Wetland Functions, Rehabilitation and Creation in the Pacific Northwest:

The State of our Understanding

Washington State Department of Ecology

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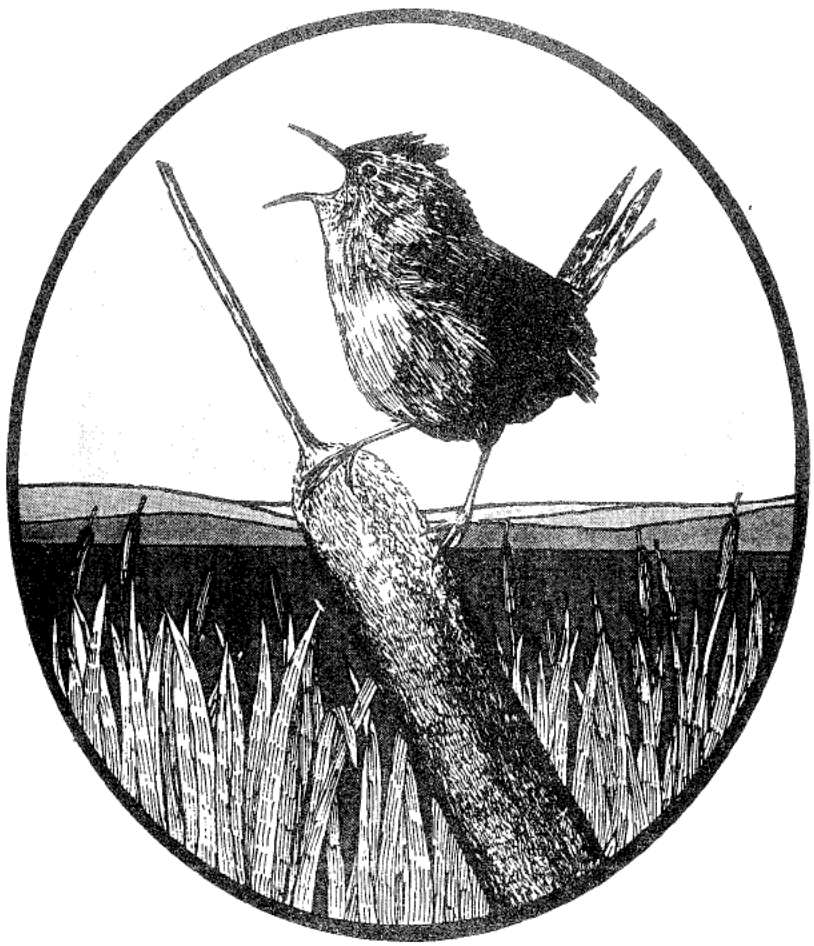
Proceedings of a Conference held April 30 - May 2, 1986
Fort Worden State Park, Port Townsend, Washington



Washington State Department of Ecology
Olympia, Washington 98504
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Proceedings of a Conference held April 30 - May 2, 1986
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Chapter 1 — Introduction

This volume presents the proceedings of a conference held on April 30 - May 2, 1986, at Fort Worden State Park Conference Center in Port Townsend, Washington, organized by the Shorelands Program of the Washington State Department of Ecology. The subject of the conference was the state of wetlands science in the Pacific Northwest, including the states of Washington, Oregon, and Idaho, and the Canadian province of British Columbia. The conference included several activities (Appendix A): a keynote address, seven plenary talks, five working group discussions, a slide show, a panel discussion, and a closing address. The goals of the conference were to document our present state of knowledge about how Northwest wetlands function, and to assess our ability to create or restore them. A primary objective was to produce a document that would provide wetland scientists, managers, planners, and policymakers with sound scientific data on which to base decisions.

Rationale for the Conference

The idea of trying to assemble and assess the present knowledge of Northwest wetlands, especially as it relates to creation and restoration, was prompted by the current status of wetlands management. Every day applications are filed for permits to drain or fill existing wetlands for development projects. The management structure for responding to these applications (including both broad policy guidelines, and specific implementation practices) is poorly developed in the Pacific Northwest. (A lengthy discussion of the recent status of wetlands management in the Puget Sound area is presented by the Puget Sound Water Quality Authority [1986]). As policymakers ponder the question of an appropriate legal framework for wetlands management, agency managers, planners, and local elected officials are required to decide the fates of individual wetlands in an information vacuum.

One of the most serious aspects of this lack of guidance, and the aspect on which this conference is focused, is the dearth of scientific knowledge available to wetlands decisionmakers. In an ideal world, both a plan by a developer and its evaluation by a regulatory agency would be based on sound scientific data about wetlands in general and about the specific wetland to be affected. Such is seldom the case, however. Not only do managers not have adequate information, they frequently do not know whether such information exists, since the existing data on wetlands in the Pacific Northwest are neither organized nor easily accessible. Furthermore, much of the available knowledge is basic research not directly applicable to the practical issues of wetlands management. In many cases, decisionmakers do not have the time or training to locate or interpret even those data that are available.

The wetlands manager, then, must literally decide the life or death of a wetland without adequate information. Such decisions are made regularly on the basis of conjecture rather than on objective facts. These decisions are commonly made at the local (municipal or county) level, generating a hodge-podge of differing *ad hoc* policies over the entire Northwest. There is little or no formal follow-up of projects to determine the consequences of decisions, or to learn from them to make better decisions in the future. One mission of the Shorelands program of the Washington State Department of Ecology is to respond to this situation by providing a link between science and management, thereby fostering more informed decision making on wetlands at all levels of government.

Wetland Functions

A scientific approach to governing the fates of wetlands has begun to evolve only recently. This evolution was stimulated in part by the discovery that the substantial disappearance of wetlands through development, especially during the last century, has been accompanied by the loss of a greater number of natural functions than had previously been suspected. Until recently, the only function widely attributed to wetlands was that of providing habitat for wildlife, particularly for waterfowl. We now know that wetlands serve a great variety of additional functions that benefit human culture and economy. These functions have emerged as key processes around which a growing science is developing.

Wetland functions that have recently emerged as being important include:

- moderating surface and ground water flow;
- controlling sediment transport, erosion, and deposition;
- mediating physical and chemical processes affecting water quality and nutrient cycling;
- generating plant matter and providing food and habitat for animals, including some rare, threatened, and endangered species.

An understanding of these functions could provide the basis for analyzing the potential impacts of development projects that might disturb or destroy wetlands, for considering measures to minimize those impacts, and for evaluating the success of such measures.

The development and use of scientific guidelines for the review of projects affecting wetlands is still in its infancy. The eastern United States is somewhat ahead of the Northwest in dealing with this problem. A procedure developed principally by Paul Adamus of A.R.A., Inc., in Augusta, Maine, is used as a formal tool for rating the performance of specific functions by specific wetlands in that part of the country (Adamus and Stockwell 1983). This procedure incorporates some scientific observations into a handbook format designed to allow local workers to evaluate wetland functions by uniform standards. This process is intended to help determine which functions are performed by particular wetlands, and which functions might be impaired by development.

It is uncertain whether the Adamus method is applicable to wetlands in the Pacific Northwest. There is much less published scientific data about Northwest wetlands than about those in the East and Midwest, so many of the beliefs and assumptions now employed by local wetlands managers are derived from information originating in the East. The data that are available suggest that many Northwest wetlands function differently from those elsewhere on the continent, and so should be managed differently. Not only is an understanding of the functions of Northwest wetlands critical to the management of existing systems, it is also essential to the development and evaluation of efforts to create new wetlands and restore degraded ones.

Creation and Restoration

A major activity of the 1980s in wetlands science is the attempt to artificially produce, reproduce, or alter wetlands. Such efforts include projects to create wetlands where none existed before, to restore wetlands that have been disturbed or destroyed, or to "enhance" wetlands for some specific use. These projects may be desired for several purposes, for example:

- to compensate for historic losses of wetland acreage;
- to attempt to treat the consequences of natural and human-caused calamities such as storms and oil spills;
- to satisfy single purposes such as the biological treatment of sewage or farm wastes;
- to generate additional aesthetic open space or wildlife habitat.

Most recently, creation and restoration of wetlands are proposed as compensation for disturbance or destruction of wetlands during land development. This practice has grown rapidly in the Northwest in this decade. This is a matter of concern for two reasons. First, attempts to create and restore wetlands are radical measures. In many people's minds, these actions are synonymous with "mitigation." True mitigative measures — those that avoid or minimize impacts — are frequently overlooked or disregarded in favor of more direct or drastic measures such as relocation or reconfiguration.

The second and more important reason that creation and restoration as forms of mitigation should be undertaken with utmost caution is that we have no evidence that such attempts succeed. Although the construction tasks are relatively straightforward, the science of wetland creation and restoration is still in its infancy. Few projects have been attempted, and even fewer have been monitored for their results. The information these projects might provide is not routinely available to scientists or managers. In addition, the state of wetlands science as a whole — that is, the slow growth of our knowledge about wetland structure and function — limits the progress of creation and restoration abilities. The proper techniques for creating artificial wetlands, and the degree of success they achieve, can't be determined without a more complete understanding of the structure and functional performance of natural wetlands. The desire to gain information about existing wetland creation and rehabilitation projects was a natural companion to the broader desire to review the current status of wetlands science in the Pacific Northwest.

Goals of the Conference

The idea for having a conference was conceived in early 1985. A **Wetlands Technical Working Group**, consisting of representatives of Washington Departments of Ecology, Game, Fisheries, and Natural Resources, the University of Washington, the U.S. Environmental Protection Agency, the U.S. Army Corps of Engineers, and the U.S. Fish and Wildlife Service, was established to carry out the detailed planning that was necessary. The Working Group had several broad goals that grew out of the information needs described above:

- to identify experts and to locate data banks, the main repositories of scientific knowledge about Pacific Northwest wetlands;
- to determine what scientific information exists (published and unpublished) and does not exist on functional performance by Pacific Northwest wetlands;
- to locate and generate information on wetland creation and rehabilitation experiences in the Northwest, and identify what wetland properties and human actions are related to success and failure;
- on the basis of the above information, to evaluate how well different types of wetlands perform different functions and how successfully they may be created or restored;

- to assess the adequacy of the data base for making the above evaluations;
- to integrate the above information, especially on prominent data gaps and scientific questions, and agree on research directions and priorities;
- to assemble the above results into a tangible product that would be accessible to a wide audience.

Thus the general outcome that was desired was to assemble data and evaluations in a retrievable form. There were several important constraints on this intention. First, only scientific evaluations of functional performance were intended, not judgements of the value of a given wetland or wetland type to society. Secondly, it was as important to identify and document gaps in the data as it was to assemble data. Thirdly, for both data and data gaps, the sources on which the evaluations were based were to be cited for documentation and keyed to the appropriate topic so that they would be retrievable along with the data. And finally, the resulting product was to be a ready reference tool accessible to and usable by a wide range of both scientists and managers in the Pacific Northwest.

Strategy for the Conference

The Working Group decided to pursue its goals in two ways: by convening a broad spectrum of Pacific Northwest wetlands specialists in a remote location where they could concentrate on the matter at hand, and by developing a way of organizing and archiving the data that would be obtained from these experts. The conference format provided a means of polling experts, of encouraging discussions that would generate ideas and exchange, and especially of forging consensuses about topics on which there were divergences of opinion. All attendees were to be contributors; there was to be no passive audience. It was hoped that the whole of a scientific assembly would be greater than the sum of its individual scientists.

The goal of organizing and archiving data was served by developing a tool called the **wetland function evaluation matrix**, around which much of the activity of the experts at the conference would be oriented. The wetland function evaluation matrix is a series of forms that serve as a framework for organizing data on the functions performed by different types of wetlands. The detailed structure of the matrix is discussed below (see also the sample matrix in Appendix E). Conference participants were asked to examine, fill in, and submit their matrix forms by mail in advance of the conference so that the resulting data could be compiled and analyzed for discussion at the conference. The compilation and analysis were performed using an interactive microcomputer database program adapted specifically for the conference. The purposes of the matrix were:

- to collect and integrate the breadth of scientific data being sought;
- to provide quick and easy access to, and analysis of, this information for discussion at the conference;
- thereby to reveal areas of agreement and disagreement in the perspectives of different experts, and to help identify data gaps and research needs;
- to provide a permanent data base that could be updated regularly and would be accessible to a wide range of potential users, including both scientists and managers.

As the data-gathering for the matrix was proceeding, regional experts were selected to review the literature in their field of specialization and to evaluate and integrate the knowledge of that subject. The experts presented their findings as plenary papers at the conference. The plenary topics assigned were the seven wetland functional categories used in the matrix (see below). The peer-reviewed and revised versions of these plenary papers are included in these proceedings.

The plenary papers were followed by a series of working-group discussion sessions, organized around the same functional categories. These working groups, for which substantive debate and consensus-building activities were planned, were the heart of the conference. Working group members were asked to:

- review the contents of the plenary papers and the wetland function evaluation matrix;
- reach a consensus as much as possible on the conclusions emerging from the plenary papers and the matrix results, and account for any failure to achieve consensus;
- evaluate the strengths and weaknesses of the data base contained in the matrix;
- exchange data and sources that other participants might not be aware of;
- generate ideas on future directions for Northwest wetlands science.

There thus was a three-tiered review of Northwest wetlands data conducted through the conference — plenary papers, matrix input, and working group discussions. Additional segments of the conference were devoted to a keynote address, a slide show of wetland creation and restoration project experiences, a panel discussion among experts on the topic of wetland creation and restoration, and a closing address (see Conference Program, Appendix A). The keynote and closing addresses, and summaries of the slide show and panel discussion, are presented in this proceedings volume.

The Wetland Function Evaluation Matrix

The matrix structure into which data on Northwest wetlands was entered served as the informational foundation of the conference in its effort to assess the state of Northwest wetlands science. The challenge facing the Wetlands Technical Working Group as it formulated the matrix structure was to find some rational and manageable way to categorize the diverse types of wetlands in the Northwest and the broad spectrum of functions that they perform. The matrix needed sufficient detail to be useful to managers and meaningful to scientists, but could not be so large as to make it unwieldy.

