ebb tide (a) Flood tide-HHW; (b) Ebb tide-LLW (from Yin et al. 1995a).

Beyond the plume to the northwest near Ballenas Island (reference station established by Harrison et al.) the seasonal cycle is very similar to that described by Harrison et al. (1983). The diatom spring bloom occurs between late March and late April (depending on sunlight and wind mixing). The development of the bloom may be slowed by wind mixing (Yin et al. 1996), light, and grazing by the large copepod *Neocalanus plumchrus* (Yin et al. 1996, 1997b). A series of blooms can occur until late June due to wind mixing (Yin et al. 1997b) (the nitracline is only at 10-15 m) and decreased grazing by *Neocalanus* which migrate to depth in May, and large spring tides in May and June (Yin et al. 1997b). By July and August, accumulated influence of freshwater and increased temperatures in the surface waters increases stability and the frequency of nitrogen limitation. However, an increase in wind speed or a fluctuation in river discharge can provide nutrients to the euphotic zone and enhance primary productivity (Yin et al. in press). St. John et al. (1993) used a computer model to estimate inputs from wind mixing. Outside the plume, winds of 8 m s^{-1} can break down summer season stratification and mix large amounts of water with NO_3 10 μM into the surface layer. Diatom blooms may occur in early fall after wind mixing and periods of sunny weather.

While these seasonal cycles in nutrients, chlorophyl, and primary productivity are relatively predictable, the day-to-day variation in these parameters is rather startling with values ranging over one order of magnitude in some months (e.g., June; Figure 4). There are no studies in the Strait showing weekly or biweekly variations in nutrients or chlorophyl over the main productivity period (April to October) similar to the excellent coverage in Saanich Inlet by Takahashi et al. (1977). These frequent samplings reveal how rapidly nitrate and chlorophyl *a* can change (Figure 5). Considering this large daily or weekly variation, it is very difficult to draw a contour map of annual primary productivity for the Strait of Georgia. However, Stockner et al. (1979) did attempt this challenge (Figure 6). Data coverage is relatively sparse in many areas, but perhaps SeaWis satellite coverage may give the combined temporal and spatial coverage required to make a contour map.

In summary, the Fraser River plume may dominate the central Strait in June when it reaches its maximum size. It has many unique features and during this brief period it could be considered to be a separate ecosystem.

4.0 SOUTHERN STRAIT OF GEORGIA

The southern Strait is defined as the area south of the main arm of the Fraser River, up to Juan de Fuca Strait. In addition to being dominated by the Fraser River plume when it flows south (e.g., during northwest winds and an ebb tide), it is significantly influenced by the tidal mixing over the shallow sills of Rosario and Haro straits during flood tides. This tidal mixing injects nutrient-rich water into the southern Strait which lessens or perhaps eliminates the frequency of nitrogen limitation in the summer. Therefore this area is considered to be highly productive, although it has not been well studied.

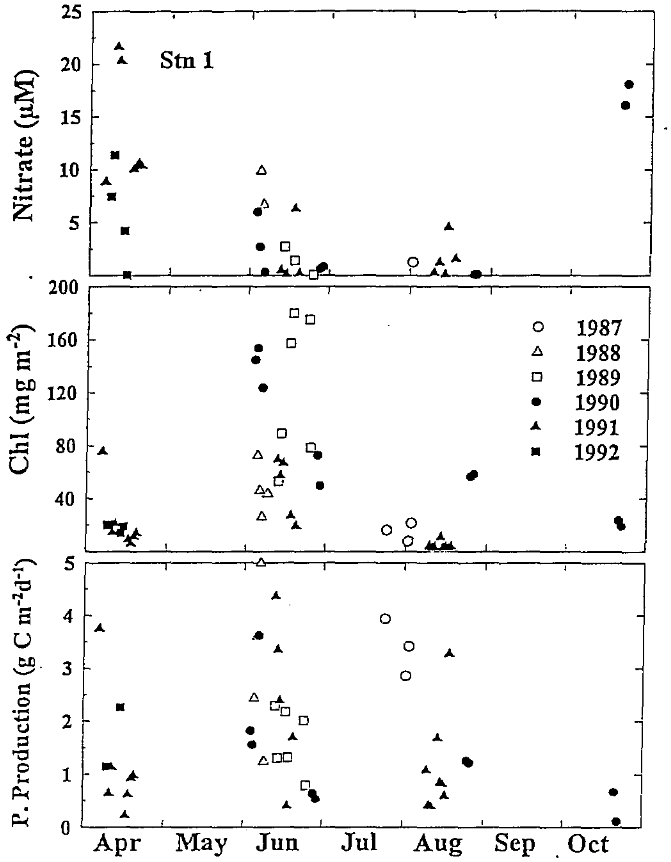


FIGURE 4. Seasonal and interannual variability in nitrate, chlorophyl *a* and primary productivity at a reference station north of Nanaimo (near Ballenas Is) (from Clifford et al. 1989, 90, 91, 92 a,b).

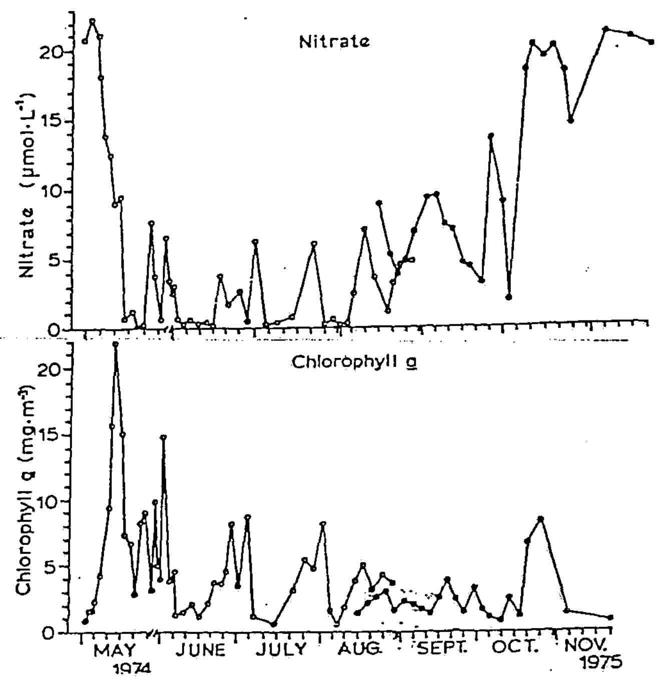


FIGURE 5. Seasonal Variation in nitrate and chlorophyl *a* in Saanich Inlet (from Takahashi et al. 1977).

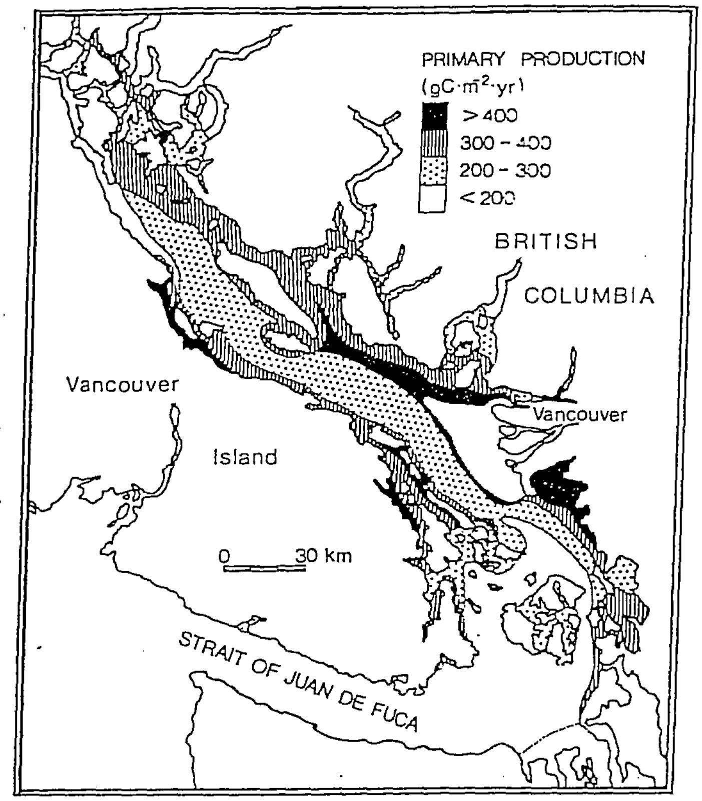


FIGURE 6. Estimates of the distribution of annual primary productivity for the Strait of Georgia (from Stockner et al. 1979).

5.0 INLETS

Five inlets empty into the Strait of Georgia: Burrard Inlet, Howe Sound, Jervis Inlet (with Sechelt Inlet), Bute Inlet, and Saanich Inlet. Studies in these inlets prior to 1983 have been reviewed by Harrison et al. (1983) and referenced in a bibliography by Harrison et al. (1984). Bute Inlet will not be discussed here since it has seldom been studied.

Burrard Inlet, composed of Vancouver Harbour, Indian Arm, and Port Moody Arm, is a fjord that receives medium runoff from the Indian River, and the outer section of the inlet is influenced by the Capilano and Seymour Rivers. During a large part of the phytoplankton growing season (May to July), silty Fraser River water decreases light penetration in the surface layer and hence primary productivity is reduced. Maximum values of annual primary productivity (532 g C m^{-2}) occurred in Port Moody Arm, while the lowest values (260 g C m^{-2}) occurred in Indian Arm (Stockner and Cliff 1979). This latter value is considered lower than the mean of 455 g C $m^{-2}yr^{-1}$ for Indian Arm that was obtained by Gilmartin (1964).

Howe Sound is a relatively high runoff inlet due to the Squamish River discharge. From May to September the river carries a heavy glacial silt load which forms an opaque, brackish surface layer that greatly restricts light penetration (Hoos and Vold 1975). A number of freshwater species were observed by Stockner et al. (1977) near the head of Howe Sound. Stockner and Cliff (1976) found more diatoms at the entrance to Howe Sound than within it. They found that the effluent from Port Mellon and Woodfibre pulp mills drastically reduced the proportion of *Thalassiosira* spp. in the spring bloom, resulting in an almost unialgal bloom of

Skeletonema costatum. The annual primary productivity determined for two consecutive years (300 and 516 g C m^{-2} for 1973 and 1974, respectively) clearly shows the large interannual variability exhibited by these inlets.

Saanich Inlet is the best studied of the inlets. It is a low runoff inlet with a shallow sill and anoxic bottom water. Since it is a low runoff inlet, it supports heavy diatom blooms which can occur sporadically during the summer due to wind and tidal mixing (Takahashi et al. 1977). Nanoflagellates form the dominant biomass in the winter, but they constitute only 10% of the phytoplankton carbon during spring and summer months. More detailed studies of Saanich Inlet have shown that primary productivity is spatially and temporally variable (e.g., annual primary productivity was 250 g C m^{-2} in 1975 and 500 g C m^{-2} in 1976).

Jervis and Sechelt inlets have been seldom studied. However, recent studies by Haigh et al. (1992) and Taylor and Haigh (1994) described the seasonal cycle of temperature, salinity, nutrients, chlorophyl, and phytoplankton species for Sechelt Inlet. They show that Sechelt Inlet is composed of the very well mixed Skookumchuck Narrows, the main inlet, and Salmon Inlet off the main inlet. Salmon Inlet is more nutrient-limited than the main inlet.

6.0 CONCLUSIONS

1) There are no clear spatial ecosystem boundaries in the Strait, primarily because of the large changes in nutrients and phytoplankton that occur on a temporal (daily to seasonal changes) basis within each area. Often the differences appear to be just a difference in timing of nutrient and bloom cycles.

2) We have divided the Strait into three areas, northern, central, and southern Strait, although the boundaries between these areas are not clear cut.

3) The northern Strait may lack a spring bloom or have a delayed spring bloom. Because of the fetch and the weak halocline (little influence of the Fraser River), wind mixing is likely to prolong or prevent pronounced bloom formation. By late summer the west side is noticeably different than the east side. The west side is diatom-dominated and more productive due to a nutrient-rich tidal jet flowing out of Discovery Passage during a flood tide. The east side is more stratified due to surface heating and a somewhat lower salinity due to the Fraser River plume (mainly in June and July).

4) The central Strait has the nutrient and phytoplankton bloom seasonal cycles that have been described previously by Harrison et al. (1983). The main features of these cycles are a diatom spring bloom, pronounced grazing by the large copepod *Neocalanus* in April and early May, and a series of smaller diatom blooms until late June. Frequent nitrogen limitation occurs in July and August (depending on the magnitude of wind events).
The Fraser River plume can dominate the central Strait in June when it reaches its maximum size. Unique characteristics of the plume are lower salinity, very high light-extinction coefficients, high $SiO4^{-4}$, low chlorophyl, and low primary productivity. Chlorophyl, zooplankton, and fish are frequently surprisingly high under the plume. During late May to early July, the plume could be considered a separate ecosystem.

5) The southern Strait can be dominated by the Fraser River plume in June (depending on wind direction and tides) and the injection of nutrient-rich water into the southern Strait during

tidal mixing over the sills in Rosario and Haro straits during flood tides. This area has higher chlorophyl and productivity for this reason.

6) Even with the combination of parameters that we have evaluated here, the pronounced seasonal variation in nutrients, chlorophyl, and primary productivity varies considerably within each of the three areas discussed. Since these areas may be temporally somewhat out of phase with each other, caution must be exercised in comparing the central Strait with the northern Strait, for example.

7) There are pronounced frontal areas in the north (near Discovery Passage) and south (near Haro and Rosario straits) due to nutrient addition by tidal mixing. The front associated with the Fraser River plume is pronounced in May, June, and July when river discharge is high.

8) In terrestrial areas, distinct plant communities are often a characteristic of a certain ecosystem. In the Strait of Georgia there is no consistent phytoplankton community that separates one area from another area, since the phytoplankton is transported by currents. The phytoplankton species succession in various areas is often temporarily out of phase with each other.

LITERATURE CITED

Beamish, R.J. and C.M. Neville. 1995. Pacific salmon and Pacific herring mortalities in the Fraser River plume caused by river lamprey (*Lampetera ayresi*). Can. J. Fish. Aquat. Sci. 52:644–650.

Catell, S.A. 1969. Dinoflagellates and vitamin B_{12} in the Strait of Georgia, British Columbia. PhD thesis. Univ. British Columbia, Vancouver, B.C.

Clifford, P.J., W.P. Cochlan, P.J. Harrison, K. Yin, M.J. Sibbald, L.J. Albright, M.A. St. John, and P.A. Thompson. 1989. Plankton production and nutrient dynamics in the Fraser River Plume, 1987. Dept. Oceanography, Univ. British Columbia, Vancouver, B.C. Manusc. Rep. No. 51. 118 p.

Clifford, P.J., P.J. Harrison, M.A. St. John, K. Yin, and L.J. Albright. 1991. Plankton production and nutrient dynamics in the Fraser River Plume, 1989. Dept. Oceanography, Univ. British Columbia, Vancouver, B.C. Manusc. Rept. No. 54. 225 p.

Clifford P.J., P.J. Harrison, K. Yin, M.A. St. John, and R.H. Goldblatt. 1992a. Plankton production and nutrient dynamics in the Fraser River Plume, 1990. Dept. Oceanography, Univ. British Columbia, Vancouver, B.C. Manuscr. Rep. No. 58. 265 p.

Clifford, P.J. Harrison, K. Yin, M.A. St. John, A.M. Waite, and L.J. Albright. 1990. Plankton production and nutrient dynamics in the Fraser River Plume, 1988. Dept. Oceanography, Univ. British Columbia, Vancouver, B.C. Manusc. Rep. No. 53. 142 p.

Clifford, P.J., K. Yin, P.J. Harrison, M.A. St. John, R.H. Goldblatt, and D.E. Varela. 1992b. Plankton production and nutrient dynamics in the Fraser River Plume, 1991. Dept. Oceanography, Univ. British Columbia, Vancouver, B.C. Manusc. Rept. No. 59. 415 p.

Cochlan, W.P., N.M. Price, and P.J. Harrison. 1991a. Effects of irradiance on nitrogen uptake by phytoplankton: Comparison of frontal and stratified communities. Mar. Ecol. Prog. Ser. 69:103–116.

Cochlan, W.P., P.J. Harrison, P.J. Clifford, and K. Yin. 1991b. Observations on double chlorophyll maxima in the vicinity of the Fraser River Plume. J. Exp. Mar. Biol. Ecol. 143:139–146.

Gilmartin, M. 1964. The primary production of a British Columbia fjord. J. Fish. Res. Board Can. 21: 505-538.

Haigh, R. 1988. The effect of stratification on microplankton communities in the northern Strait of Georgia. MSc thesis, Univ. British Columbia, Vancouver, B.C.

Haigh, R. and F.J.R. Taylor. 1991. Mosaicism of microplankton communities in the northern Strait of Georgia, British Columbia. Mar. Biol. 110:301–314.

Haigh, R., F.J.R. Taylor, and T.F. Sutherland. 1992. Phytoplankton ecology of Sechelt Inlet, a fjord system on the British Columbia coast. I. General features of the nano- and microplankton. Mar. Ecol. Prog. Ser. 89:117–134.

Harrison, P.J., P.J. Clifford, K. Yin, M.A. St. John, M.J. Sibbald, L.J. Albright, W.P. Cochlan, and P.A. Thompson. 1991. Nutrient and plankton dynamics in the Fraser River Plume, Strait of Georgia, British Columbia. Mar. Ecol. Prog. Ser. 70:291–304.

Harrison, P.J., J.D. Fulton, G. Miller, C.D. Levings, F.J.R. Taylor, T.R. Parsons, P.A. Thompson, and D.A. Mitchell. 1984. A bibliography of the biological oceanography of the Strait of Georgia and adjacent inlets, with emphasis on ecological aspects. Can. Tech. Rep. Fish. Aquat. Sci. No. 1293. 140 pp.

Harrison, P.J., J.D. Fulton, F.J.R. Taylor, and T.R. Parsons. 1983. Review of the biological oceanography of the Strait of Georgia: pelagic environment. Can. J. Fish. Aquat. Sci. 40:1064–1094.

Hoos, L.M. and C.L. Vold. 1975. The Squamish River Estuary. Status of enviromental knowledge to 1974. Report of the Estuary Working Group, Dept of Environment, Regional Board, Pacific Region, Spec. Estuary Ser. 2: 361 p.

Mackas, D.L. and P.J. Harrison. 1997. Nitrogenous nutrient sources and sinks in Juan de Fuca Strait/Strait of Georgia/Puget Sound estuarine system: Assessing the potential for eutrophication. Estuarine Coastal Shelf Sci. 44:1–21. (1996).

Parsons, T.R., R.J. LeBrasseur, and W.E. Barraclough. 1970. Levels of production in the pelagic environment of the Strait of Georgia, British Columbia: A review. J. Fish. Res. Bd. Can. 27:251–1264.

Parsons, T.R., K. Stephens, and R.J. LeBrasseur. 1969. Production studies in the Strait of Georgia. I. Primary production under the Fraser River plume, February to May, 1967. J. Exp. Mar. Biol. Ecol. 3:27–38.

Parsons, T.R., J. Stronach, G.A. Borstad, G. Louttit, and R.I. Perry. 1981. Biological fronts in the Strait of Georgia, British Columbia and their relation to recent measurements of primary productivity. Mar. Ecol. Prog. Ser. 6:237–242.