The matrix format used for the conference is presented in Tables 1-1 and 1-2 (a sample of the matrix is shown in Appendix E). Wetland types were classified in a hierarchical scheme compatible with that developed by Cowardin et al. (1979) for the U.S. Fish and Wildlife Service National Wetlands Inventory. Categories included were salinity, flooding regime, vegetation, water chemistry, elevation, and substrate (Table 1-1). Wetlands were also classified as "natural," "disturbed," "created," or "restored," and as belonging to one of seventeen physiographic regions (Appendix D). Matrix cells were assigned to characterize each of these wetland categories with respect to fifteen functions. The functions were grouped into six broad classes: hydrology, sedimentology, water quality, carbon and nutrient cycling, primary producers, and consumer support (Table 1-2). An additional cell was provided to characterize what is known about the potential of each wetland type to be created or restored. These wetland functions and types were, of necessity, a compromise between scientific rigor and manageability of the resulting data base.

The principal exercise of the matrix was to make two evaluations: to rate how well each category of Northwest wetland performs each function (and the potential of each for creation/restoration); and to rate the adequacy of the data base supporting the prior evaluation. A simple numerical scheme using scores from one (no performance of the

Table 1-1
Categories of wetlands used in the Wetland Function Evaluation Matrix (See Also Appendices B and E).

Wetland Type	Substrate
Marine	Bedrock/Boulder
Estuarine	Cobble/Gravel
Freshwater Impounded	Sand
Riparian	Silt/Mud
	Clay
Flooding Regime	Organic
High Intertidal	
Low Intertidal	**Elevation/Special Interest**
Shallow Subtidal	Sphagnum Bogs
Seasonally Flooded or Saturated	Alkali Inland Saline
Permanently/Semipermanently Flooded	Marl Fens
Backwater	Serpentine
	Vernal
Vegetation	Alpine
Unvegetated (Non-Macrophyte)	Subalpine
Submergent (Macrophyte)	Midmontane
Emergent	Low Elevation
Shrub	
Forested	**Status**
	Natural
	Disturbed
	Created
	Restored

function or no available data) to ten (very strong functional performance or complete data adequacy) was used for the evaluation. There were no formal quantitative criteria for arriving at these scores; they were simply a shorthand for encoding and recording the scientific opinions of experts. All prospective conference participants were invited to contribute to the matrix data base, but were asked to evaluate only wetland types, functions, and geographic regions with which they were familiar, so as to maximize reliability of the data and minimize the individual workload. To guide them in use of the terminology, participants were given a glossary of definitions (Appendix C) used in formulating the matrix. In addition, for each matrix cell rated, participants were asked to provide references to literature, data banks, and resource persons that could provide further information about that entry. Participants were asked to return the completed matrix forms one month before the conference, so that the data could be analyzed for discussion.

All of these numerical ratings were entered into a user-oriented data base software package, (RBASE 5000: Microrim, Inc., Bellevue, WA) using a Compaq II microcomputer equipped with a 20-megabyte hard disk. For the wetlands matrix, the program was adapted to calculate and display means and variances for all entries in each matrix cell, and for entries aggregated within or across all regions or within wetland categories (e.g., wetland type, substrate, flooding regime, vegetation, etc.). The program also archived the supporting information on literature, data banks, and resource persons for each matrix entry. This feature of the program would be used to create a permanent repository for a

Table 1-2
Functional categories used in the Wetland Function Evaluation Matrix

Hydrology Ground Water Recharge Ground Water Discharge Flood Storage and Desynchronization	**Primary Producers** Productivity Diversity Complexity
Water Quality Physical Filtration Biochemical Processing	**Consumer Support** Breeding/Rearing Feeding/Foraging Refuge Migration
Sedimentology Shoreline Anchoring Sediment Trapping	**Summary** Can you Create? Can You Restore?
Carbon and Nutrient Cycling Carbon/Detritus	

Northwest wetlands data bank that would be available to users region-wide and would be updated regularly as new data became available.

Working Group Discussions

Working groups were organized around the same functional categories used in the wetlands matrix and chosen for the plenary topics. Conference participants were assigned to groups according to their expertise. The plenary speakers acted as moderators for the working group sessions on their respective topics. They were assigned rapporteurs to assist with recording the discussion and presenting the working group results. Some functions were combined for discussion purposes (sedimentology was included with hydrology, and carbon/nutrient cycling with water quality) to give five working groups. The working groups were instructed to:

- review and discuss the content of the plenary paper(s) on their functional category;
- review and discuss the results of the matrix;
- respond to four discussion questions developed by the Wetlands Technical Working Group (Table 1-3) and any additional questions posed by the plenary speakers.

It was planned that working group discussions of the matrix results would yield consensus values of functional performance and data adequacy scores for individual and aggregated wetland types and possibly augment the resource information. The variances of matrix results were to be used to indicate points on which there was the least agreement, and that might need the most discussion or explanation.

Organization of This Volume

The sections of this document are organized in the approximate order in which events took place at the wetlands conference. First is the keynote speech by Dr. Joy Zedler of San Diego State University, who set the tone for the rest of the conference. Dr. Zedler pointed out that wetlands scientists and managers have the choice between two approaches to wetlands restoration: a haphazard method in which the techniques employed are somewhat arbitrary and the results are poorly monitored, or a scientifically

Table 1-3

Questions to be addressed by all working groups.

1. What outside or site-specific factors that are not included in the matrix (such as topography, location, adjacent land use) severely limit you in evaluating a wetland's functional performance? (Example: Storm Desynchronization may be more dependent upon the number and geographic location of wetlands in a watershed than it is upon the soil, vegetation, or flooding regime of an individual wetland.)
2. Does a wetland's performance of one function depend on one or more of the other functions in the matrix, thus limiting or preventing a meaningful rating of that function in the matrix? That is, are there vital synergistic effects or a high degree of covariation among functional categories that cannot be represented in the matrix format? (Example: Can Nutrient Cycling in a wetland be meaningfully evaluated independently from Primary Productivity?)
3. Are there important wetland functions that are not considered in the matrix? Are there finer divisions that must be made in the functions listed in order to properly evaluate the wetland function? (Example: The Biofiltration capacity of a wetland may differ significantly depending on the class of pollutant in question.)
4. What direction should research take? What are the unanswered questions? Which of these are realistically answerable, and which of those are most important? Establish research priorities.

organized method that seeks the best solutions to problems and maximizes learning from experience.

The plenary speeches on wetland functions are next, each accompanied by highlights of the working group discussion on that particular function. Included with the highlights of the working group discussion on wetland creation and restoration are excerpts of two events that began the final phase of the conference: a slide show of experiences with creation and restoration projects, and a panel discussion among wetland creation and restoration specialists.

The concluding section of this volume includes the closing address by Dr. Millicent Quammen of the U.S. Fish and Wildlife Service National Wetlands Research Center in Slidell, Louisiana, who added a national perspective to the results of the plenary papers and working-group discussions. This is followed by the conclusions of the conference organizers about the working group discussions and about the conference as a whole.

The volume closes with appendices that include: A) the conference program; B) the wetland classification scheme; C) definitions of terminology used in formulating the wetland function evaluation matrix; D) maps of the Pacific Northwest physiographic regions as defined for use in the matrix; E) sample of a matrix page; and F) a roster of conference participants. Subsequent volumes will include: 1) a directory to regional wetlands scientists and managers, data sources, and inventories; and 2) the complete list of bibliographic citations contained in the matrix.

Acknowledgements

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Chapter 2 — Keynote Address

Wetland Restoration: Trials and Errors or Ecotechnology?

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Introduction

Wetland restoration is being proposed and attempted in a wide variety of situations in California. I have been involved in the planning, review, implementation, and assessment of several projects in southern California and will contrast the art as it is being practiced (trials and errors) with how it should be done, i.e., the scientific approach based on long-term observation and experimental manipulation of hydrology and habitat types (ecotechnology).

The coastal wetlands of southern California are natural habitats with several unique qualities. They fall into two basic categories: estuarine wetlands, which are well flushed with tidal seawater, and lagoonal wetlands, with ocean inlets that tend to close. Between Point Conception and the U.S. - Mexico border, there are some 26 coastal salt marshes, most of which are associated with lagoons.

Over the past decade, our wetland studies have been supported by the California Sea Grant Program, NOAA Sanctuary Programs Division, and the U.S. Fish and Wildlife Service. I am indebted to several research associates, including students who have worked in the water, on the land, and in the mud.

The region's coastal wetlands support a variety of habitat types, each with its characteristic hydrology and dependent species:

Habitat	Selected Dependent Species
Beach and Dunes	least terns, tiger beetles, globose dune beetles
Dune Slack	salt grass, wandering skipper
Channels	fishes, benthic invertebrates, California least terns
Lower Marsh	light footed clapper rail
Mid-to-upper Marsh	Belding's Savannah sparrow
Upper Marsh Fringe	salt marsh bird's beak
Salt Pannes	rove beetles, mudflat tiger beetles

When Restoration Occurs

Most of the region's wetlands are disturbed and most could use some restoration. Restoration of wetlands takes place in two types of projects: restoration as mitigation for development, and restoration to solve specific habitat management problems.

The more frequent catalyst to wetland restoration is the mitigation process. In privately-owned wetlands, permission to fill or otherwise disturb part of a wetland is often granted in exchange for restoration of the rest. For example, Bolsa Chica is a large (ca. 1,300 acres [520 ha]) wetland in the Los Angeles area that is mostly privately owned; the owner will be allowed to develop a large area if the remaining 915 [366 ha] acres are restored. As currently proposed, development would include cutting a new ocean inlet (navigable if that proves feasible), dredging a deep channel, building a marina, and constructing housing and commercial structures adjacent to that inlet and channel. The existing wetland is degraded by dikes that prevent tidal flushing around several historic and active oil wells; a part of the area has been reopened to tidal flushing; and that part is being managed by the California Department of Fish and Game. Restoration plans are still very general.

In another project, the Port of San Diego constructed an 80-acre [32 ha] dredge spoil island as mitigation for dredging the J-Street Boat Basin. The island destroyed subtidal habitat but created least tern nesting habitat. The dredging was done several years ago, and the promised wetland and fish habitats are still under construction. The pilot cordgrass plantings were very successful; however, monitoring was limited to assessing mortality, and factors that led to success went undetermined.

In a third project, Caltrans widened Interstate-5, covering lower salt marsh habitat. As mitigation, they lowered the elevations of a disturbed higher marsh habitat, created tidal channels, and planted cordgrass. In addition, they salvaged some of the vegetation for later reestablishment. However, all of the mitigation projects took place in areas of disturbed wetland, causing a net loss in habitat area. Furthermore, the planted cordgrass has not done as well as elsewhere, and there is insufficient monitoring to determine why.

The second type of project is designed to solve specific management problems, a process usually initiated by a resource agency. In southern California, it is no longer possible to maintain coastal wetlands by "leaving them alone." Their natural hydrology and local topography have already been modified to excess. As an example of this type of project, an attempt was made to reconstruct the barrier dune at Tijuana Estuary. This dune had been denuded by trampling, and was washed into the marsh by the 1984 winter storm. Managers removed dune sand from the estuarine channels to restore tidal flushing and used the dredged material to recreate the barrier dune. However, the sands were not stable, and the 1985 winter storm caused severe damage.

Why So Many Trials and Errors?

Wetland restoration projects can differ dramatically, depending on whether they are catalyzed by a proposed development or initiated specifically to solve a wetland management problem. Having watched both kinds of projects, I have noticed several contrasts (Table 2-1).

The most ambitious restoration work is being done under the mitigation process, in part because development generates funding. For example, restoration of 209 acres [84 ha] at Ballona Wetland (in Los Angeles) and development of a visitor center on the site will cost the developer $10 million. The planning process for Ballona Wetland, however, is being carried out by the National Audubon Society. Of the mitigation plans I've evaluated, this one has incorporated the most elements from column one above. Still, it is important to recognize that nearly every mitigation project involves a trade-off between quantity and quality of wetland habitat. Developers promise to "enhance the functional

Table 2-1

Contrasts in wetland restoration projects.

Optimal Situation for Restoration	Restoration as Mitigation
Knowledge of wetland ecology is critical to success.	The less you know, the easier it is to promise success.
Hydrological planning puts needs of wetland restoration first.	Hydrology is engineered to suit development needs first.
Project can incorporate restoration experiments and adaptive management.	Project is constrained by need to complete work in 1-2 years.
Funding and personnel are not constraints; spending depends on need.	Costly restoration measures may be used to justify the development.
Careful documentation is encouraged; especially if long-term iterative restoration is planned.	Developer gains little if failures are documented.
(Ecotechnology)	**(Trial and Error)**

capacity" of the wetland, while its total area shrinks. Very often the promise of improved habitat quality is never realized. At best, a disturbed habitat of one type is turned into a disturbed habitat of another type. Thus, larger area of one type is traded for a different but smaller habitat type, which may or may not help to maintain the region's natural wetland resources.

At some point there simply isn't enough area left to support native species. It appears that the threshold for habitat loss has been reached in southern California. We have several endangered species (one plant, five birds) that are wetland-dependent, and the cause for many is loss of area of suitable habitat (e.g., Mission Bay). This constitutes a trial-and-error approach, where the ultimate error is extinction. A recent article in the San Diego Union revealed developers' hopes for similar "amenities" in south San Diego Bay, which is now a series of salt ponds. These wetlands are admittedly disturbed, but they still function as valuable habitats for birds.

Unfortunately, restoration is not working very well. There are three important steps in the process — planning, implementation, and assessment — and there have been failures at every step. In many cases these were due to inadequate planning; in some cases the implementation phase broke down; and in most cases there was no assessment. These claims follow from several case studies.

Planning. In proposals for restoration under the mitigation process, a number of modifications are purported to "improve" wetlands. These include plans to:

- increase tidal flushing (not always desirable);
- increase habitat diversity (usually undefined);
- plant cordgrass (which may or may not be desirable);
- add a bird-nesting island (often an excuse to dump dredge spoil);

- cut a moat to prevent access (often doesn't exclude dogs);
- create ponds (not helpful if dredge spoils are dumped in wetland);
- vegetate salt flats (which may destroy habitat for rare insects).

For example, at Agua Hedionda Lagoon, 13 acres [5 ha] of wetland were destroyed to build a four-lane road. Project proponents promised to increase the diversity and "functional capacity" of the lagoon. As part of the mitigation, ponds were planned for a wetland transitional area (itself a rare habitat type) to create brackish ponds. There was no hydrologic study. During the implementation, pits were dug to a depth of six feet [1.8 m], but ground water was not encountered. At the same site, a two-acre [0.8 ha] dredge spoil island was to be built for bird-nesting, even though such areas are considered too small to be of use to the endangered least tern.

Implementation. Even if planning is adequate, there are problems implementing restoration projects. This phase is probably the trickiest, because it requires coordination between construction engineers and biologists. At Elkhorn Slough, a National Estuarine Sanctuary, a well-thought-out plan was developed but not followed. In what was an on-again, off-again project, the entire plan was scrapped at the last moment, with bids let to cut old dikes and return a pasture to tidal action. The contractor that bid to move the most earth for the money got the job, and a marina-like wetland resulted. This wetland functions as fish habitat, and plants are invading the "benches." But the variety of habitats that might have been provided was not.

Assessment. Finally, if planning and implementation go as proposed, there is still the possibility that assessment will fail. It is easy to request that a project be monitored. But it is more difficult to find the funding necessary to carry out the sampling program that would allow us to decide what happened in response to the project, versus what might have happened without it. As I discussed in the introduction, we are dealing with highly variable systems. Wetlands change a lot in response to many environmental variables, such as differences in rainfall and streamflow volumes, and differences in timing and duration of rainfall and streamflow. Relating the changes that occur in a wetland to a project that was done there is difficult. It requires that the before-after comparison be viewed relative to changes at other non-project wetlands and relative to annual changes in regional wetlands. In other words, a broad-based comparison is necessary.

The Alternative: Ecotechnology

How can wetland restoration be planned and implemented so that the natural variety of habitats and species are maintained? It must be based on a sound understanding of what controls wetland structure and functioning. This necessarily involves detailed study of hydrologic controls. By monitoring different wetlands under various environmental conditions, we have developed an understanding of how the salt marsh responds to different hydrologic regimes. Our ideas about hydrologic control then get tested in replicated, manipulative experiments at the Pacific Estuarine Research Laboratory. The field studies plus the experimental tests then lead to recommendations on how to manipulate the hydrology to produce desired wetland habitats. This is "ecotechnology." Of necessity, our ideas are under constant revision; with new information comes refinement in our recommendations. To date, our work has been primarily on the plants — additional or different advice may be necessary for the rest of the ecosystem.

In southern California, there is high temporal variability, with seasonal and year-to-year deviations from average conditions, plus occasional or rare catastrophic events. The natural hydrology incudes high variability in inundation, salinity, and circulation conditions. Several patterns and their implications for restoration and management have been identified.

Winter flooding allows maintenance of a diverse salt marsh plant community. Long-term streamflow records at Tijuana Estuary show that there are few if any years with average streamflow — there are many years with no flow, and occasional years with flooding. The natural estuarine hydrology thus includes continual tidal flushing with occasional river floods that play a role that is disproportionate to their frequency. Catastrophic flooding occurred in 1980; streamflow that year was 28 times the mean annual volume. Flooding reduced soil salinity briefly that year, and led to a major increase in cordgrass reproduction. Data show recruitment of seedlings tripled and vegetative expansion of clones doubled.

The implication for restoration planning is that links with river flow and occasional flooding must be maintained. The long-term maintenance of salt marsh plant populations requires occasional flooding so that species can occupy new areas or expand their distributions vegetatively.

Deviations from the natural hydrology may be detrimental to the maintenance of salt marsh plant populations. Two types of disturbances have been observed, and their impacts on the salt marsh have been documented. These are prolonged flooding by reservoir discharge, and by mouth closure and drought. Both hydrological disturbances alter soil salinity.

Prolonged flooding causes abnormally long periods of low salinity: this can stimulate freshwater/brackish marsh species to germinate. For example, at the San Diego River, reduced salinities allowed the salt marsh to convert to cattails, bulrushes, and exotics such as brass buttons. Prolonged inundation killed pickleweed; brackish marsh invaded and persisted for several years. Recovery has been slow.

The implications for restoration are that if salt marsh is desired, too much freshwater can convert the wetland to brackish marsh. On the other hand, if brackish marsh is desired, continuous freshwater inflows are not necessary. It should be sufficient to provide prolonged flooding every spring or every other spring in order to maintain vegetation such as cattails and bulrush.

Disturbance that prolongs the period of hypersalinity has different effects. Relief from tidal inundation is also important to the coastal wetland, and periods with neither flooding nor high tides are part of the normal hydrology. Normally, the intertidal marsh is relatively dry in September during neap tides and warm weather; soils become hypersaline, often over 45 parts per thousand. Salt pannes are maintained in the upper marsh by these periods of exposure.

In 1984, prolonged drought and hypersalinity occurred at Tijuana Estuary when the mouth closed and a drought followed. Soil salinity increased to three times that of sea water. Cordgrass had high mortality, and bare patches developed. In addition, short-lived plant species neared extinction — two species that were widespread a decade ago are now very hard to find — and the extremes of drought and hypersalinity, which are rare for Tijuana Estuary, have nearly eliminated annual pickleweed and sea-blite. At the same time perennial pickleweed expanded. These events led us to understand how the longer periods of extreme conditions in lagoon marshes reduce plant species richness and usually produce monotypic stands of pickleweed.

Implications for management are that long periods of mouth closure during years of little rainfall will eliminate many wetland plants. Monotypic pickleweed will survive and perhaps expand; reestablishment of the more diverse marsh community may be slowed by competition with pickleweed.

Conclusions

Because of the complex interactions between hydrology and habitat, and the interconnectedness of habitats within a wetland, restoration of wetland ecosystems can be very complex. The less we know about a system, the easier it is to promise to recreate it artificially. The more we know about what occurs there and what determines the presence and abundance of each population, the more cautious we become about the restoration process. In southern California coastal wetlands, we can't afford to make many more mistakes. Instead of trials and errors in planning, implementation, and assessment, we need a science of wetland restoration — ecotechnology.

Three elements are essential in applying ecotechnology to the wetland restoration process:

1) Recognition that wetland management and restoration require very careful control of the hydrology, with slightly different conditions required for each wetland community. It is no longer adequate to propose simply that tidal flushing be created or restored or maintained. The amount, the timing, and the duration of both tidal and streamflow influences must be carefully planned and implemented. Bring the necessary expertise into the earliest planning stages.

2) Recognition that restoration is still experimental. Wherever possible, an experimental element should be built into project design to maximize information gain. One must be prepared to modify plans as restoration work proceeds: we need adaptive management. Projects that succeed best will probably be those that develop interactively over a period of years, gradually adjusting the hydrologic conditions to favor the desired species groupings.

3) Documentation of findings. Because there is so much to learn, each project needs to be followed with a regional and long-term perspective, so that results are documented and evaluated in relation to original project goals.

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Chapter 3 — Hydrology and Sedimentology

Hydrologic Functions of Wetlands of the Pacific Northwest

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Abstract

The water level fluctuations in a wetland are the combined result of a number of separate hydrologic processes. The relative importance of a process, such as surface water inflow, ground water exchange, or evapotranspiration, depends on the climatic and geologic characteristics of the site.

A reasonable understanding of the basic operation of a specific wetland can be obtained with the aid of a seasonal water budget, publicly available hydrologic and meteorologic data, and site-specific physical measurements.

Ground water exchange may be the least dynamic element of the water budget, but its magnitude and periodicity may significantly influence water level fluctuations. Although ground water discharge and recharge are sometimes thought of as separate processes, they are described by the same flow equation and are quantified by the same methods.

A wetland's ability to temporarily detain floodwaters and reduce downstream flooding depends upon the physical dimensions of the wetland and its outlet, and on the characteristics of the inflow flood. In general, wetlands can be efficient at reducing downstream flooding associated with typical flood events. They are less efficient during major floods when the inflow is large in comparison to the available floodwater storage volume of the wetland.

The physical hydrologic processes affecting a wetland's seasonal water level fluctuation, ground water exchange, and ability to detain floods are well known and documented. The reliability of a mathematical solution of a specific wetland's water budget or floodwater detention capability is primarily dependent upon the time and effort available to collect and analyze pertinent data.

Introduction

Numerous hydrologic processes may be interacting at any given time in a wetland area. Two specific processes, ground water exchange and flood-water detention, have been identified as having value to "society" and have been included in many wetland value ratings. The efficiency with which a specific wetland performs either of these two functions depends on the geological, physical, and climatic characteristics of the site.

Although these two processes are considered important, it is equally important that someone who is assessing the value of a wetland have a good understanding of the basic hydrologic processes. Inasmuch as the hydrologic processes control the water level fluctuations in a wetland, they influence to varying degrees the other chemical and biological processes. Nutrient budgets, carbon cycling, plant and animal community dynamics, and sediment movement and entrapment are all dependent upon the inflow, outflow, and storage of water.

Water Budgets

A water budget is a mathematical description of the hydrologic processes of a wetland. Because much is known about the basic hydrologic processes of wetlands, the water budget is theoretically valid and often yields very usable results. Through the use of the water budget, it is possible to gain an understanding of the basic operation of the wetland, and to identify the magnitude and relative importance of each climatic and hydrologic variable.

A seasonal or annual water budget, or water balance equation, is simply an expression of conservation of mass. The water budget summarizes the inflow, outflow and storage of the wetland and can be defined on a volumetric basis for a specific time period as:

Inflow - Outflow = Change in Storage. . . . . (1)

$P + I + I_D \pm G_{EX} - O_S - E_T - O_W = \Delta S$. . . . .(2)

Where:

P = Direct precipitation on the wetland

I_S = Surface water inflow

I_D = Inflow from sources outside the watershed, including tidal inflow for marine and estuarine wetlands and freshwater inflows from diversions and canals

G_{EX} = Ground water exchange, ± depending on recharge or discharge dominant

O_S = Surface water outflow

E_T = Evaporation plus transpiration from plants

O_W = Outflow withdrawn or consumed from the wetland

ΔS = Change in volume of water stored in the wetland

A rough quantification and solution of a water budget for a specific wetland can usually be constructed from field observations and measurements, some limited data collection, and published climatic and geologic information. A water budget may not answer all the questions on hydrologic processes that are of importance to a specific wetland. However, it can provide information for studies in other disciplines or establish the framework or need for other more intense hydrologic studies.

Discussions of water budgets applied to wetland studies are numerous; three of note are Allred et al. (1971), Kadlec (1983), and LaBaugh (1986). The result of the interaction of the hydrologic variables is ΔS, or the change in storage, and the related change in water levels in a wetland. **Seasonal water level changes are the "heart beat" of the wetland system** — they may be great or small, regular or irregular, depending on the magnitude and dynamic nature of the individual variables.

The magnitude and duration of the seasonal water level changes are important because they directly influence the chemical and biological processes in a wetland. Thus an understanding of the normal hydrologic behavior of a specific wetland can be a valuable aid to the wetland ecologist in the understanding and assessment of the type of wetland development and the chemical and biological elements involved. It should also be recognized that the climatic factors that drive the hydrologic processes are inherently variable and this natural variability can be a mechanism for change. Major aberrations in the hydrologic cycle and resulting consequences on biological processes are to be expected during any long-term period of interest.

The seasonal water level fluctuations of wetlands are expectedly diverse. For example, large water level changes typically occur in "perched" mid-montane and alpine wetlands with no surface water outflow or ground water exchange. These changes are dominated by the climatic influences of precipitation and evapotranspiration. Large water level changes may also occur in marine and estuarine wetlands because of tidal influences.

Moderate water level changes typically occur in low elevation "kettle" or freshwater impounded wetlands with no surface outlet and ground water exchange as flow through the wetland. They may also occur in riverine wetlands where surface water inflows dominate the other processes.

The smallest water level changes occur in sphagnum bogs and wetlands with outlet elevations controlled by physical features, particularly if surface water inflows are not great and a steady ground water discharge dominates the other processes.

Ground Water Exchange

Ground water exchange in wetlands in the Northwest includes ground water recharge (deep percolation to the water table) or ground water discharge (inflow from an aquifer). In some cases it may include both processes, with ground water discharge in one season followed by ground water recharge later in the year.

Controversies over the value of ground water exchange in wetlands are not new and have not been resolved for wetlands in general. Many researchers, including Allred et al. (1971) and Kadlec (1983) for example, have quantified ground water recharge (seepage or subsurface outflow) from wetlands in various parts of the country. The fact that deep percolation or ground water recharge occurs from wetlands is not in much doubt. The significance or value of this recharge, though, is a subject of much debate.

The fact that some wetlands exist because of their topographic position and local ground water conditions, either intercepting the water table or lying immediately downgradient of an aquifer, and receive ground water discharge, can be shown for particular cases. The significance or value of the wetland's ability in these cases to express ground water flows as a ponded or open-water body is also of some debate.

Ground water exchange is a slow, steady process compared to the other variables of the water budget. Both ground water recharge and discharge depend on three basic conditions: the hydraulic gradient, the permeability and stratification of the substrate, and the cross-sectional area of the flow path.

The rate of ground water recharge is comparatively slower than ground water discharge because of lower hydraulic gradients and an unsaturated flow component. Typical rates are on the order of 0.003 feet/day [0.91 mm/day]. Allred et al. (1971) calculated an average seepage (or recharge) rate of 0.0032 feet/day [0.98 mm/day] for 46 small ponds and lakes of the prairie regions in Minnesota. Kadlec (1983) calculated recharge rates of 0.0004 to 0.001 feet/day [0.12-0.30 mm/day] for small diked marshes in South Central Manitoba.

Ground water discharge is comparatively more efficient because of greater hydraulic gradients in the aquifer, and discharge rates are usually on the order of one to five feet/day [0.3-1.5 m/day]. Both ground water recharge and discharge can be quantified by the same methods, including:

- Water budgets and residuals analysis;
- Direct measurement with seepage meters and potential probes;
- Flow net analysis and graphical procedures;
- Mathematical simulation models;
- In some cases, chemical analysis.

Various studies have applied these methods to wetlands on areas outside of the Pacific Northwest, particularly in the prairie pothole region of the Midwest. The following examples are a few of these studies: Erickson (1981) presented the results of different direct measurement techniques for a water table lake in North Central Minnesota; Carr and Winter (1980) presented summaries of designs and applications of various types of direct measurement devices; LaBaugh (1986) presented a comparative analysis of water budget applications to wetlands studies; and Gardner et al. (1980) presented a marsh hydrology model to complement a nutrient budget study for Lake Wingra in Wisconsin.