Price, N.M., W.P. Cochlan, and P.J. Harrison. 1985. Time course of uptake of inorganic and organic nitrogen by phytoplankton in the Strait of Georgia: Comparison of frontal and stratified communities. Mar. Ecol. Prog. Ser.27:39-53.

Shim, J.H. 1976. Distribution and taxonomy of planktonic marine diatoms in the Strait of Georgia, B.C. PhD thesis, Univ. British Columbia, Vancouver, B.C.

Stockner, J.G. and D.D. Cliff. 1976. Phytoplankton succession and abundance in Howe Sound, British Columbia: a coastal marine embayment under stress. Fish Mar. Serv. Tech. Rep. 658: 24 p.

Stockner, J.G. and D.D. Cliff. 1979. Phytoplankton ecology of Vancouver Harbour. J. Fish Res. Board Can. 36: 1-10.

Stockner, J.G., D.D. Cliff, and D.B. Buchanan. 1977. Phytoplankton production and distribution in Howe Sound, British Columbia: a coastal marine embayment-fjord under stress. J. Fish. Res. Bd. Can. 34:907–917.

Stockner, J.G., D.D. Cliff, and K.R.S. Shortreed. 1979. Phytoplankton ecology of the Strait of Georgia, British Columbia. J. Fish. Res. Bd. Can. 36:657–666.

St. John, M.A., J.S. Macdonald, P.J. Harrison, R.J. Beamish, and E. Choromanski. 1992. The Fraser River Plume: Some preliminary observations on the distribution of juvenile salmonids herring and their prey. Fisheries Oceanogr. 1:153–162.

St. John, M.A., S.G. Marinone, J. Stronach, P.J. Harrison, J. Fyfe, and R.J. Beamish. 1993. A horizontally resolving physical-biological model of nitrate fluxes and primary productivity in the Strait of Georgia. Can. J. Fish. Aquat. Sci. 50:1456–1466.

Takahashi, M., d.L. Seibert, and W.H. Thomas. 1977. Occasional blooms of phytoplankton during summer in Saanich Inlet, B.C., Canada. Deep-Sea Res. 24:775–780.

Taylor, F.J.R. and R. Haigh. 1994. Phytoplankton ecology of Sechelt Inlet, a fjord system on the British Columbia coast. II. Potentially harmful species. Mar. Ecol. Prog. Ser. 103:151–164.

Waldichuk, M. 1957. Physical oceanography of the Strait of Georgia, British Columbia. J. Fish. Res. Board Can. 14:321-486.

Yin, K., P.J. Harrison, and R.J. Beamish. 1997a. Effects of a fluctuation in Fraser River discharge on primary productivity in the central Strait of Georgia, British Columbia, Canada. Can. J. Fish. Aquat. Sci. 54:1015–1024.

Yin, K., P.J. Harrison, P.J. Clifford, and R.J. Beamish. In press. Importance of wind and river discharge in influencing nutrient dynamics and phytoplankton production in summer in the Central Strait of Georgia. Mar. Ecol. Prog. Ser.

Yin, K., P.J. Harrison, R. Goldblatt and R.J. Beamish. 1996. Spring bloom in the vicinity of the Central Strait of Georgia: interactions of river discharge, winds and grazing. Mar. Ecol. Prog. Ser. 138:255–263.

Yin, K., P.J. Harrison, R.H. Goldblatt, M.A. St. John, and R.J. Beamish. 1997b. Factors controlling the timing of the spring bloom in the Strait of Georgia estuary, British Columbia, Canada. Can. J. Fish. Aquat. Sci. 54:1985–1995.

Yin, K., P.J. Harrison, S. Pond, and R.J. Beamish. 1995a. Entrainment of nitrate in the Fraser River Plume and its biological implications. I. Effects of the salt wedge. Estuarine Coastal Shelf Sci. 40:505–528.

Yin, K., P.J. Harrison, S. Pond, and R.J. Beamish. 1995b. Entrainment of nitrate in the Fraser River Plume and its biological implications. II. Effects of spring vs neap tides and river discharge. Estuarine Coastal Shelf Sci. 40:529–544.

Yin, K., P.J. Harrison, S. Pond, and R.J. Beamish. 1995c. Entrainment of nitrate in the Fraser River Plume and its biological implications. III. Effects of winds. Estuarine Coastal Shelf Sci. 40:545–558.

DISCUSSION

Rick Thomson: Kedong, I'm glad you mentioned the Discovery Passage jet. I was going to mention it, but I forgot. Looking at your overhead showing increased productivity —the work by Haigh and Taylor that showed the productivity — looking along that line all the way across the Strait, you can see that there's productivity in that whole line all across the Strait, so it doesn't just come in as a jet from Discovery Passage; it influences that narrow part. If that jet really is impacting, it looks like it has a strong impact across the whole width of the Strait. Is that correct?

Kedong Yin: Yes, that's true, but that depends on the season. What happens is that when you have high nutrients accompanying it, obviously it has not been consumed by phytoplankton. Therefore, biomass should be low in that jet. They are only going to be high when they are spreading through the Strait of Georgia or they can be ready and waiting for the phytoplankton to pick up. If you don't capture that progress, you missed part of the show. That is a time scale. It's also important.

ZOOPLANKTON AND NEKTON

D.L. Mackas
Institute of Ocean Sciences
P.O. Box 6000
Sidney, B.C. V8L 4B2

The purpose of this presentation is to identify the physical and biological factors most likely to control the distribution and productivity of zooplankton and nekton in coastal marine waters such as the Strait of Georgia, and implications for an ecosystem approach to marine management.

1.0 DEFINITIONS

Zooplankton:

- are small (1 mm to 5 cm) animals that can readily control their vertical position, but mostly drift around with horizontal currents; and
- eat phytoplankton, protozoans, and each other.

Nekton:

- are larger (5 cm to 2 m) animals that swim fast enough to control both their vertical and horizontal position;
- eat zooplankton and each other; and
- many are effectively zooplankton during early stages of their life.

2.0 MAJOR ENVIRONMENTAL CHARACTERISTICS AND GRADIENTS WITHIN THE STRAIT OF GEORGIA

- Compared to most coastal marine environments, the Strait of Georgia is a deep basin (mean depth >150 m, large % of total area > 200 m depth). This permits a range of "oceanic" as well as estuarine depth distributions and life cycle strategies.
- The basin also includes a variety of strong "edges" (both bathymetric and hydrographic).
- Influence of the Fraser River is very strong and affects environmental characteristics such as stratification, turbidity, estuarine circulation (but not direct nutrient loading).
- Tidal currents are also strong, and affect productivity and distribution through transport and mixing, and site-dependent interaction with estuarine circulation.
- Seasonality is pronounced for both physical and biological variables.

- Circulation characteristics, and to a lesser extent water properties, differ between the deep main basin and fringing fjords and shallows.

3.0 ZOOPLANKTON

The major zooplankton taxonomic categories and their approximate percentage contribution to annual average zooplankton biomass are:

- large annual copepods (e.g., *Neocalanus*) 35%;
- euphausiids (e.g., *Euphausia pacifica*) 20%;
- gelatinous predators (e.g., ctenophores, medusae, siphonophores) 15%;
- small- to medium-sized copepods (e.g., *Pseudocalanus, Metridia, Oithona*) 10%;
- amphipods 7%;
- chaetognaths 7%; and
- meroplanktonic larvae of fish and benthos 6%.

Major ecological factors affecting local zooplankton productivity, distribution, and community composition include:

- strong seasonality of primary and secondary productivity, biomass, and vertical distribution;
- aggregation of many zooplankton species along environmental "edges," either hydrographic (e.g. the margins of the Fraser plume) or bathymetric (banks and shoals in the main basin, sills and lateral margins of both the main basin and adjoining inlets); and
- spatial gradients of nutrient input and primary productivity.

An important point regarding the workshop objective of ecosystem delineation is that although the above features may be strongly spatially localized at any given time, the "hot spots" shift spatially at a variety of time scales (tidal, weather system, seasonal, and interannual).

4.0 NEKTON

- The major nektonic taxa and their approximate resident biomass (liveweight Kt) include:
- Pacific hake (*Merluccius productus*) 150 Kt;
- Pacific herring (*Clupea harrengus*) 80 Kt;
- Spiny dogfish (*Squalus acanthias*) 60 Kt;
- Walleye pollack (*Theragra chalcogramma*) 20 Kt;
- Salmon (*Onchorhynchus* spp.) <5 Kt resident, 30 Kt transient;
- Other groundfish (cod, sole, rockfish, etc.) 10 Kt? and
- Seabirds, marine mammals <<5 Kt.

The major ecological factors affecting the amount and distribution of nektonic species include;

- food supply (climate),
- predators other than people (climate and fishery dependent),
- fishing mortality,
- habitat loss (especially nearshore spawning and nursery), and
- migration to and from other ocean regions (usually annual but often with strong year-to-year variation in amplitude).

Perhaps even more than for the zooplankton, small fractions of the total Georgia Basin habitat volume can have disproportionately large importance to ecological dynamics of nektonic species at any given time. Also, as for the zooplankton, their exact locations are likely to vary over time. A nice example of this is (Hay, pers. comm; Hay and McCarter 1997) demonstration of interannual variability of herring spawning sites in B.C. coastal waters.

5.0 IMPLICATIONS FOR ECOSYSTEM DELINEATION

Current policy is that marine management information and decisions should become more ecosystem-based. My own interpretation of the principle behind this policy is that we need to broaden our field of view of what species, processes, and places might affect a particular site or population.