Flood Detention

The ability of riparian and fresh water impounded wetlands to temporarily detain floodwaters and attenuate flood peaks is common knowledge. The magnitude of attenuation (Figure 3-1) is a function of the wetlands' floodwater storage capacity and outlet discharge capacity relative to the magnitude and volume of the inflow flood. Mathematical methods capable of quantifying the flood control characteristics of a wetland have been employed since at least the 1920s. Flood routing procedures are based either on the solution of conservation of mass (hydrologic routing) (Chow 1959, 1964; Linsley 1975; U.S. Army Corps of Engineers 1960, 1981) or on the simultaneous solution of conservation of mass and momentum (hydraulic routing) (U.S. Army Corps of Engineers 1960; Chow 1964; Mahmood et al. 1975). In either case, the inflow flood to the wetland must be known or estimated (Figure 3-1) in conjunction with the physical geometry of the site and the discharge characteristics of the outlet from the wetland. These methods can be applied to any wetland and watershed at various levels of sophistication, depending on time, money, and manpower constraints. For example, a flood and hydrologic routing analysis for a wetland in a simple, rural watershed might typically require several days. Detailed data collection and analyses for more complex watershed and wetland combinations, or for extensively urbanized areas, may require several weeks or months of a hydrologist's time.

In general, riparian and freshwater impounded wetlands are more efficient at attenuating the typical flood events; i.e. the two-year to five-year flood event. They become less efficient as the magnitude of the inflow flood increases (Figures 3-1 and 3-2). This phenomenon is easy to comprehend because the volume of floodwater storage available on the wetland represents a smaller portion of the volume of an inflow flood as the magnitude of the flood increases.

A rough estimate of the amount of attenuation of typical flood events produced by wetlands can be obtained by employing the results of a flood study conducted by Bodhaine and Thomas (1960; Figure 3-3). The results shown in Figure 3-3 should be viewed with some reservations owing to the nature of correlation, cross-correlation and data limitations inherent in any multiple regression analysis. While Figure 3-3 does correctly display the basic trends, it should contain a family of curves. The curves in the upper portion of the graph would represent watersheds in the well-watered areas of the Olympics and Cascades. The family of curves in the central portion of the graph would

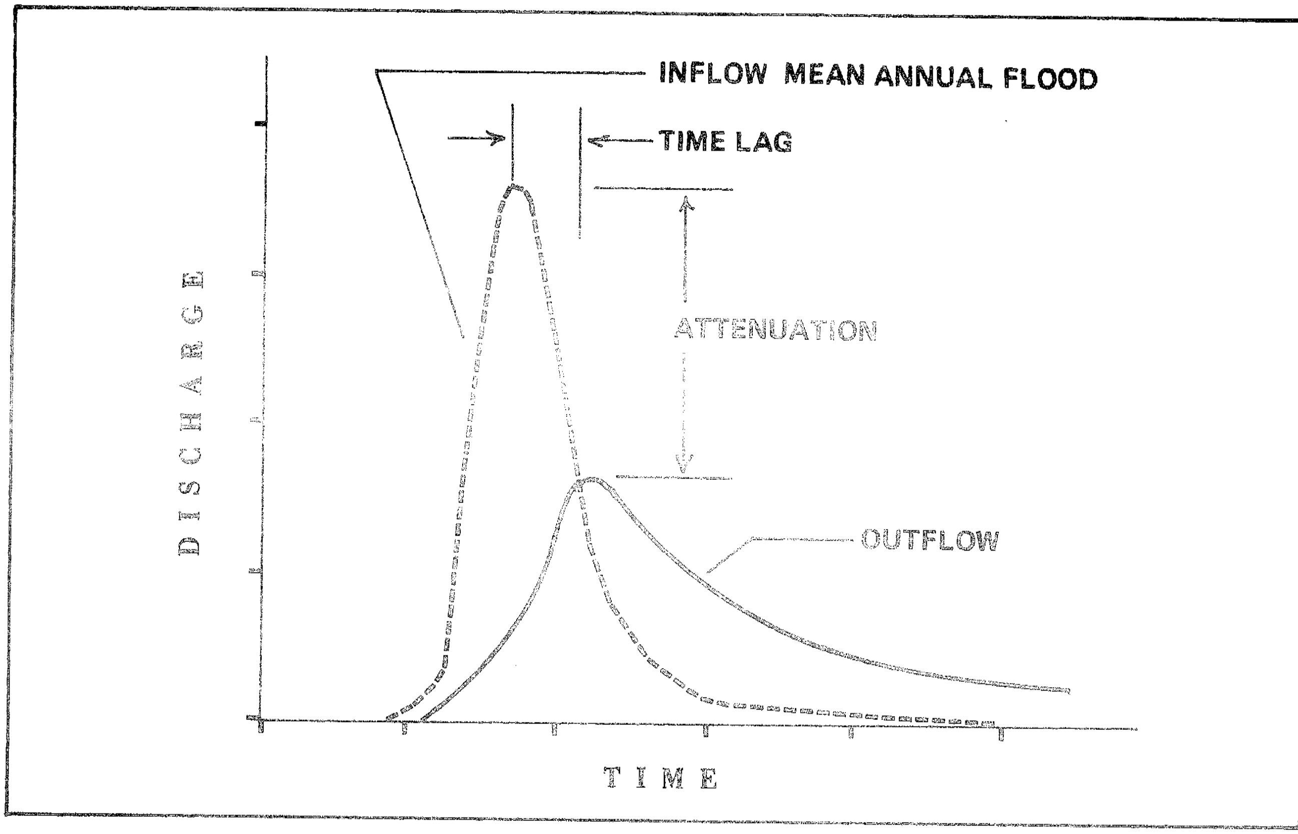

Figure 3-1. **Typical inflow and outflow hydrographs for the mean annual flood.**

represent the semi-arid and arid watersheds of Eastern Washington. The difference in attenuation occurs (all other factors being equal) because the floods in Eastern Washington are smaller relative to the floods in Western Washington.

Another function attributed to wetlands is the "desynchronization" of floodpeaks. Desynchronization occurs when, at some point of interest downstream of the wetland, the flood peak discharge from the wetland does not coincide in time of occurrence with the peak discharge from other tributary drainage areas of the watershed. This situation can be seen to occur as a result of the time lag (Figure 3-1) produced by the attenuation of the inflow flood. The time of occurrence of the flood peak discharge from the wetland is delayed by comparison to that which would have occurred had the wetland not been present. This is a natural by-product of the physics of the flood routing process.

Desynchronization may or may not occur on any specific watershed. There will be some cases where the time lag produced by the wetland causes peaks to synchronize at some lower point in a watershed. In those cases, the flooding may be slightly increased compared to what would have occurred if the wetland had not been present. In general, the flood peak attenuation afforded by the wetland is usually much more important than the issue of desynchronization. In those cases where desynchronization is deemed important, an assessment can be made using the aforementioned flood routing techniques. Similarly, when the watershed of interest contains numerous wetlands, posing a cumulative affect, or where man-made or natural complexities occur, flood routing techniques can be used to assess the situation.

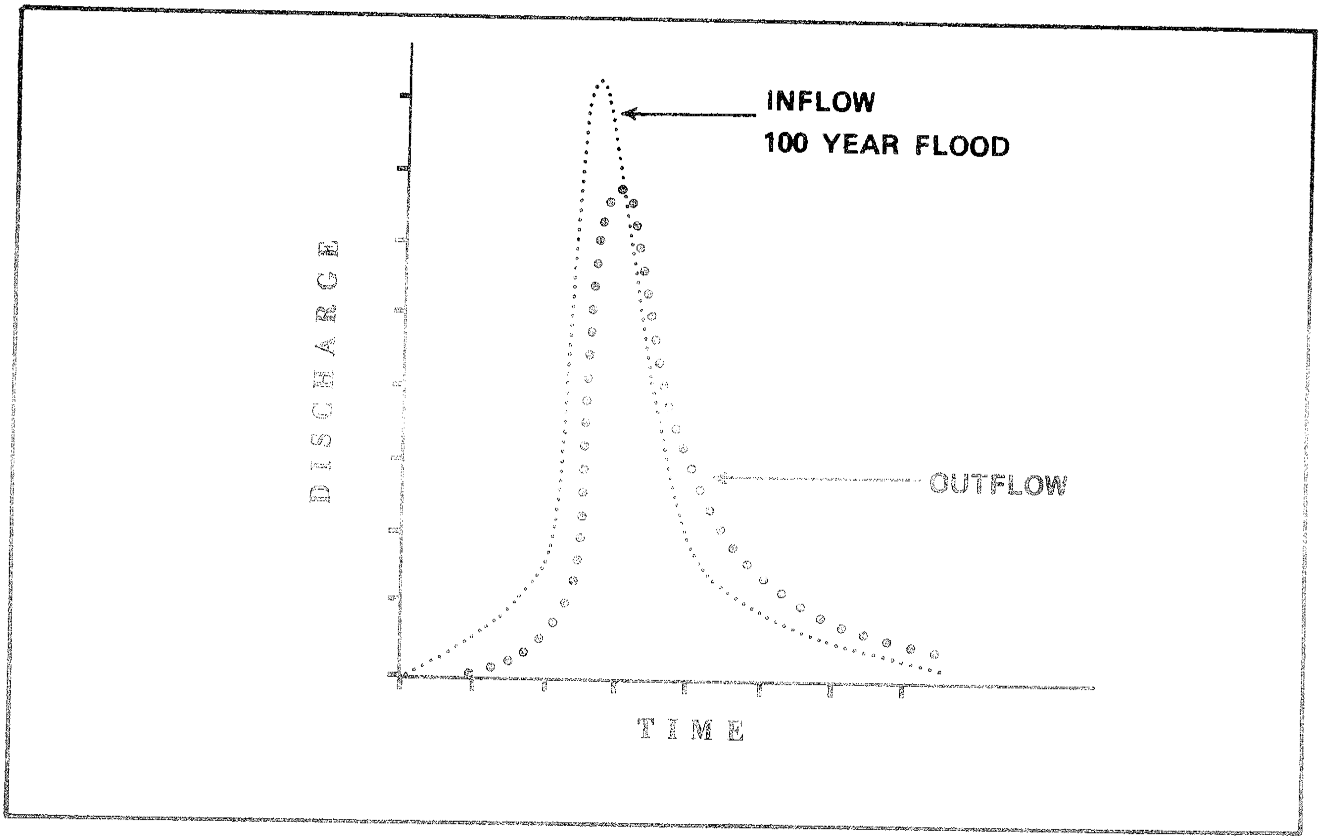

Figure 3-2. Typical inflow and outflow hydrographs for a 100-year flood.

Summary and Conclusions

Three hydrologic characteristics of wetlands — normal water level fluctuations, ground water exchange, and floodwater detention — have been discussed.

As part of the assessment process for wetlands, it is important that the wetlands ecologist have an understanding of the basic hydrologic operation and normal water level fluctuations to be expected at a specific site. This knowledge should significantly aid in the assessment of non-hydrologic wetland values, because of the dependency of the chemical and biological processes on the hydrologic environment.

The physics describing the hydrologic processes applicable to wetlands are well known and documented. Methodologies are available for assessing and quantifying normal and abnormal water level changes, ground water exchange, and floodwater detention characteristics. The reliability of a mathematical solution of a wetland's water budget, ground water exchange, or floodwater detention capability is primarily dependent upon the time and effort available to collect and analyze pertinent data.

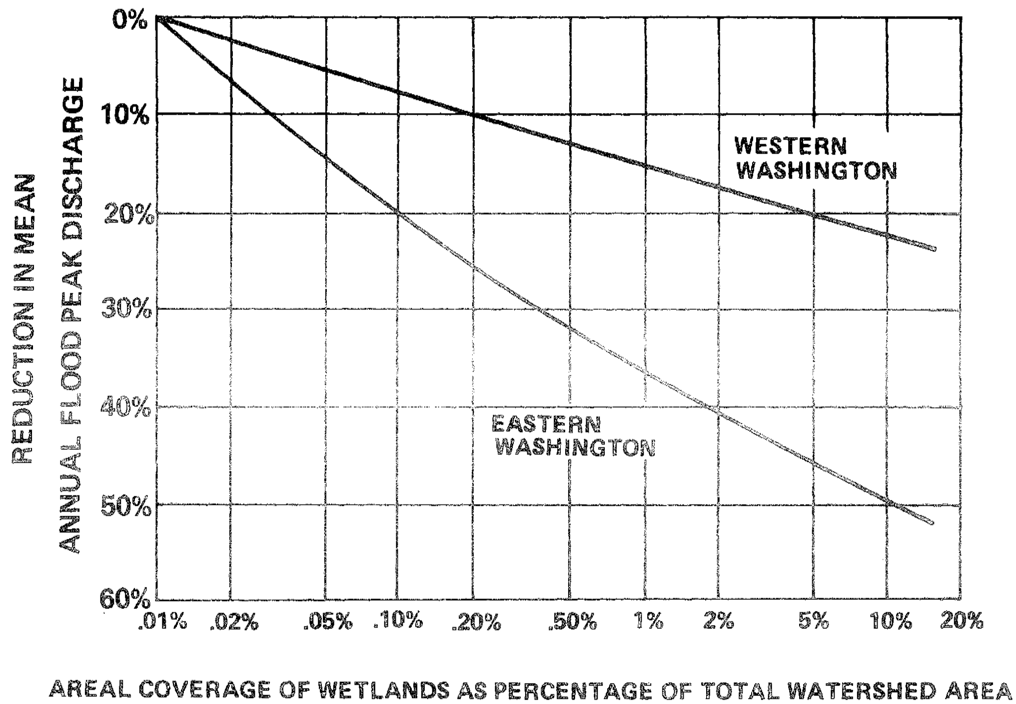

Figure 3-3. **Generalized relationship for mean annual flood peak discharge as affected by increased storage of floodwaters on wetlands.**

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Sediment Trapping in Northwest Wetlands — The State of Our Understanding

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Abstract

The sediment trapping functions of the four major wetland types are better known for large geographic areas than for specific sites. The processes involved in these functions are also reasonably well known, but there is little quantification of sedimentation rates. For example, there are numerous papers that indicate the trapping of sediment in marine wetlands along the southwest Washington coast is largely a function of the amount of sediment supplied to the system. Yet there is little information about specific stretches of the coast. Estuarine wetlands are recognized as sediment traps for both marine and riverine sediments. One of the major factors affecting the sediment trapping efficiencies of such wetlands is change of sea level. A rapid sea level rise results in higher sedimentation rates for the estuarine systems. Studies of riparian wetlands in other regions indicate that they trap some of the sediments supplied to them during flooding. Freshwater impounded wetlands are a diverse group that has a wide range of capabilities for sediment trapping. Lakes and bogs trap sediment to the extent that water passes through them, however they all trap some part of the sediment load delivered to them.