How much will an ecosystem approach be aided by blocking out areas on a marine chart? Certainly in terrestrial ecosystems, landscape ecology has provided a useful tool for identifying important influences and interactions. One reason for this success might be that important terrestrial spatial structures (drainage basins, soil types, vegetation patterns) are persistent over interannual and longer time scales. Spatial structures within marine ecosystems are also strong, and often persistent in a probabilistic sense (e.g., there will be a riverine plume front somewhere in the southern Strait of Georgia, and this front will pass through some locations more often than others). But much of this environmental spatial structure is (literally) fluid; we must expect and account for both dispersal and temporal heterogeneity.

LITERATURE CITED

Hay, D.E. and P.B. McCarter. 1997. Larval distribution, abundance, and stock structure of British Columbia herring. J. Fish Biology 51 (Supplement A): 155-175.

ESTUARINE AND MARINE HABITAT AND ECOSYSTEM CLASSIFICATION: ATTRIBUTES OR PROCESSES?

Charles Simenstad
Wetland Ecosystem Team
School of Fisheries, Box 357980, University of Washington
Seattle, WA 98195-7980

Tom Mumford
Washington State Department of Natural Resources
Seattle, Washington

The following is a summary of the topics covered in the presentation.

1.0 HABITAT/COMMUNITY-ATTRIBUTE-BASED CLASSIFICATION AND MAPPING SYSTEMS AS APPLIED TO COASTAL ECOSYSTEMS IN THE UNITED STATES

- Cowardin et al. (1979) is the basis for USFWS National Wetland Inventory mapping of wetland status and trends (Table 1).
- General adoption as the standard for all wetland/coastal habitat mapping and change analyses (e.g., EPA-EMAP, NOAA Coastal Ocean Program, NASA Earth Sciences Research Program).
- Dethier (1990) WDNR modification of Cowardin et al. system for marine and estuarine habitat in Washington State (Table 2).
- Puget Sound Ambient Monitoring Program (PSAMP) Nearshore Habitat Mapping Program.

2.0 ECOSYSTEM CONCEPT AND ECOSYSTEM MANAGEMENT

- Exceedingly scale-dependent relative to frame of reference (nematodes vs. salmon).
- Implicitly includes abiotic environment in addition to biological components (distinguishes from community?).
- Implied ecosystem function as *integrated holistic dynamics* (functions as an organism?).
- Ecosystem structure is distribution of matter and energy among system components.
- Ecosystem processes are abiotic and biotic dynamics that determine structure and function.

3.0 ECOSYSTEM HIERARCHY

- Ecosystem concept applies across hierarchy of nested spatial or landscape and temporal levels of organization (depending upon frame and scale of reference!).
- Allows one to relate various ecosystems to surrounding units in landscape.
- Could be used to further examine inter-ecosystem (landscape) interactions and management implications.

4.0 ECOSYSTEM CLASSIFICATION AND DELINEATION

- Primarily based on integrated associations of attributes;
  - macroclimate,
  - landforms (and their evolution),
  - vegetation,
  - oceanography, and
  - representative species.
- Often captures landform evolution processes but not active processes.
- New approaches, e.g., EPA-ERC watershed-estuary continuum typology.
- See Albert et al. (1986), Omernik and Griffith (1991), and Bailey (1980, 1983, 1995, 1996).

5.0 CLASSIFYING AND MAPPING ECOSYSTEM ATTRIBUTES VS PROCESSES

- Often misses critical landscape setting and interactions (relative to management needs).
- Landscape-scale processes that structure habitats and ecosystems typically not included.
- Mapping fixes structures that are often spatially and temporally dynamic (both naturally and anthropogenically).
- *de facto* importance on (habitat) area rather than habitat-ecosystem associations and interactions.
- Anthropogenic changes in structure and process not typically incorporated into ecosystem classifications and mapping.

LITERATURE CITED

Albert, D.A., S.R. Denton, and B.V. Barnes. 1986. Regional landscape ecosystems of Michigan. Univ. Michigan, Ann Arbor, MI. 32 p. + maps.

Bailey, R.G. 1980. Description of the ecoregions of the United States., USDA Forest Service, Washington, DC. USDA Misc. Publ. No. 1391.

Bailey, R.G. 1983. Delineation of ecosystem regions. Environ. Mgmt. 7:365–373.

Bailey, R.G. 1995. Description of the ecoregions of the United States. 2nd ed. rev. and expanded (1st ed. 1980). USDA Forest Service, Washington, DC. USDA Misc. Publ. No. 1391. 108 pp.

Bailey, R.G. 1996. Ecosystem geography. Springer-Verlag, New York, NY. 204 pp.

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. Fish and Wildlife Service, U.S. Dep. Interior. FWS/OBS-79/31 59 p.

Dethier, M.N. 1990. A marine and estuarine habitat classification system for Washington State. Washington Natural Heritage Program. Department of Natural Resources, Olympia, Wash. 59 p.

Omernik, J.M., and G.E. Griffith. 1991. Ecological regions versus hydrologic units: Frameworks for managing water quality. J. Soil Wat. Conserv. 46:334–340.

TABLE 1. Classification hierarchy of wetlands and deepwater habitats, showing systems, subsystems, and classes. (From Cowardin et al. 1979.) The Palustrine system does not include deepwater habitats.

WETLANDS AND DEEPWATER HABITATS

System	Subsystem	Class
Marine	Subtidal	Rock Bottom
		Unconsolidated Bottom
		Aquatic Bed
		Reef
	Intertidal	Aquatic Bed
		Reef
		Rocky Shore
		Unconsolidated Shore
Estuarine	Subtidal	Rock Bottom
		Unconsolidated Bottom
		Aquatic Bed
		Reef
	Intertidal	Aquatic Bed
		Reef
		Streambed
		Rocky Shore
		Unconsolidated Shore
		Emergent Wetland
		Scrub-Shrub Wetland
		Forested Wetland
Riverine	Tidal	Rock Bottom
		Unconsolidated Bottom
		Aquatic Bed
		Streambed
		Rocky Shore
		Unconsolidated Shore
		Emergent Wetland
	Lower Perennial	Rock Bottom
		Unconsolidated Bottom
		Aquatic Bed
		Rocky Shore
		Unconsolidated Shore
		Emergent Wetland
	Upper Perennial	Rock Bottom
		Unconsolidated Bottom
		Aquatic Bed
		Rocky Shore
		Unconsolidated Shore
	Intermittent	Streambed
Lacustrine	Limnetic	Rock Bottom
		Unconsolidated Bottom
		Aquatic Bed
	Littoral	Rock Bottom
		Unconsolidated Bottom
		Aquatic Bed
		Rocky Shore
		Unconsolidated Shore
		Emergent Wetland
Palustrine		Rock Bottom
		Unconsolidated Bottom
		Aquatic Bed
		Unconsolidated Shore
		Moss-Lichen Wetland
		Emergent Wetland
		Scrub-Shrub Wetland
		Forested Wetland

TABLE 2. Outline of the system (omitting modifiers). The following includes only habitat types that exist (and have been surveyed) in Washington. It is subject to modification. (From Dethier 1990)

MARINE

- **Intertidal**
  - Rock (solid bedrock)
    - Exposed (wave action)
    - Partially exposed
    - Semi-protected and Protected
  - Boulders
    - Exposed
    - Partially exposed
    - Semi-protected
  - Hardpan
  - Cobble: Partially exposed
  - Mixed-Coarse: Semi-protected and Protected
  - Gravel
    - Partially exposed
    - Semi-protected
  - Sand
    - Exposed and Partially exposed
    - Semi-protected
  - Mixed-Fine
    - Semi-protected and Protected
  - Mud: Protected
  - Organic (e.g., wood chips, marine detritus)
  - Artificial (e.g., pilings, tires, concrete)
  - Reef (e.g., oyster, worm) (not imp. in Wash.)
- **Subtidal**
  - Bedrock and boulders
    - Moderate to high energy
    - Low energy
  - Cobble
    - High energy
  - Mixed-Coarse
    - Moderate to high energy
    - Low energy
  - Gravel
    - Low energy
  - Mixed-Fine
    - High energy
    - Moderate energy
    - Low energy
  - Mud and Mixed-Fine
    - Low energy
  - Organic
  - Artificial
  - Reef

ESTUARINE

- **Intertidal**
  - Bedrock: Open
  - Hardpan
  - Mixed-Coarse: Open
  - Gravel
    - Open
    - Partially enclosed, Eulittoral
  - Sand
    - Open
    - Partially enclosed, Eulittoral
    - Lagoon
  - Mixed-Fine
    - Partially enclosed
    - Lagoon
  - Mud and Mixed-Fine
    - Partially enclosed, Eulittoral
    - Lagoon
    - Channel-Slough
  - Mud: Partially enclosed and enclosed
  - Organic: Partially enclosed, Backshore
  - Artificial
  - Reef
- **Subtidal**
  - Bedrock and boulders: Open
  - Cobble: Open
  - Mixed-Coarse: Open
  - Sand
    - Open
    - Partially enclosed
  - Mixed-Fines: Open
  - Mud
    - Open
    - Partially enclosed
  - Sand and Mud: Channel
  - Organic
  - Artificial
  - Reef

DISCUSSION

Mary Morris: I have a specific question. You mentioned the landscape polygon development for the estuary part of Willapa Bay. What are you using as your data source for that?

Si Simenstad: Actually, we're going to try two independent data sources. One is a 1995 ADAR 5500 mobile spectral scanner image, which has a 2.5-metre resolution. The other is another remote image, LANDSAT, combined with panchromatic, which has a 5-metre resolution. So we can do those two separately and also look at different scales to see if our scale affects aggregation — if there is any change in the output or interpretation.

I'd be glad to spend some time on this later on. This ADAR 5500 image that I brought is the first cut. It has some GIS problems and spectral problems, but hopefully these are going to be refined. I just want to say that if you have a chance, take a close look at it. Willapa Bay is about 60% intertidal. Take a look at the complexities of geomorphic features like the dendritic channel system, the spectral responses from eelgrass, and if you're interested in exotic species, the rapid expansion of *Spartina alterniflora* in this system. You can see why trying to delineate, if we can, functional differences in the intertidal area relative to the watershed and in estuary use has a pretty strong management application.

Don Howes: How do you build time into this, for example if you have watersheds where you have rates of cut and a high frequency of landslides until you get the reforestation? There's a time element that's going to influence your estuary. How are you building that into this interaction?

Si Simenstad: We're building into it from the changes, especially in erosion, landslide, frequency, that Dave Montgomery is doing. He's using a DM-driven model to generate classification of the frequency disturbances, and then overlaying the cutting history on that. Unfortunately, we don't have anything like that historic dataset for the estuary. All we can do, in spots, is look at cores and look at the sedimentation rate, interpreting potential pollen and other factors in terms of how that has affected the local proximal estuarine portion. We can't do it at the estuary; we can at the watersheds.

John Pringle: Si, I think you were warning against trying to map ecosystems because of the pitfalls. Are you really suggesting not doing it or doing it with those cautionary factors in mind?

Si Simenstad: I was trying to suggest that trying to delineate ecosystem structure, particularly habitat structure, at the finest level of resolution might not get us to the point of the management tool which is trying to understand and classify the processes that are dictating that structure, including variable processes like disturbance.

Bill Austin: What about using animals? To what degree could you use the organisms there as indicators, as integrators of particular processes? In other words, I think it's really important that I know more than a name in terms of looking at those habitats, and those species may be able to tell you something along those lines.

Si Simenstad: The problem is actually having timed sequences, chrono-sequences, for the fauna there. In places like Tatoosh, you've probably got some studies that you've been looking at for a long time. As a mapping dataset, that's pretty hard. One potential is the chrono-series that might be embedded in things like bivalve shells that could be used to "hind-cast" variability in systems. Some long-lived species might give you indicators to that. That's the only thing I can think of.

THE LOWER FRASER/GEORGIA BASIN ECOSYSTEM INITIATIVE

Bruce Kay
Georgia Basin Initiative
Environment Canada
1200 West 73rd Ave.
Vancouver, BC V6P 6H9

1.0 INTRODUCTION

Ecosystem initiatives are cooperative efforts on targeted ecosystems of national priority designed to address and solve complex environmental issues as identified and agreed upon by partners/communities. They are characterized by use of an ecosystem approach to management that is guided by an overall perspective of sustainability; an integrated approach that takes into account human and ecosystem wellbeing together: environmental, social, economic, cultural, and political aspects.

Thus, while traditional environmental concerns will be central to this initiative, others will also play an important role. This breadth of emphasis is essential if the holistic and long-term perspective of sustainability is to be applied, if a commitment to open and consensual processes is to be maintained, if gains in government efficiency and effectiveness are to be achieved, and most importantly, if the wellbeing of people and the ecosystem that is their home are to be maintained and improved.

The fastest growing communities in Canada are now located in British Columbia. Similarly, the Greater Vancouver–Seattle axis is one of the most rapidly expanding urban/suburban concentrations in North America. With its location and high quality of life, it has emerged as a major gateway to the Pacific Rim group of countries.

Two thirds of B.C.'s population (2.7 million people) and three-quarters of the labour force live in the Georgia Basin. In 1990, the combined Washington/B.C. population in the Georgia Basin was 5.7 million. The population within the Lower Fraser/Georgia Basin (LF/GB) ecosystem (which includes the large metropolitan areas of Greater Vancouver and Metro Seattle), is projected to double in the next 20 years. Development pressures are now imposing unprecedented levels of physical, chemical, and biological stress on the ecosystem. Unchecked, the increasing level of human imposed stress will put at risk the very ecosystem conditions that provide the foundation of the region's economy, the health of individuals, and the overall quality of life that attracted people here in the first place. With appropriately managed growth, a remarkable opportunity exists for this region to provide an example of how to do it right — of providing for the wellbeing of people and their communities while maintaining (as a minimum) — or preferably improving — ecosystem health.

For all of these reasons, the LF/GB ecosystem has been assigned the highest priority for attention by Environment Canada, Health Canada, and other federal and provincial counterparts. It is here where the greatest concerns are, it is here where the greatest gains are to be made, and it is here where successful resolution of sustainability issues will have the greatest impact on similar problems facing other parts of British Columbia, Canada, and abroad.

The LF/GB Ecosystem Initiative has not emerged in a vacuum. Rather, it has been built on decades of activity at the federal, provincial, regional district, and municipal level. For example, the experience and successes of the Fraser River Estuary Study and resulting Fraser River Estuary Management Plan (FREMP), the Fraser River Action Plan (FRAP), the Fraser River Management Plan (FRMP) and its successor the Fraser Basin Council (FBC), the province's Georgia Basin Initiative (GBI), the evolving Growth Management Plans of the Regional Districts, the BC–Washington Environmental Cooperation Council, and a number of more discrete federal and provincial programs have all provided essential input.

2.0 THE LF/GB ECOSYSTEM INITIATIVE

2.1 Purpose

The LF/GB Ecosystem Initiative is an evolving, results- and science-based integrated action plan. The ***purpose*** is to engage communities and enhance coordination and collaboration amongst the many government and non-government stakeholders while achieving measurable improvements in:

- conditions affecting environmental health and human well-being;
- capacity of individuals and families, businesses and organizations, and all orders of government to deal with issues of sustainability; and
- efficiency and effectiveness of government.

The Initiative is taking an approach to dealing with priority issues that is holistic, long-term, consensus-based, and inclusive of affected stakeholders. In doing so, it is attempting a new approach to problem solving and delivery of government services. It is not simply doing more of what has been done already over the years.

2.2 Vision

A draft ***vision*** statement for the Initiative has been developed collaboratively with participants.

VISION

Managing growth to achieve healthy, productive,

and sustainable ecosystems and communities.

2.3 Goals

Similarly, the following three broad ***goals*** have been identified:

GOALS

- to enhance environmental health
- to enhance society's capacity to achieve sustainability
- to enhance human well-being.

2.4 Guiding Principles

Developing and implementing the LF/GB Ecosystem Initiative will be guided by a series of ***principles:***

The Lower Fraser/Georgia Basin Ecosystem Initiative will:

- be guided by an ecosystem approach to management within an overall perspective of sustainability;
- recognize Aboriginal rights and title;
- consider both substance and process aspects of solution building;
- emphasize partnerships and collaboration between existing players rather than creating new institutions;
- seek early and broad citizenship/community involvement;
- emphasize local capacity building;
- build on relevant local, provincial, and federal work to date; and
- strive to be performance- and science-based, and results oriented.

3.0 ECOSYSTEM APPROACH

The purpose, vision, goals, and principles all recognize the multi-faceted, environmental, social, economic, cultural, and political nature of achieving progress toward sustainability. In addition, the network of collaborators that is being established reaches well beyond traditional "environmental" partners to include many government agencies and businesses and organizations of civil society that capture this breadth of perspective.

The initiative includes three primary streams of activities (Figure 1). In each stream and in each program element, environmental, social, economic, cultural, and political implications play a role in program design, implementation, and assessment of success.

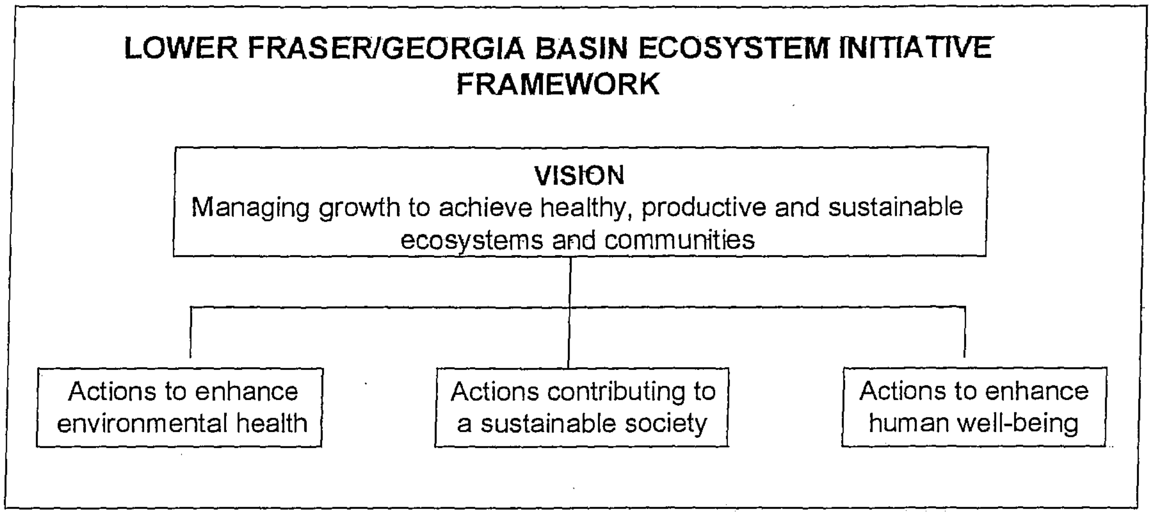


FIGURE 1. Organization of the Lower Fraser/Georgia Basin Ecosystem Initiative.

4.0 ISSUES

Key issues facing the LF/GB ecosystem which will be addressed by the Initiative include:

- the pervasive issue of growth management;
- Lower Mainland air quality (emissions, resulting conditions and implications, solutions);
- continuing point and non-point discharges to surface water and related programs of pollution prevention;
- contamination of groundwater, particularly by agricultural activities;
- sewage contamination of shellfish production areas;
- toxic chemicals, in particular endocrine disrupters;
- degradation and loss of coastal and uplands habitat (often from urban and suburban expansion) and the related land management regimes; and
- shifting responsibilities between federal, provincial, and local orders of government and the need for effective cooperation and collaboration.