General Sedimentology of Wetlands

Sediment trapping is defined as the process by which particulate matter is deposited and retained within a wetland (Appendix B). This paper will deal with mineral particulates and their associated organics, introduced into the wetland from an outside source by water. It does not deal with organic particulates produced within the wetlands themselves.

There are some general properties that may be applied to all wetlands with respect to their ability to trap sediments. These properties are: water velocity, residence time, available sediment, age of the wetland, and base level.

The **velocity** of the water must be fast enough to transport sediment to the wetland and then slow enough through the wetland to allow the sediment to be deposited there.

The **residence time** of the water is the length of time it remains in the wetland. Generally long residence times are necessary to allow the clay fraction to settle out of the water column. As the residence time increases so does the proportion of the sediment load that will be deposited in the wetland.

Available sediment refers to the amount of sediment that is transported to the wetland. If more sediment is brought to the wetland than can be transported away, then it will accumulate there. On the other hand, if there is only a small source and the wetland is sediment starved, there will be little accumulation.

Pethick (1981) pointed out that as the **age of a wetland** increases, the accretion rate will decrease. His work in English coastal marshes suggested that a profile of equilibrium is quickly reached in such marshes and thereafter accumulation rates diminish

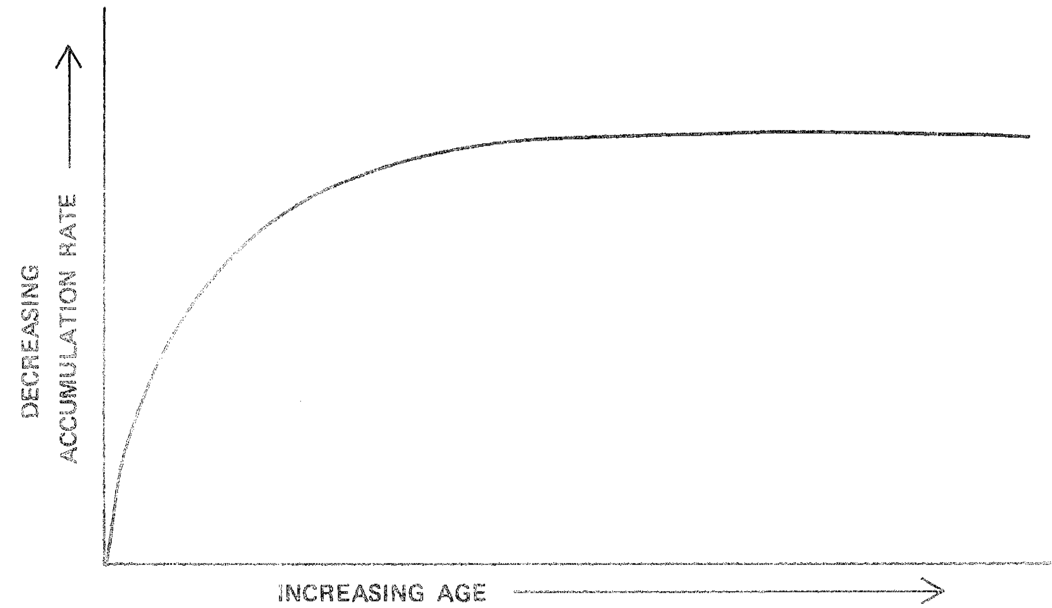

Figure 3-4. As the age of the wetland increases, the rate of sediment accumulation decreases.

exponentially. He pointed out that Kestner (1975) observed exactly the same relationship for English tide flats.

At the conference this concept was extended to apply to all wetlands (with the agreement of the participants). In general, younger wetlands have higher accumulation rates (Figure 3-4). The accumulation of sediment may result in an increase in area as well as an increase in sediment depth.

The **base level** of a wetland is the level above which there can be no deposition. For the marine-associated wetlands it is sea level, and for the riverine-associated wetlands it the height of water during flooding. As the level of the sediment-water interface approaches base level the wetland will experience a decreased vertical growth (as in aging above) and start to accumulate horizontally, if that is possible.

The wetlands described in this paper can be grouped into two major types: those wetlands that are related to the sea and are controlled by sea level as base level (marine and estuarine wetlands), and those that generally have a riverine system as a base level (riparian and freshwater impounded wetlands).

Marine Wetlands

Marine wetlands include the ocean and its associated high energy coastline, extending seaward from the upper limit of high water to a depth of -20 meters (Appendix B). In the Northwest, this would be the Pacific Ocean beaches and the nearshore.

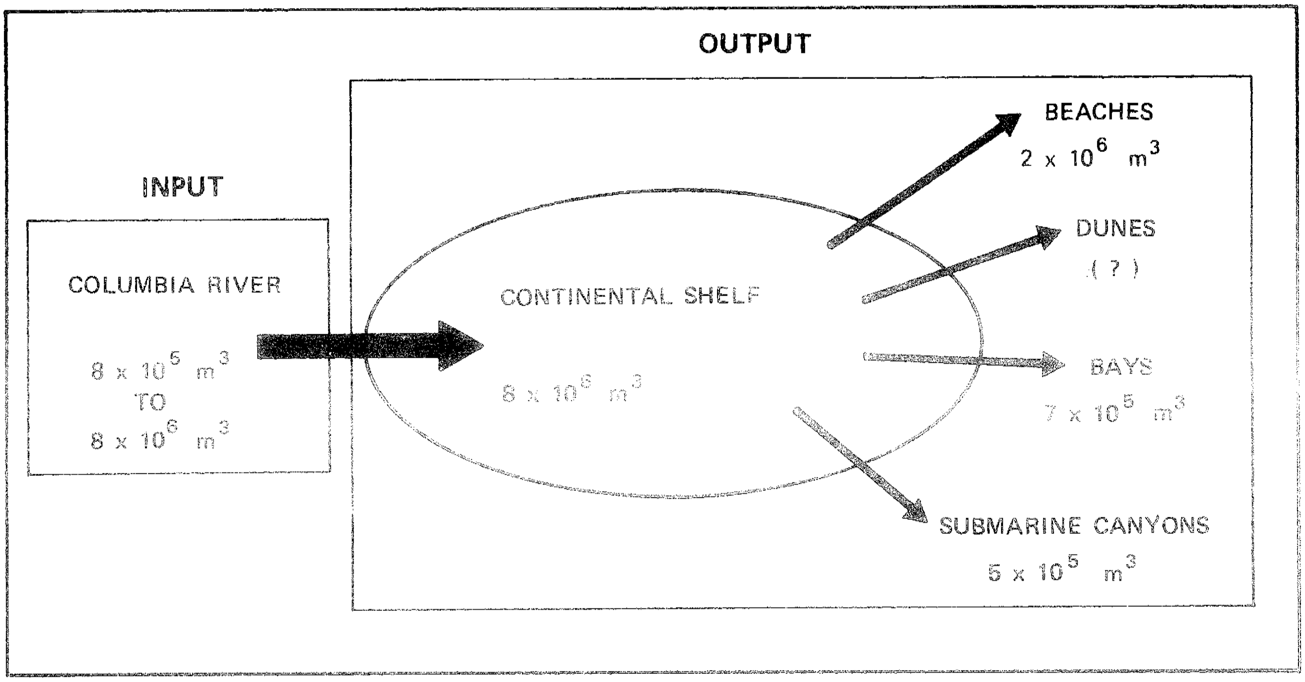

Figure 3-5. **The annual sand budget for the southwest Washington coast (after Phipps 1978).**

Sediment sources are the transportation of sediment by rivers through their estuaries, and erosion of sea cliffs. The major sediment transport mechanisms are ocean waves, which are often large enough to transport sediment in water much deeper than the -20 m defined in this report. Seasonal deposition in this wetland is primarily dependent upon ocean wave periods (see Komar 1976). In the longer term (decades) the amount of sediment available for deposition seems to determine whether the shoreline accretes or erodes. Pacific Ocean beaches maybe be better described as slow moving rivers of sand rather than as sediment traps. If the supply of sand to the beach does not equal the transportational demands of the waves, the beach will erode. The high wave energies available can easily erode 150 to 250 feet [46-76 m] of shoreline per year, if the conditions are right. An example of such a case is the erosion at North Cove, Washington, which is aptly called "wash-a-way" beach by the local residents.

Sand budgets can be made for segments of the coast where one can identify a closed system with known (or assumed) sediment volume input and output. An example of such a budget for the southwest Washington coast is shown in Figure 3-5 (Phipps 1978). This is a "first approximation" budget. The values used were only poorly constrained and it does not balance. But it is an example of an important step in dealing with the sedimentation in the marine wetlands.

Estuarine Wetlands

Estuarine wetlands are defined as tidal wetlands and the associated deep water (to -20 meters) habitats that are usually semi-enclosed by land but have open, partly obstructed, or sporadic access to the open ocean, and in which ocean water is at least occasionally diluted by freshwater runoff from the land.

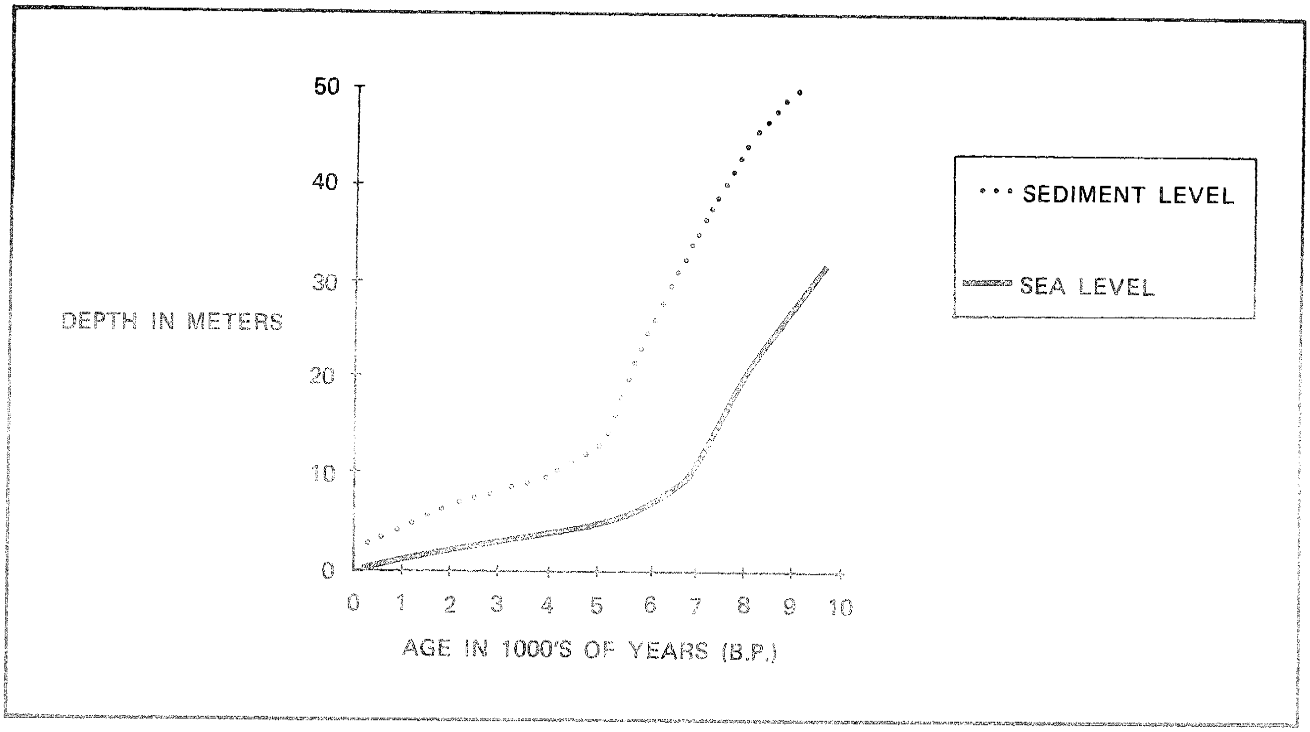

Figure 3-6. The relationship between sea level and the level of sediment in the Alsea estuary, Oregon (after Peterson et al. 1984).

Since estuaries are traps for both riverine sediments and marine sands, riverine hydraulics and ocean wave transport mechanisms bring the sediments to the estuary. Once in the estuary the sediments can be moved about by tidal currents and wind waves. Estuaries trap almost all of the riverine sands and gravels, but some of the muds pass through the estuary as suspended sediments. For example, Hubbell et al. (1971) showed that only 30 percent of the riverine silt clay fraction is retained in the Columbia River estuary. Only the coarse fraction — sediments, sands and some gravel — is furnished to estuaries by marine sources.

In a well documented study of the Alsea estuary in Oregon, Peterson et al. (1983) showed that the trapping efficiency of riverine sediments was directly related to sea level rise (Figure 3-6). During the early part of the Holocene the sea level was rising rapidly, the estuary was constantly being rejuvenated, and the sedimentation rate was high (1.1 cm/yr). For the last 6000 years, the sea level rise has decreased, and the sedimentation rate has diminished to about 0.21 cm/yr. The accumulation rate of beach sand remained constant during this same time period.

Studying estuaries in Oregon and Washington, Peterson et al. (1984) suggested that amount of beach sand in an estuary can be related to estuarine hydrography (specifically to the ratio of tidal-prism volume to mean fluvial discharge volume). So those estuaries with large tidal volumes tend to trap relatively more beach sands than the smaller estuaries.

Riparian Wetlands

Riparian wetlands are defined as out-of-channel, palustrine wetlands associated with a riverine system. The major geological factor that transports sediments to such wetlands is the river flow during floods. If the associated river is prone to annual floods, the wetland gets an annual dosage of sediments. Sedimentation rates measured in the Barataria Basin in Louisiana support what the morphologies of Northwest rivers show — that the sedimentation rate is highest next to the river and lower at greater distances from the river bank.