To address these issues, multi-agency working groups have been established to develop detailed action plans. Figure 2 summarizes the action plans currently under development.

Actions to Enhance Environmental Health	Actions Contributing to a Sustainable Society	Actions to Enhance Human Well-being
• Achieving Clean Air • Preventing Pollution and Reducing Toxics • Conserving and Protecting Nature	• Building Community Capacity and Enhancing Collaboration (Governance) • Providing Knowledge for Sustainable Development • Measuring Performance	(Under development by Health Canada in collaboration with provincial health partners)

FIGURE 2. Lower Fraser/Georgia Basin Ecosystem Initiative Action Plans.

5.0 BOUNDARIES

Ecosystem initiatives are space-based and boundaries are related to meaningful ecosystem attributes, in this case a drainage basin. The Lower Fraser/Georgia Basin ecosystem encompasses an area of approximately 135,000 square kilometres and includes the land and inland sea (Strait of Georgia, Puget Sound, and Juan de Fuca Strait) defined by the heights of land formed by the Vancouver Island Ranges, the Coast Ranges, the Cascades, and the Olympic Mountains. The boundary is roughly marked by Campbell River in the north, Olympia in the south, Hell's Gate in the Fraser Canyon to the east, and Race Rocks in the Strait of Juan de Fuca to the west.

This definition is recognized by the Government of British Columbia through its Georgia Basin Initiative, and forms the basis of the Washington State–BC Environment Cooperation Agreement.

In 1996, the Pacific and Yukon Region of Environment Canada analyzed and ranked environmental issues in all of the Region's major ecological units and assigned the highest priority for a future initiative to the Lower Fraser/Georgia Basin *(Ecosystem-Based Planning Framework and Priority Areas for Action - April, 1996).*

A Synopsis of the "State of the Basin"

- **Changing biodiversity**

  As of 1995, only 1.7% of marine water and islands along the B.C. coast were protected. Current state-of-environment reporting indicates decreasing populations in more than half of the salmon, groundfish, and shellfish species surveyed. In the marine ecozone, of 70 species or groups of species having long-term data, 30% are at historic lows. The gray whale no longer travels through the waters the Strait of Georgia.

- **Degradation and loss of coastal and uplands habitat**

  Approximately 82% of saltmarsh in the Fraser estuary, 54% in the Nanaimo estuary, 53% in the Cowichan estuary and 93% in Burrard Inlet have disappeared.

- **Air quality in Greater Vancouver and the Fraser Valley**

  Based on twice-daily tests of 58 farmworkers in Abbotsford over two months in summer, lung capacity declined by about 5% the day following exposure to smog.

- **Toxic contamination**

  Based on Fraser River Action Plan research, concentrations of polycyclic aromatic hydrocarbons (PAHs) in Fraser River Estuary bed sediments exceeded federal guidelines and provincial criteria for the protection of aquatic life. Similarly, concentrations of dioxins and furans in sediments exceeded the draft federal guidelines for aquatic life.

- **Groundwater quality in the Fraser Valley**

  Sampling by Environment Canada in the Abbotsford aquifer showed that, from 1991 to 1995, 85% of wells sampled exceeded the Canadian Drinking Water Guidelines.

- **Sewage contamination of shellfish production areas**

  There are approximately 300 sewage outfalls in the Lower Fraser/Georgia Basin Ecosystem. Close to 60,000 hectares of shellfish habitat have been closed because of bacterial contamination and toxins crises in commercial and recreational fisheries.

- **Unsustainable natural resource extraction**

  Halibut, abalone, and lingcod no longer exist at commercial levels, and salmon are now absent from at least a third of the 350 tributaries that historically contributed to Georgia Basin stocks.

  Only two of the 50 free-flowing streams that once supported salmon in Vancouver still exist.

  About a third of the salmon stocks that once spawned in the Strait of Georgia are gone or virtually gone.

  Only about half of the 350 streams that contributed significantly to the Strait's four species of salmon are still productive.

- **Quality of life**

  Transportation is the largest single source of air pollution in the province. It accounts for about 75% of air pollution in the Lower Fraser Valley — and vehicles and traffic are projected to double over the next 25 years.

  A recent survey in the Lower Mainland revealed more than half the residents feel population growth negatively affects their quality of life; 95% recommend governments work together to do more long-range regional planning.

PLENARY DISCUSSION OF SEVEN QUESTIONS POSED BY THE ORGANIZERS

SUMMARY DERIVED FROM NOTES AND TRANSCRIPTS

The seven questions posed by the organizing committee were discussed in a Plenary Session. These discussions were summarized by the organizers and circulated to attendees for their input and comments. See Appendix B for comments received from attendees. A verbatim text of the discussions was transcribed from tapes made at the meeting, and is appended as an electronic file (in Word 6.0) on a disc included with this volume. Additional copies are available from John Pringle at the address on the cover.

Question 1. What are the major issues in Georgia Basin that need resolution using an ecosystem approach?

- Establishment of a network of marine protected areas.
- Establishment of a habitat management approach that takes into consideration cumulative effects.
- Integration of watersheds and coastal zone in any planning process.
- Reconciliation of the scientific definition of ecosystem with that of the habitat manager.
- Interagency and international cooperation/coordination.
- Establishment of the role of NGOs / community groups in the habitat management process.
- Reconciliation of the "ecosystem" vis-a-vis the "no net loss" approaches.
- Communication of scientific results to the public in a manner understood by the layperson.

Question 2. Are we now ready and able to define and delineate marine ecosystems of the Georgia Basin using available geographic techniques and present biophysical information?

- Yes, particularly near shore, but it is very much scale-dependent.
- More than 15 schemes are currently in place and used by habitat managers.
- Boundaries should not be tightly defined, but left broad and "fuzzy."
- Definition is hampered by inter-agency differences in goals, approaches, and principles.
- Development of a classification procedure may benefit from exploration of procedures developed for terrestrial environment.

Question 3. What are the existing techniques and criteria that we should adopt to best accomplish this definition and delineation?

- The need to develop coordination and communication techniques to advance discussions and develop processes.
- The use of a formal peer-review process to assess existing techniques and criteria.
- Get on with the process using whatever criteria/process is deemed best for the purpose/question at hand.
- Assess the Guelph agro-ecosystem approach for a method that integrates both criteria from the top down and the bottom up.

Question 4. What time and space scales are appropriate for the different management demands of the Georgia Basin?

- DFO habitat managers requested that ecosystem delineation begin at the scale that provides the most detail possible.
- The scale chosen must allow for the tracking, documentation, and impact assessment of cumulative effects.
- Temporal scale is more difficult to assess than spatial scale, given climate and regime shifts and population growth; the latter will set the temporal scale.
- Whatever scale is used, it must be understood there is poor understanding of the scale of ecological processes such as eutrophication.
- If indicator species are used, the scale will vary with the species chosen.
- The myriad categories of management decisions dictate the temporal and spatial scales used.

Question 5. How should ecological boundaries of marine ecosystems be linked with others, such as DFO statistical areas?

- Deployment of observers on-board commercial vessels has improved data quality.
- Advances in geo-referencing of fisheries data should enable its aggregation into schemes that would abet ecosystem delineation.
- Numerous datasets are available that could be used, ranging from terrestrial systems to marine fish larvae. It was noted that any attempt to bring together datasets from various agencies should be done cautiously.
- The technique used by Al Tyler in Hecate Strait to identify fish assemblages should be explored.

Question 6. What boundaries of marine ecosystems can we actually now delineate in Georgia Basin to improve our management of key issues? Do these boundaries meet the expectations of habitat managers?

- A zoning process, such as ICZM, should be set up to provide guidelines prior to ecosystem delineation, because the process is dependent on scale and indicator species, in addition to the impact of sociological and managerial implications.
- Participants proposed Georgia Basin as one macro-scale ecosystem with a number of nested micro-scale ecosystems.

Question 7. What are some key ecosystem properties that should be measured in the future in support of ecosystem-based management?

- Distribution and abundance of "keystone" species, e.g., forage species.
- Sand lance — though not a commercially important species, is an important prey item for many species of fish and birds.
- Ichthyoplankton and invertebrate larvae.
- The extent of shoreline now in specific zones.
- Data from rocky areas, areas of strong currents, and deep water areas.
- Data that denotes the impact of humans, e.g., number and extent of shellfish closures.
- Whatever sampling scheme is employed, data should be collected at the finest scale possible.
- Because of changing conditions on a temporal scale, we require process parameters in addition to size spectrum data, species diversity, endangered species, exotics, primary production, and key nutrients, etc.
- Extant databases must be captured before they are lost through retirement of scientific staff.

APPENDIX A

AGENDA

DFO WORKSHOP ON ECOSYSTEM DELINEATION — GEORGIA BASIN

4–5 November 1997
Institute of Ocean Sciences
Sidney, B.C.

Agenda November 4 Morning Session (0900-1230)

1. Welcome, introduction, purpose of the workshop — John Pringle, Colin Levings.
2. A review of ecosystem classification: Delineating Strait of Georgia — Jane Watson (Malaspina College) [Report distributed before workshop].
3. What does DFO Habitat and Enhancement Branch need to implement an ecosystem — Steve Samis (DFO Habitat and Enhancement Branch).
4. A marine ecological classification for Canada — Lee Harding (Environment Canada).
5. Marine resource inventory and classification in British Columbia's coastal and marine waters: A systems approach — Don Howes (BC Land Use Coordination Office).
6. Practical insights into marine region classification: The BC Marine Region Classification Scheme — John Harper (Coastal and Ocean Resources Inc.) and Peter Wainwright.
7. Modeling Georgia Basin intertidal biophysical for shoreline gap analysis — Mark Zacharias (BC LUCO) and Mary Morris (Archipelago Marine Research).
8. Water mass characteristics of the Georgia Basin — Rick Thomson (DFO, Science Branch).
9. Ecosystem delineation in the Georgia Basin based on nutrients, chlorophyll, phytoplankton species and primary productivity — Kedong Yin, Paul Harrison and Max Taylor (UBC Oceanography).
10. Secondary production and nekton — Dave Mackas (DFO, Science Branch).
11. Estuarine-marine habitat and ecosystem classification and mapping: Attributes or processes? — Charles (Si) Simenstad (University of Washington) and Tom Mumford (Washington Department of Natural resources).