The efficiency of sediment trapping by such Pacific Northwest wetlands has not been measured. Obviously it would vary greatly, depending to a large degree upon the residence time of the water in the wetland. An example of long residence times would be flood water ponds that eventually soak into the groundwater system and thus leave their entire sediment load. In contrast, waters that simply cut across a meander would have a very short residence time, and may in fact erode the wetland.

Sediment budgets for riparian wetlands would need to consider the streams' hydrographs for flooding frequency, and, if possible, to obtain some kind of sediment transport values for flood stages. The author is unaware of any studies in the Pacific Northwest that have measured a decrease in the sediment load of flooding rivers downstream from wetlands.

Freshwater Impounded Wetlands

Freshwater impounded wetlands are defined as palustrine or lacustrine wetlands formed in topographic depressions or by the natural or artificial damming of rivers, streams, or other channels. Sediments are brought to such wetlands by rivers, so the annual river sediment load is a primary sediment budget consideration. Other budget considerations for such wetlands would be their age and the residence time of the water in the wetland.

The effect of age can be illustrated by a hypothetical case of a new midmontane beaver dam. Such a dam would probably fill rather rapidly when it was first built and then later pass the sediments as the trapping efficiencies decreased with age. Even then, the initial sediment trapping efficiencies might be rather low. For example, Megahan (1975), working in such midmontane environments, found that the sediment retention dams he constructed on several creeks only trapped 80 percent of the sediment supplied to them.

The effect of residence time of the water in lakes can be illustrated by considering the lowland lakes in the formerly glaciated areas of Mason and Thurston Counties, Washington. These lakes are simply depressions filled with groundwater, with no outlet. Their waters have long residence times. They have essentially no external sediment sources, and would consequently have very low sedimentation rates, but extremely high trapping efficiencies.

In general there in not much information on lake sedimentation in the Northwest. While there are dozens of atlases describing Washington and Oregon lakes, unfortunately none of them describe the sediment trapping properties of the lakes.

Where Do We Go From Here?

To initiate some ideas of sediment trapping efficiencies, one would have to know how much sediment entered the wetland and either how much remained there or how much emerged. While there are data available on the amount of sediment transported by northwest rivers, there is almost no information on how much sediment gets from the rivers to the wetlands. There are data on some Washington beaches and Oregon estuaries, but most marine and estuarine wetlands in the Pacific Northwest have no available sediment data.

The ongoing and future sea level rise (Barth and Titus 1984) that is drowning wetlands on the Atlantic (Pilkey et al. 1984) and Gulf coasts (Hatton et al. 1983) will probably not be as severe a problem in the Pacific Northwest because of the difference in tectonic conditions. The Pacific Northwest is an active continental margin which has uplift rates that are similar to the projected sea level rise. On the passive margins the land is not rising and thus the wetlands are flooding. The wetlands on passive continental margins should show higher sedimentation rates than Pacific Northwest coastal wetlands because of changes in the base level. That is, the newly flooded areas, such as the Barataria Basin, are "younger" and have a higher sedimentation rate.

Pacific Northwest rivers (and associated wetlands) exist in a unique climatic and topographic region characterized by high rainfall and frequent flooding. Such rivers are naturally subject to high sediment loads. These high sediment loads are exacerbated by logging and agricultural activity. It is significant that most recent sediment studies on streams have been done by people with logging or fisheries concerns.

Obviously there is a paucity of information concerning Pacific Northwest wetland sediment trapping. It would seem that information from other areas, while valuable in terms of processes, would not be useful in terms of sedimentation rates. So indeed, one must pull on the boots and venture out into the swamp to see for oneself.

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Working Group Report:
Hydrology and Sedimentology

Melvin Schaefer, Alan Wald, and James Phipps, Moderators
Thomas Terich, Rapporteur

"If you try to make a cookbook, you're going to get a lot of cooks. But since we already have a lot of cooks, we had better make a cookbook!"

Review of Plenary Papers

The working group felt that wetlands scientists and managers are not sufficiently aware that long-term hydrologic processes (water level fluctuations, groundwater exchange, and flooding) are central to understanding wetland ecology. One of these functions, groundwater recharge, is commonly ignored in wetland assessments. Much discussion in the working group focused on the importance of temporal variability of hydrologic processes that are mechanisms for ecological change in wetlands. For example, timing may be as important as volume of flow in determining the dynamics and effects of groundwater exchange. Annual and seasonal cycles are important time scales for understanding wetland hydrology. Research and monitoring work should recognize the potential for long-term trends and extreme hydrologic events. Decisionmakers should be advised of the risks and impacts to wetlands associated with hydrologic variability.

The group discussion clarified that sediment trapping efficiency is defined as the fraction of sediment entering the wetland that does not leave it. The important factors in assessing sediment transport and trapping functions are: sediment supply (amount); flow velocities, discharge, and distribution; residence times; and water chemistry. An understanding of both the physical and biological effects of sediment deposition is important to wetland studies. Shoreline anchoring functions may be (more) important in low-energy, low-frequency wetland environments.

Discussion of Matrix

The group disagreed with or modified some of the preliminary results of the matrix. Low values were obtained in the matrix results for groundwater exchange functions. The group felt this reflected lack of data and understanding rather than actual low performance of this function. The group agreed that wetland type and substrate are probably the two most important factors for groundwater exchange. Groundwater recharge depends more on substrate than on elevation, but the implications of recharge are not understood due to lack of data. Very little quantitative information is available on groundwater exchange by wetland types in this region. The value of marine and estuarine wetlands for groundwater exchange should not be discounted, because they may be very important for regulating saltwater intrusion and characteristics of the fresh/saltwater interface.

Flood detention performance in wetlands depends on site-specific physical characteristics. Freshwater impounded and to some extent riparian wetlands generally are more efficient at performing this function, and marine and estuarine wetlands have little or no ability to perform this function. Regional distinctions may be important for flood detention, because climatic regimes are distinctive in their effects on floods. For example, semi-arid regions typically have smaller inflow floods. Thus flood storage should be more important east of the Cascades. However, the polling results of the matrix were the opposite. Assessing flood detention in created and restored wetlands is a function of their design — the hydraulics can be designed to operate as desired. Therefore created or restored wetlands deserve high ratings for this function, but are rated low in the matrix. Overall, this function has a high data adequacy due to a large number of flood studies and methodologies.

The effectiveness of sediment trapping varies with wetland type. In descending order of efficiency are freshwater impounded, riparian, estuarine, and marine wetlands. In the matrix, high elevation wetlands are rated highest among riparian environments for this function, and submergent vegetation is rated higher than emergent. Processes involved in sediment trapping are well understood qualitatively, but there is little quantification of these processes for different wetland types in the Northwest.

Discussion Questions

Outside or Site-specific Limiting Factors

The matrix does not include several key characteristics that affect groundwater exchange. These include substrate permeability and stratification, adjacent surface and ground water levels, timing and seasonal variation in groundwater flows, and groundwater chemistry.

Flood detention efficiency depends on the relative magnitude of the inflow flood, the wetland's detention capacity, its outlet condition, and its position in the watershed.

Interdependence of Functions

Flood detention can be affected by vegetation creation/restoration efforts. Sediment transport and trapping are affected by water chemistry and vegetation. Sediment can be generated by processes associated with vegetation, primary producers, and consumers.

Data Gaps and Research Needs

There is little site-specific information on the hydrology of Northwest wetlands.

Cumulative effects of multiple wetland losses on all three hydrologic functions should be investigated.

There is a need for a simplified assessment technique/methodology (a handbook or chart procedure) for identifying relative efficiencies of flood detention in specific wetlands.

Both pure and applied research are needed to understand and quantify the dynamics of groundwater exchange. An interdisciplinary effort is needed to clarify physical soil/water interactions in groundwater exchange; these include the roles of soil water chemistry, soil texture changes, and biological activity.

Research is needed to define the significance of sedimentation to ecological processes. Interdisciplinary studies should attempt to establish and quantify relationships between sediment dynamics and other commonly measured wetland parameters. Quantitative budgets of known parameters affecting sediment transport and trapping in several wetlands of each type should be calculated.

The tolerance threshold of vegetation for sedimentation and water quality changes is uncertain.

Chapter 4 — Water Quality and Carbon and Nutrient Cycling

A Review Of Wetland Water Quality Functions

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Abstract

Views of wetlands and their water quality are changing. Former attitudes of wetlands as worthless lands, poor in water quality, and best converted to other uses, are being replaced by interest in their ecological significance and their role in protecting adjacent open water systems from contamination. Numerous quantities define wetland water quality, including pH, solids, oxygen, nutrients, and the various metallic, organic, and pathogenic contaminants originating in human activities. Constituents in water participate in complex mechanisms in dynamic wetland systems, with notable differences evident among different wetland types. Hydrologic and hydraulic parameters have important influences on these mechanisms that have often been ignored. More research has been performed on nutrient cycling than on any other mechanisms, and substantial seasonal variability in mass flux across wetland boundaries has been observed.

Relative to other regions, research on water quality functions in Pacific Northwest wetlands is scant and uncoordinated, although results from studies on lacustrine, riverine, estuarine, and coastal wetlands in the region appear in the literature. Reports from around the world have documented a wide range of experience in using wetlands for advanced sewage treatment; cases of stormwater treatment are much scarcer. Most attention thus far has been directed to nutrient removals, which generally decline at the close of the growing season. Consideration is now turning to other pollutants, to their effects on wetland structure and function and on adjacent open waters, and to managing wetlands for treatment purposes. Because of the opportunities they offer for proper management and for replacing lost natural wetlands, artificially constructed wetlands are receiving substantial attention.

Introduction

Until recently, the quality of water in wetlands was a secondary issue. More fundamental was the question of whether wetlands should continue to exist, or should be drained or filled for development when that opportunity was presented. Moreover, even when the biological functions of wetlands gained some recognition, little connection was made between performance of those functions and water quality. The view, even among scientists, was that wetlands were inherently poor in water quality relative to more capacious and physically dynamic open-water systems.

This attitude is undergoing a thorough change at the present time for a number of readily identifiable reasons. First, in consideration of the substantial losses of wetland areas in most of the developed world, there is now general agreement among scientists, policy-makers, regulators, and managers that every effort should be made to preserve still existing wetlands. With this consensus, attention has turned to what had been secondary issues, such as various wetland functions, including water quality. Also stimulating this growing interest is the experience of recent decades that rivers, lakes, and even oceans, with seemingly more than adequate capacities to absorb the refuse of civilization, can change and be structurally and functionally impaired. There is no reason to believe that wetlands are immune from this occurrence.

Interest in wetland water quality also is stimulated by the relationships between wetlands and what, in the past, have been more valued adjacent open-water systems. These relationships include the contributions of the biologically productive resources of wetlands to open waters, and the ability of wetlands to sequester contaminants, thus limiting the quantities reaching adjacent waters. A major reason for the current heightened interest in wetland water quality is the desire to exploit this relationship by using wetlands for advanced wastewater treatment to protect open receiving waters.

A final incentive for better understanding wetland water quality functions is the appearance of dramatic cases of wetland water quality degradation and consequent biological impairment. The most celebrated of these cases is the Kesterson (California) National Wildlife Refuge. After the refuge received undiluted irrigation water draining from the west side of the San Joaquin Valley for only two years, biologists discovered unusually large numbers of deformities in hatchling and embryonic birds, as well as adult bird mortalities and the disappearance of other species. Further research identified the cause as toxic concentrations of the metal selenium, leached from agricultural fields (Schneider 1985). The Kesterson discovery has led to a search for other potential similar cases throughout the irrigated West. Other dramatic cases of wetland contamination with severe effects on biota are associated with hazardous waste sites of various types. The ongoing investigations of these cases are certain to raise the profile of wetland water quality issues still higher.

This paper will review the current state of our understanding of wetland water quality functions, with reference to both the general literature and Pacific Northwest studies. It will first cover the quantities defining wetland water quality and then will review the mechanisms governing their functions in wetlands. After a brief discussion of considerations for monitoring wetland water quality, the paper will turn to the question of using wetlands for wastewater treatment. Finally, it will summarize the state of our understanding, draw conclusions, and make recommendations.

Quantities Defining Wetland Water Quality

The quantities defining wetland water quality are essentially the same as those determining the water quality of open-water systems. However, a greater range of values over space, time, or both is often observed in wetlands compared to open waters.

pH, Oxygen, and Solids

The pH is the negative logarithm of the hydrogen ion concentration expressed on a 0 to 14 scale, with pH 7 being neutral, less than 7 acidic, and greater than 7 alkaline. Under entirely natural conditions, routine pH can range from 3 in poorly buffered northern bogs to 10 in minerotrophic arid region marshes (Kadlec and Kadlec 1979).

Along with pH, dissolved oxygen (DO) determines the biota that can inhabit a wetland and governs a number of mechanisms involving other water quality components. DO exhibits a strong diel variation in many wetlands and can range from zero to 200 percent saturation (Schwegler 1977). A high correlation frequently exists between DO and the tidal cycle in estuarine wetlands (Simpson and Whigham 1978).

Dissolved oxygen concentrations are reduced by bacterial decomposition and chemical oxidation of organic matter. These processes are represented, although somewhat artificially, by measurement of Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). BOD measures oxygen consumption in decomposition during incubation for a standard length of time at a standard temperature, usually five days and 20°C, respectively. COD measurement compresses chemical oxidation processes that would be very slow under natural conditions into one to three hours in the laboratory, using severe oxidizing conditions created by acid addition, catalysts, and heat. These tests are primarily valuable in providing relative measures of demand on oxygen resources.

Solids have a substantial effect on both the physical and chemical nature of wetlands. Those in particulate form, either from external sources or of biological origin within, reduce light penetration and tend to deposit in the quiescent conditions prevalent, at least periodically, in most wetlands. Particulate solids are measured by filtration and weighing as Total Suspended Solids (TSS), also termed Nonfilterable Residue (NFR). The light-scattering effect of these particles can also be measured as nephalometric turbidity. In addition to their ability to restrict light, abrade organisms, modify benthic habitat, and reduce water depth, particles are a significant transport medium for many other substances, including nutrients, metals, and organics (Kadlec and Kadlec 1979).

Total Dissolved Solids (TDS) are also often measured in water samples, by evaporation and weighing, and represent the total quantity of ions present. In marine and estuarine systems, TDS is usually expressed as salinity. Chloride is the major constituent of TDS in salt water systems, and is often prevalent in fresh waters as well. This dissolved, conservative anion often passes through wetlands with little change in form or quantity and can be used as a tracer (Kadlec and Kadlec 1979).