Agenda Nov. 4 Afternoon session (1330-1630)
Plenary Discussion of Questions 1 to 4 (listed below)

Agenda Nov. 5 Morning session (0830-1200)
Plenary discussion of Questions 5 to 7 (listed below)

1130-1200 Summary and final discussions

Discussion Questions

Question 1. *Chaired by Rick Higgins and Karen Hutton*

What are the major issues in the Strait of Georgia that need resolution using an ecosystem approach? For example, are those issues recently reported by the recent BC/Washington Environmental Cooperative Council adequate for our purposes?

Question 2. *Chaired by Paul G. Harrison*

Are we now ready and able to define and delineate marine ecosystems of the Strait of Georgia using available geographic techniques and present biophysical information?

Question 3. *Chaired by John Harper*

If so, what are the existing techniques and criteria that we should adopt to best accomplish this definition and delineation?

Question 4. *Chaired by Jennifer Nener and Rob Russell*

What time and space scales are appropriate for the different management demands of the Strait of Georgia?

Question 5. *Chaired by Jeff Fargo*

How should ecological boundaries of marine ecosystems be linked with others such as DFO statistical areas?

Question 6. *Chaired by Bruce Kay and Mike Dunn*

What boundaries of marine ecosystems can we actually now delineate in the Strait of Georgia, to improve our management of key issues? Will these boundaries meet the expectations of habitat managers?

Question 7. *Chaired by Brian Smiley*

What are some key ecosystem properties that should be measured in the future, in support of ecosystem-based management?

Workshop steering committee

Colin Levings, (Research Scientist and Head, Coastal and Marine Habitat Science Section, DFO Science Branch, Pacific Environmental Science Centre, North Vancouver).

John Pringle (Head, Marine Environment and Habitat Division, DFO Science Branch, IOS., Sidney).

Steve Samis (Ocean Act Coordinator, DFO Habitat and Enhancement Branch, Vancouver).

Brian Smiley (Head, Aquatic Assessment Section, DFO Science Branch, IOS, Sidney).

APPENDIX B

LIST OF ATTENDEES

Name		Affiliation
Ed	Anderson	Ed Anderson Marine Sciences Ltd., Sidney, BC e-mail na[1]
Bill	Austin	The Marine Ecology Station, Cowichan Bay, BC. mareco@islandnet.com
Julie	Barr	Fisheries & Oceans Canada, Vancouver, BC Barrj@dfo-mpo.gc.ca
Doug	Biffard	BC Parks. dbiffard@prkvctoria.elp.gov.bc.ca
Jacqueline	Booth	booth@saltspring.com
Beth	Bornhold	University of British Columbia, Vancouver, BC bornholdb@unixg.ubc.ca
Darlene	Boyle	Osprey Environmental Services, Vancouver, BC osprey@mailhome.com
Dick	Carson	Fisheries & Oceans Canada, Vancouver, BC carsond@dfo-mpo.gc.ca
Barron	Carswell	BC Ministry of Agriculture, Fisheries & Food, Victoria, BC baron.carswell@gems8.gov.bc.ca
Al	Colodey	Environment Canada, Vancouver, BC al_colodey@ec.gc.ca
Jon	Day	Queensland (Australia) Dept. of Environment / World Wildlife Fund jday@wwfcanada.org
Chris	Dragseth	Fisheries & Oceans Canada, Nanaimo, BC dragsethc@dfo-mpo.gc.ca
Michael	Dunn	Environment Canada, Delta, BC michael_dunn@ec.gc.ca
Jeff	Fargo	Fisheries & Oceans Canada, Nanaimo, BC fargoj@dfo-mpo.gc.ca
Gordon	Goodman	BC Land Use Coordination Office, Victoria, BC e-mail na
Heidi	Guest	Secter Environmental Resource Consulting, Victoria, BC e-mail na
Lee	Harding	Environment Canada, Vancouver BC..lee_harding@ec.gc.ca
John	Harper	Coastal & Ocean Research Inc., Sidney, BC cori@islandnet.com

[1] na - not available

Paul G	Harrison	University of British Columbia, Vancouver, BC zmar@unixg.ubc.ca
Doug	Hay	Fisheries & Oceans Canada, Nanaimo, BC hayd@dfo-mpo.gc.ca
Rick	Higgins	Fisheries & Oceans Canada, Nanaimo, BC higginsr@dfo-mpo.gc.ca
Don	Howes	BC Land Use Coordination Office, Victoria, BC don_howes@gems7.gov.bc.ca
Karen	Hutton	Fisheries & Oceans Canada, Vancouver, BC huttonk@dfo-mpo.gc.ca
Glen	Jamieson	Fisheries & Oceans Canada, Nanaimo, BC jamiesong@dfo-mpo.gc.ca
Sabine	Jessen	Canadian Parks & Wilderness Society, Vancouver, BC sjessen@cpawsbc.org
Helen	Joseph	Fisheries & Oceans Canada, Ottawa, ON josephh@dfo-mpo.gc.ca
Bruce	Kay	Environment Canada, Vancouver, BC bruce.kay@ec.gov.bc.ca
Phil	Lambert	Royal British Columbia Museum, Victoria, BC plambert@rbmLo1.rbcm.gov.bc.ca
Mike	Lambert	BC Environment, Victoria, BC mlambert@nanaimo.env.gov.bc.ca
Jennifer	Lash	Marine Life Sanctuary Society Fax: 250-973-6581 e-mail na
Norm	Lemmen	Fisheries & Oceans Canada lemmenn@dfo-mpo.gc.ca
Colin	Levings	Fisheries & Oceans Canada, West Vancouver, BC levings@dfo-mpo.gc.ca
Dave	Mackas	Fisheries & Oceans Canada, Sidney, BC mackasd@dfo-mpo.gc.ca
Jeff	Marliave	Vancouver Aquarium, Vancouver, BC marliaj@vanaqua.org
Brad	Mason	Fisheries & Oceans Canada, Vancouver, BC masonb@dfo-mpo.gc.ca
Francine	Mercier	Parks Canada mercierf@pch.gc.ca
Ken	Morgan	Environment Canada, Victoria, BC morgank@ios.bc.ca
Mary	Morris	Archipelago Marine Research Ltd, Victoria, BC marym@archipelago.bc.ca
Jennifer	Nener	Fisheries & Oceans Canada, Vancouver, BC nenerj@dfo-mpo.gc.ca
Linda	Nichol	Linda Nichol Ecological Consulting, Nanaimo, BC lnichol@islandnet.com

John	Pringle	Fisheries & Oceans Canada, Sidney, BC pringlej@dfo-mpo.gc.ca
Don	Radford	Fisheries & Oceans Canada, Prince Rupert, BC radfordd@dfo-mpo.gc.ca
Rob	Russell	Fisheries & Oceans Canada, Nanaimo, BC russellr@dfo-mpo.gc.ca
Steve	Samis	Fisheries & Oceans Canada, Vancouver, BC samiss@dfo-mpo.gc.ca
Jon	Secter	Secter Environmental Resource Consulting, Victoria, BC jpsector@islandnet.com
Charles(Si)	Simenstad	University of Washington, Seattle, WA csimenstad@lternet.edu
Brian	Smiley	Fisheries & Oceans Canada, Sidney, BC smileyb@dfo-mpo.gc.ca
Sean	Standing	Fisheries & Oceans Canada, Vancouver, BC standings@dfo-mpo.gc.ca
Craig	Stephens	Malaspina College, Nanaimo, BC ceh@mala-bc.ca
Jim	Stronach	Hayco, Vancouver BC stronach@hayco.com
Rick	Thomson	Fisheries & Oceans Canada, Sidney, BC thomsonr@dfo-mpo.gc.ca
Joe	Truscott	BC Ministry of Agriculture, Fisheries & Food, Victoria, BC joe.truscott@gems7.gov.bc.ca
Scott	Wallace	University of British Columbia, Vancouver, BC wallaces@unixg.ubc.ca
Jane	Watson	Malaspina College, Nanaimo, BC watsonj@mala.bc.ca
Bob	Wilson	2WE Associates Consulting Ltd., Victoria, BC wilson@bc.sympatico.ca
Larry	Wolfe	Quadra Planning Consultants Ltd., Vancouver, BC wolfe_quadra.@compuserve.com
Kedong	Yin	University of British Columbia, Vancouver, BC kedong@unixg.ubc.ca
Mark	Zacharias	BC Land Use Coordination Office, Victoria, BC Mark.Zacharias@gems6.gov.bc.ca
Fran	Aitkens	Victoria, BC aitkens@island.net

APPENDIX C

ADDITIONAL COMMENTS ON PLENARY SESSION SUMMARY PREPARED BY ORGANIZERS

Consensus answers to the seven questions posed during the Plenary Session were circulated to attendees for comments. The following comments were received.

General comments

Doug Hay: [The] synopsis might have started, or ended, with a statement about the overall objectives of the workshop.