Nutrients

Plant nutrients have been the subject of more study than any other water quality constituents in wetlands. Most attention has been given to phosphorus (P) and nitrogen (N), one of which is usually the nutrient limiting plant growth. Phosphorus is more commonly limiting in freshwater wetlands, while nitrogen tends to limit in estuarine and marine systems.

These nutrients are present in a number of forms. For phosphorus, the basic categories are: 1) total P (TP); 2) total soluble P (TSP); 3) soluble reactive P (SRP); and 4) particulate P (PP). The soluble and particulate classes each contain inorganics and organics. TP encompasses all of the succeeding forms. Orthophosphates (PO_4^{-3}, HPO_4^{-2}, and $H_2PO_4^{-1}$, with proportions depending on pH), condensed pyro- and tripolyphosphates, and some high molecular weight organics make up the SRP fraction. In addition to SRP, TSP includes organic colloids (Wetzel 1975). PP is the difference between TP and TSP.

For nitrogen the basic categories are: 1) total N (TN); 2) total Kjeldahl N (TKN); 3) ammonium-N (NH_4^+-N) and dissolved gaseous ammonia-N (NH_3-N); 4) nitrite-N (NO_2^--N); and 5) nitrate-N (NO_3^--N). TN encompasses all the other forms. TKN is the sum of NH_4^+-N, NH_3-N, and total organic N, which is divided into dissolved (DON) and particulate organic N (PON). NO_2^--N and NO_3^--N are often grouped together, since most NO_2^--N is quickly oxidized to NO_3^--N in aerated waters.

The matter of greatest functional importance to wetlands is the relative availability of the various nutrient forms to plants and the speed with which unavailable forms become available through biochemical processes. SRP is essentially all available, either immediately or within a short time (Paerl and Downes 1978; Schaffner and Oglesby 1978). The organic colloid fraction of the TSP is thought to become available in a fairly short time (Wetzel 1975). The inorganic NH_4^+-N, NH_3-, NO_2^--, and NO_3^--N forms are all soluble and readily available to plants. Free amino compounds among the DON are easily degraded by bacteria to release soluble inorganic N, but polypeptides are more stable (Wetzel 1975). The availability of PP and PON is unpredictable, in general, and depends on the specific organic chemicals or mineral associations involved.

In addition to N and P, numerous other elements are required by plants. Among them, potassium (K), magnesium (Mg), and calcium (Ca) are needed in the largest quantities. Trace mineral requirements include many of the heavy metals, some of which can be toxic in higher concentrations.

Metals

A number of heavy metals may be introduced to wetlands from natural mineral deposits or anthropogenic sources. Of widest interest and concern are potential toxicants such as lead (Pb), zinc (Zn), copper (Cu), nickel (Ni), and cadmium (Cd). Certain investigations may center on or also include other potential toxicants such as mercury (Hg), arsenic (As), chromium (Cr), and selenium (Se). Aluminum (Al) is a light metal that has gained attention as a fish toxicant when released by acid deposition. Iron (Fe) and manganese (Mn) are nontoxic at relatively high concentrations but participate in important chemical reactions governing phosphorus and other quantities in water.

In general, the distribution of metals between dissolved and solid phases is under pH control. Most tend to be particle-bound near neutral pH but can be solubilized by pH decline. A metal ion in solution is usually associated with one or more groups that stabilize the ion and keep it in solution (Bard 1966). This specie, composed of the metal ion and its associated groups (ligands), is called a complex ion. Ligands may be neutral or anionic inorganics or organic chelating agents. Along with pH, the extent and the types of complexation determine the availability of heavy metals as toxicants to aquatic biota.

Organic Compounds

Many organic chemicals could be involved in wetland water quality. Various fulvic and humic compounds result from autochthonous processes and natural allochthonous sources. Anthropogenically, petroleum products and a multitude of more or less refractory organics can be introduced. The refractory compounds include: 1) air- or water-borne combustion by-products, such as polycyclic aromatic hydrocarbons (PAHs); 2) industrial chemicals, such as polychlorinated biphenyls (PCBs), pentachlorophenol, (PCP) and many others; and 3) pesticides such as chlorinated hydrocarbon and organophosphate insecticides, phenoxy herbicides, and others. Many potential toxicants, carcinogens, and mutagens are among these compounds. As with the metals, organics tend to be associated with the solids but are under the control of pH and other conditions.

Pathogens

Pathogenic organisms represent another category of water quality constituents receiving attention. Bacterial pathogens are usually not measured individually, but coliform indicators are used as general measures. The fecal coliform test measures coliform organisms, principally *Escherichia coli*, prevalent in the intestines of mammals. The total coliform test also reflects coliform bacteria that may have a soil origin. Fecal streptococci, which generally are present in relatively higher amounts in livestock versus human waste, have also been measured in wetland studies (Kadlec and Kadlec 1979). Viruses are important to public health but are not commonly measured, even in studies of advanced sewage treatment by wetlands. Now gaining some attention are wildlife pathogens, such as *Clostridium* bacteria that can be made viable by anaerobic conditions and cause botulism.

Other Quantities

Taste, odor, or color of wetland waters are sometimes issues, especially if they affect a nearby human settlement, an open water environment, or a potable water source. Good measuring techniques are lacking for these quantities, although an objective scale is available for color. Odor is most frequently an issue when a wetland has extended anaerobic periods and produces hydrogen sulfide, while color usually comes to attention when an acidic bog releases brown water high in humic acids.

Mechanisms Governing Wetland Water Quality

Hydrologic and Hydraulic

A central quality of many wetland systems is their dynamic nature. They are subject to both stochastic and time-varying events that are important determinants of water quality and other characteristics (Kadlec and Kadlec 1979). These events are generally of a hydrologic or hydraulic nature. Of the stochastic factors, weather systems have a strong influence on, particularly, freshwater riparian, impounded, and palustrine systems. Annually varying climatological patterns substantially govern both freshwater and estuarine wetlands, while variations on the diurnal and monthly time scales (e.g., tides) are crucial to marine and estuarine systems.

Gosselink and Turner (1978) have pointed out that, to the extent that the hydrologic regime distinguishes emergent wetlands from terrestrial and open-water aquatic environments, it is the primary determinant of all wetland systems. Yet, quantification of hydrodynamic characteristics has often been missing in wetland studies, a fault that should be redressed in future work. These observers modeled the relationships among hydrology, water quality, and ecosystem response, as illustrated in Figure 4-1. They named as the most fundamental hydrodynamic parameters the water source, velocity, renewal rate, and timing. For example, water source distinguishes an acidic, mineral-poor ombrotrophic bog subsisting on rainwater from a well buffered, minerotrophic system fed by surface flow. The chemistry of the minerotrophic fen, typically dominated by calcium and bicarbonate, differs greatly from the bog chemistry, in which hydrogen ion and sulfate are the dominant species (Richardson et al. 1978).

The mass balances of water quality constituents in a wetland depend on actual transit times rather than overall water renewal rates. In a study of Lake Tahoe Basin wet meadowlands, Morris et al. (1981) discovered that inflow and outflow TSS, P, N, and organic carbon were essentially the same in channelized systems with rapid passage, but that at least 75 percent removals occurred in meadows without channels.

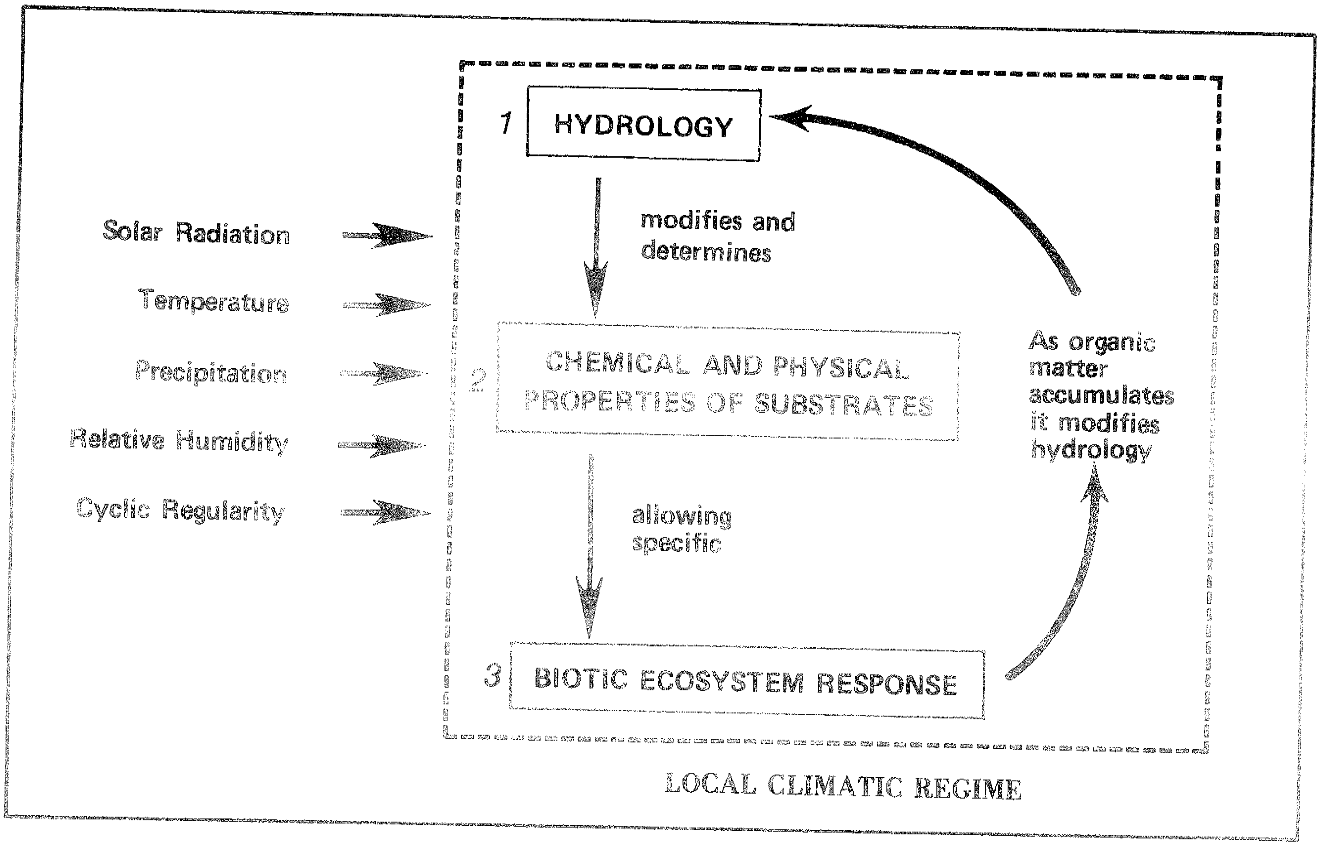

Figure 4-1. General conceptual model of the role of hydrology in wetland ecosystems (after Gosselink and Turner 1978).

The relationships among hydrodynamics, water quality, and ecosystem response are governed by several feedback mechanisms (Gosselink and Turner 1978). Vegetation is a silt trap and increases the sedimentation rate. As the wetland elevation increases, the frequency of occurrence and depth of standing water decrease; then more of the primary production is deposited as peat, and less is exported. These factors all operate to close nutrient cycles, leading to reduced nutrient flux across wetland boundaries.

Sedimentation and Resuspension

Accretion of particulate organic and inorganic matter, whether of internal or external origin, is a second determinant of wetland character. Wetlands can be either sources or sinks of solids, or can differ seasonally in that respect. Sedimentation generally is a rather straightforward process of gravity settlement, controlled by particle size and residence time, and by physical filtration by plant stems and leaves. In estuarine wetlands, however, high ionic strength sea water reduces clay particle negative charges and assists their flocculation and settlement (Boto and Patrick 1979).

Resuspension depends primarily upon the energy of hydrodynamic events, such as storm runoff and tidal action. Because solids transport many other quantities, the cycles of these quantities are also intimately involved with sedimentation and resuspension processes.

Table 4-1
A comparison of nutrient budgets for blanket bogs, perched bogs, and forested watersheds (after Richardson et al. 1978).

Parameters	Nutrients (kg/ha/yr) N	P	K	Ca
	Pennine, England, blanket bog			
Input				
Precipitation	8.20	0.69	3.07	8.98
Output				
Stream (dissolved)	2.94	0.39	8.97	53.81
Peat (in stream)	14.63	0.45	2.06	4.83
Fauna (in stream)	0.06	0.01	0.01	0.00
Sheep (harvesting and sale)	0.05	0.01	0.01	0.02
Yield or total output	17.68	0.86	11.05	58.66
Net loss	9.48	0.15	7.97	49.68
	Glenamoy, Ireland, blanket bog			
Yield 11.2[a]	0.15	4.7	22.0	
	Minnesota, USA, perched bogs			
Yield				
Bog ws-2	1.91	0.08	1.26	3.46
Bog ws-4	1.97	0.08	1.41	3.55
	New Hampshire, USA, hardwood forest			
Yield	2.3[a]	0.01	1.7	7.5
	Ontario, Canada, hardwood forest			
Yield	2.3[a]	0.16	1.5	12.30
	Michigan, USA, aspen forest			
Yield (soil leachate at 1m)	0.4[a]	0.3	7.6	38.8

[a] $NH_4^- - N + NO_3^- - N$

Nutrient Cycling

More study has been done on phosphorus and nitrogen cycling than on any other wetland water quality functions. Cycling of other nutrients has also received some attention. The studies yielding the most understanding have used a mass balance approach to quantify, annually or seasonally, nutrient fluxes across wetland boundaries and the sediment-water interface. The most detailed of these investigations were also concerned with the mechanisms governing the exchanges and with internal transformations.

It has been suggested that wetlands may function as nutrient traps. Water and nutrient budget data are required to evaluate that proposition. A number of wetland studies, summarized in Table 4-1, have measured nutrient yields, but few have compared yields to nutrient income. The yields reported are similar to those from terrestrial ecosystems. Results of the one study that reported complete mass balances demonstrated net loss of the four nutrients measured. Wetlands may efficiently capture nutrient income, but, because of large reservoirs, losses can still be considerable (Richardson et al. 1978).