Doug Hay: [I]n my view, few of the responses seemed to really bite the bullet and address "DELINEATION" which is what the exercise was about. Nevertheless, from the following I detect a potentially interesting conceptual dichotomy that could be useful. I suggest that participants in the workshop may fall in to two camps. In one, ecosystems are seen as "two-dimensional mosaics" with fuzzy boundaries that blend and change with time. In the other, ecosystems are multi-dimentional and nested, with little ecosystems as substructures of bigger systems. I prefer this latter approach, because it allows for some changes in the components without necessarily having to change the whole.

Ken Morgan: I feel that the notes sent out for us to review are far too "ichthyocentric." A useful scheme for delineating ecosystems should be one that can satisfy many different interests; it should not be determined solely by fisheries management needs. If my memory serves me correctly, I seem to recall lots of discussions relevant to the topic of ecosystem delineation, but not directly related to fisheries management. Those points seem to have been left out of this summary.

Question 1. What are the major issues in Georgia Basin that need resolution using an ecosystem approach?

Si Simenstad: Bullet 2 should read "Establishment of (a) habitat management approachES that take(s) into consideration BOTH ECOSYSTEM PROCESSES AND cumulative effects."

Doug Hay: The question does not match the responses below (or vice versa). I would re-word the question as "What initiatives or developments are prerequisite to ecosystem management in Georgia Strait?" Even after this, I do not feel enlightened by either the question or the answers.

Ken Morgan: Bullet 5: I suggest that you should also mention Intra-agency cooperation/coordination. I think we witnessed as much disagreement within DFO staff as between different agencies.

Question 2. Are we now ready and able to define and delineate marine ecosystems of the Georgia Basin using available geographic techniques and present biophysical information?

Si Simenstad: Add this as Bullet 2 and move others down. "No, not until we develop consensus (?) on hierarchies of habitat-ecosystem structure, delineating attributes that are mapable and indicators of process, in addition to structure".

Is Bullet 3 feasible given management needs?

Bullet 5: This could particularly be the case if the use of landscape ecology metrics were found to be helpful in identifying and delineating coastal ecosystems.

Don Howes: Bullet 2: Again the community in BC has already explored and used lessons gained from terrestrial ecosystem mapping in developing the ecological classification. These comments in the document suggest that these actions have not taken place when in reality they have been looked in great detail — why revert back to something already completed?

My notes also strongly suggest that participants at the meeting were in general agreement with the work to date by the Province and Environment Canada on ecosystem classification, agreed with the two tiered Provincial approach and supported continued development of the approach using the integrated data set for Georgia Basin.

Doug Hay: Bullet 1: This is the only reply that really seems to address the question.

Ken Morgan: The comments point out that there are a variety of schemes in place and used by managers, but they give me the impression that DFO is about to embark upon re-inventing the wheel. There is no mention of the work that LUCO has done - I think that with some minor modifications, their system could be used by DFO. More importantly, any ecosystem delineation/classification scheme that is adopted should be one that is transferable among agencies/governments. It should not be fisheries driven, regardless of the fact that it will be used by DFO and others. I feel that the system should be based upon biophysical/oceanographic features that are totally independent of political/jurisdictional/sectoral boundaries.

Question 3. What are the existing techniques and criteria that we should adopt to best accomplish this definition and delineation?

Don Howes: Bullet 3: BC has for a number years been developing a method that is top and bottom down; it is already accepted by the scientific community in BC and there was strong support from participants on the approach currently being developed by the Province.

There was also strong consensus from the participants that the Province had the information to work and develop the ecological classification at lower levels using the Georgia Basin. The Guelph approach is not new to us who have been working on it.

Doug Hay: Bullet 1: coordination between whom? what processes?

Bullet 2: I recommended the expansion of the present PSARC process, or something like it, to include all habitat issues. Not only is this peer review, but it is, in theory, bottom-up advice to management.

Bullet 3: This last item is the only thing on the list that responds to the question, and even this reads as an afterthough. In effect, there are no substantive replies to question 3 in this list.

Question 4. What time and space scales are appropriate for the different management demands of the Georgia Basin?

Si Simenstad: add this bullet:

> "Developing a hierarchial structure that is logical in terms of scaling of ecosystem processes will, in the long-term, facilitate the various needs/uses for management at different scales."

Emphasize Bullet 2.

Bullet 3: But role of temporal variation needs to be taken into account, especially because many coastal processes vary around 'event' scales (e.g., storms, high runoff) that are poorly characterized.

Doug Hay: None of these replies appears to provide a satisfactory answer to the question. To answer this question properly, a matrix or a table is required that matches the objective with the spatial resolution required.

Question 5. How should ecological boundaries of marine ecosystems be linked with others, such as DFO statistical areas?

Si Simenstad: General comment: The highest priority, however, should be the scientific bases of habitat and ecosystem structure, rather than statistical areas that may relate more to the demographics of fish landings or other unrelated factors (e.g., those that relate to catch of adults).

Doug Hay: Bullets 1, 2, 3, 4: [Are they] relevant to the question?

Ken Morgan: My response is similar to [response to Q 2]. Why is it necessary for the ecological boundaries to link with DFO statistical areas? With the capabilities of GIS, it should be quite simple (once the classification scheme is adopted and the mapping is done) to determine the locations and extent of all ecosystem types within each statistical area.

Ken Morgan: Bullet 2: Not certain if I fully understand this one, but if it is implying that fisheries data (e.g. catch statistics) can help determine ways to delineate ecosystems, then again, I repeat that the system should be based upon real biophysical features, not fisheries data.

Question 6. What boundaries of marine ecosystems can we actually now delineate in Georgia Basin to improve our management of key issues? Do these boundaries meet the expectations of habitat managers?

Si Simensatd: Need to consider beyond — or at least ecotones among — Georgia Basin to adjacent systems such as northern Puget Sound and southern Johnstone Strait that may be jurisdictionally separate but highly integrated with Georgia Basin.

Doug Hay: This seems to be a re-statement of Question 2.

Bullet 1: [T]his seems like a solid answer to a question, but what is ICZM?

Question 7. What are some key ecosystem properties that should be measured in the future in support of ecosystem-based management?

Si Simenstad: Add bullet - Indicators of ecosystem processes (and the processes themselves!) that structure biological communities, e.g., estuarine and coastal circulation, sedimentation, predator-prey and competitive interactions, disturbance regimes, etc.

Ken Morgan: - Bullet 1: I recommend that it will be far better to identify the major habitat types the keystone species depend upon and to map their location, rather than to determine the distribution and the abundance of the keystone species. For example, if Sandlance require a certain substrate type, exposure type, current type, etc. it will be more profitable to determine what those are, and then to identify and map the location of those features. You will never succeed in getting the money to determine the distribution and abundance of sandlance.

Doug Hay: - Ichthyoplankton and invertebrate larvae required (I doubt this!)

Bullet 3 - If we all did everything to the finest scale possible, we all be using electron microscopes. The correct answer is that we need 'suitable' scales, but this is self evident.

think we can do better than the responses above. My answer(s) would be that we already measure the following:

1. Overall fish abundance: we know the approximate abundance (and/or abundance indices), measured annually or periodically, of 5+ major fish species (herring, 4 salmon species, hake, lingcod, some rockfish;
2. Fish distribution (annual data are available on recreational salmon catches (creel census), herring spawn, etc.;
3. Marine mammal abundance distribution. Annual estimates examine the numbers and distribution of seals and sea lions. Some whales might also be added to this;
4. Marine birds. I know there are counts of a number of species made annually;
5. Plankton conditions and surveys, including incidence of red tides;
6. Ocean climate and oceanographic factors (temp., salinity, etc.);
7. Extraneous input, in the form of river runoff could be assessed; and

8. I think there are various annual measures of anthropogenic factors, such as total sewage input, total volumes of dredge material dumped, coliform counts, total number of recreation boats and estimated number of people that poop in the water.

In addition we also could include:

A few other key fish species that are important ecosystem components: This could include: sand lance (Ammodytes); deep sea smelts (Leuroglossus). Probably, we also could include measures of intertidal/subtidal fishes as assessed in a few key locations;

Estimates of total macrophytes could be monitored through periodic surveys. There probably are now enough data to determine if there are any major changes in time; and

In short, we could put together enough "indices," in one form or another, to compile an overall index of the health or well-being of the Strait, if we can decide on what is healthy — and I think we can.

APPENDIX D

LIST OF ABBREVIATIONS USED

BCMEC	British Columbia Marine Ecological Classification
BIEAP	Burrard Inlet Environmental Action Plan
CCME	Canadian Council of Ministers of the Environment
CEPA	Canadian Environmental Protection Act
CHS	Canadian Hydrographic Service
CWS	Canadian Wildlife Service
DFO	Department of Fisheries and Oceans (federal)
DOE	Department of Environment (federal)
EEZ	Exclusive Economic Zone
FAO	Food and Agriculture Organization (of the UN)
FRAP	Fraser River Action Plan
FREMP	Fraser River Estuary Management Plan
GIS	Geographic Information System
GSC	Geological Survey of Canada
GVRD	Greater Vancouver Regional District
HEB	Habitat and Enhancement Branch (of DFO)
IAM	Integrated Area Management
ICO	Interdepartmental Committee on Oceans
ICZM	Integrated Coastal Zone Management
IOS	Institute of Ocean Sciences (Sidney BC)
IUCN	World Conservation Union
LME	Large Marine Ecosystem
LUCO	Land Use Coordination Office
MEC	Marine Ecosystem Classification
MEQ	Marine Environmental Quality
MEQAG	Marine Environmental Quality Advisory Group
MOU	memorandum of understanding

MPA	Marine Protected Area
NAFO	North Atlantic Fish Organization
NGO	non-government organization
NOAA	National Oceanic and Atmospheric Administration (USA)
PSARC	Pacific Stock Assessment Resource Committee
SAMPA	Science and Management of Protected Areas Association
SOE	State-of-the-Environment
UNCLOS	United Nations Conference on the Law of the Sea