Nixon and Lee (1985) reviewed the state of knowledge of wetlands as sources, sinks, and transformers of N, P, and metals. Figure 4-2 summarizes their nationwide findings relative to N and P retention as a function of loading rate. Retention ranged from near zero to near 100 percent, but exhibited no association with loading rate or wetland type.

Some investigators have been concerned with the relative mobility of the various plant nutrients in wetland systems. Chamie and Richardson (1978) rated the order of mobility (from most to least mobile) as:

$$K > Mg > P > N > Ca$$

Davis and van der Valk (1978) generally concurred with these ratings, and added Na as falling among the most mobile elements and Al and Fe as the least mobile.

Figure 4-3 schematically illustrates nitrogen and phosphorus cycles in wetlands. Somewhat simplified, these diagrams represent numerous biologically- and chemically-mediated processes. These processes vary seasonally under hydrologic, hydraulic, oxygen, pH, light, and temperature control. Occurring in both cycles are import and export, biotic uptake and release, plant translocation to and from sediments, transport within plant tissue, sedimentation and resuspension, and burial in the sediments.

Having solid, liquid, and gas phase components, the nitrogen cycle is more complex than the phosphorus cycle. Certain attached and planktonic blue-green algae, and the rhizospheres of some macrophytes, can fix atmospheric nitrogen and supply a significant proportion of N needs (van der Valk et al. 1979). Aerobic bacteria oxidize NH_4^+-N to NO_2^--N and then to NO_3^--N in the nitrification process. Under anaerobic conditions, bacteria can reduce NO_3^--N in denitrification, releasing gaseous free nitrogen. Wetlands often are well suited for denitrification because of abundant organic carbon and periods of anaerobiosis. Removal from the wetland ecosystem by this process can be as much as 3.5 kgN/ha/day (Sloey et al. 1978). Because of denitrification, wetlands are potential nitrogen sinks, although, as pointed out earlier, they may not actually function as sinks over the whole annual cycle.

Chemical rather than biological mediation is more the rule in the P cycle, compared to the N cycle. Anaerobic conditions and low oxidation-reduction potential reduce ferric iron to the more soluble ferrous form and, simultaneously, tend to release phosphorus from the sediments. The return of dissolved oxygen reverses that process. P can also participate in a number of precipitation and complexation reactions (Lee et al. 1975).

Seasonality is the key to understanding why natural wetlands usually are not long-term nutrient sinks. With the onset of the growing season and increased plant uptake, dissolved nutrient concentrations decline. As summer progresses, water levels fall, allowing greater aeration of the sediments. Aeration decreases P solubility, increases nitrification, and stops denitrification: Water column NO_3^--N then can begin to increase again (Richardson et al. 1978). Eventually, decomposition of plant detritus will mineralize nutrients and may reduce oxygen concentrations, tending to release sedimentary P and promote denitrification. At the end of the growing season massive plant death releases much of the accumulated nutrients. Decline in pH at this time also promotes nutrient release. By this point low temperature suppresses denitrification (Richardson et al. 1978). Simpson and Whigham (1978) found in studying a New Jersey freshwater tidal marsh that up to 80 percent of the accumulated N and more than 80 percent of the stored P was released within one month after macrophyte death. However, inorganic N and P remained depressed through spring in pond-like areas that had phytoplankton.

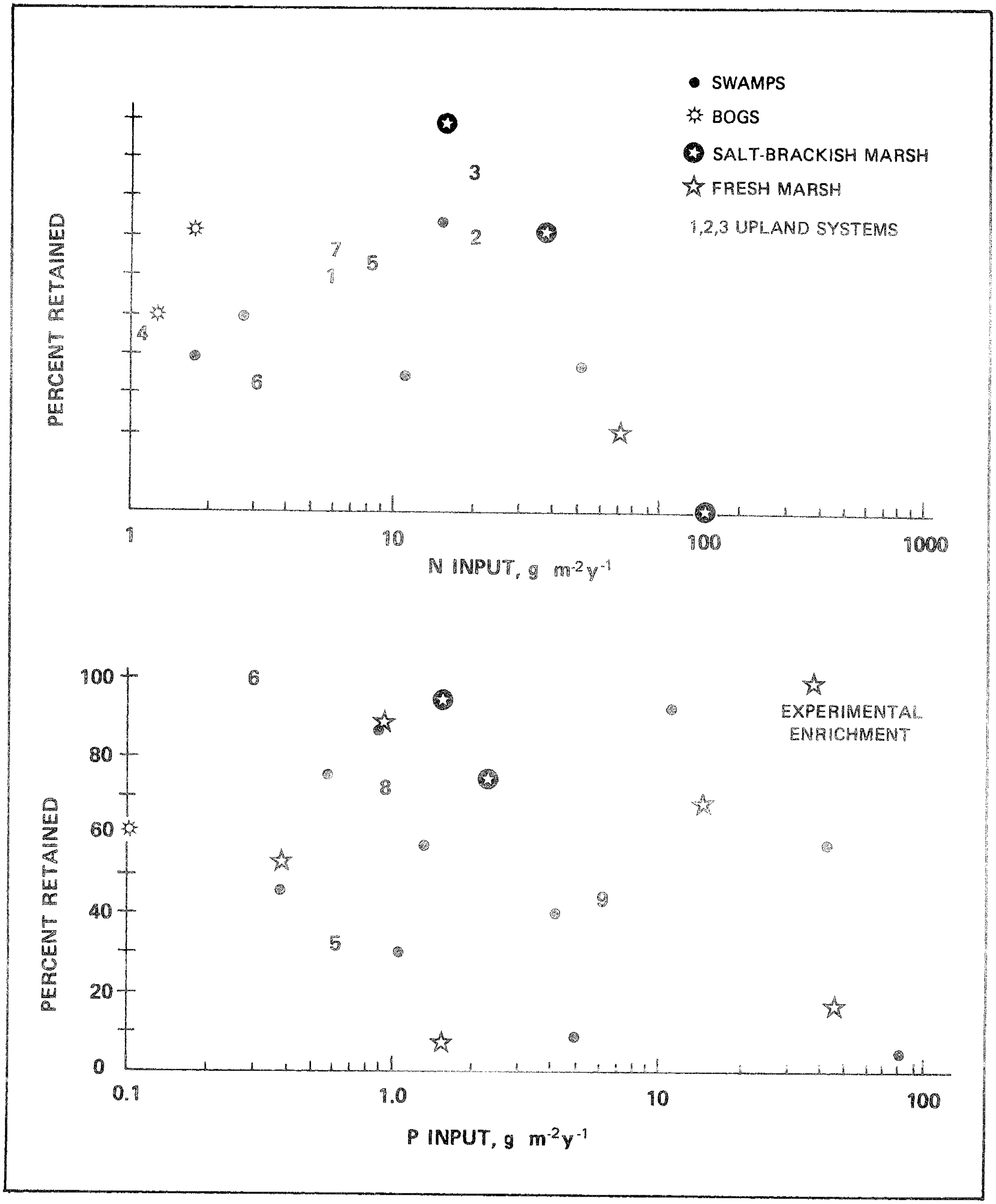

Figure 4-2. Nitrogen and phosphorus retention versus input in a number of United States wetlands (after Nixon and Lee 1985).

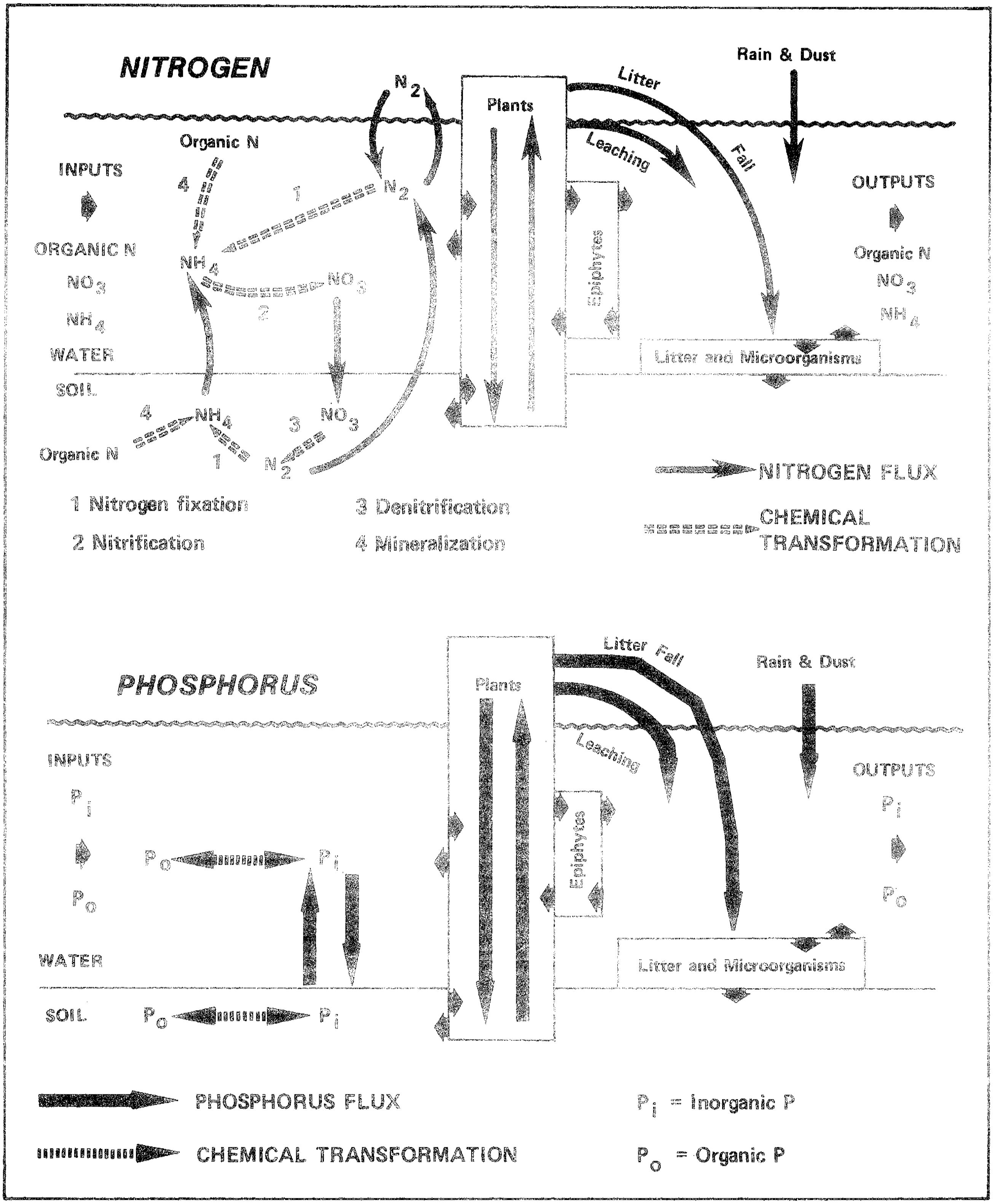

Figure 4-3. **Nitrogen and phosphorus cycles in a hypothetical wetland receiving surface inflow (after van der Valk et al. 1979).**

On the basis of lakeshore marsh studies, Prentki et al. (1978) stated that, unless effective harvesting can be done, burial or denitrification (for N) must be the ultimate sinks for intercepted nutrients. However, burial is often inefficient relative to upward nutrient translocation by vegetation. As discussed, denitrification requires anaerobiosis and relatively high temperatures, and thus often is not factor over much of the year. Sloey et al. (1978) were pessimistic about the effectiveness of late-season harvesting in reducing nutrient release, apparently because stem and leaf nutrient content declines through the growing season (Richardson et al. 1978), and standard harvesting techniques do not remove roots. While N is generally labile in soils, P is bound more tightly and is not subject to bacterial processes, as N is. As a consequence of these characteristics, P saturation of wetland sediments is a possibility. Richardson (1985) found that P retention capacity is concomitant with Al and Fe content in the soil. This capacity was exceeded in a few years with wastewater loadings, with the subsequent export of large quantities of phosphorus.

These circumstances suggest the need for specific management if a wetland is to be used for trapping nutrients in a wastewater (Sloey et al. 1978). Management may be easier and less disruptive to other functions if carried out in an artificial wetland specifically designed for the purpose.

Heavy Metal Cycling

Distribution of metals between liquid and solid phases depends on equilibrium chemistry (Clark and Clark 1979). More specifically, a number of physicochemical mechanisms are involved in wetland heavy metal cycling, including sedimentation, plant uptake, adsorption, ion exchange, precipitation, and complexation. The relative importance of these processes depends on the metal, the plant species, soil characteristics, and such conditions as pH, oxidation-reduction (redox) potential, and salinity.

Early studies dealt primarily with partitioning of heavy metals between plants and sediments. For example, in an investigation of metals addition to a Massachusetts salt marsh, it was observed that only six to eight percent of the Pb was taken up by grasses, with the remainder retained in sediments (Banus et al. 1975). On the other hand, larger proportions of Zn and Cd entered the plants. A number of opportunities exist for incorporation of metals in or on the sediments, including capture at clay particle ion exchange sites, adsorption within iron and manganese colloidal hydroxides, precipitation as insoluble sulfides, and complexation by fulvic and humic acids (Boto and Patrick 1979). The availability of sediment metals to plants is governed by physicochemical conditions in the sediments (Center for Wetland Resources 1977).

A question little addressed in earlier studies but pursued more vigorously recently is the permanence of metal trapping in wetlands. In one sense, permanent capture is desirable to prevent more general distribution of heavy metals in the environment. However, many metals have a tendency to bioaccumulate, with possible negative consequences to organisms at higher trophic levels in wetland food webs (Kadlec and Kadlec 1979). It is agreed that, although removal varies with metal and wetland type, wetlands do tend to accrete metals (Giblin 1985). Evidence is building, however, that much of the entering metals may later leave wetlands. Table 4-2 summarizes data drawn from a number of studies of different saline and freshwater wetlands and presented by Giblin (1985). These data suggest that majorities of most influent metals eventually pass through wetlands, although the relative insolubility of Pb increases its retention if loading is not excessive (Giblin 1985). Banus et al. (1975) also observed a strong effect of loading rate on Cd retention, which dropped from 80 percent at a dosage rate of 15 $mg/m^2/y$ to 35 percent at 43 $mg/m^2/y$.

Table 4-2

Ranges of metal accretion rates and percentages of incoming metals subsequently released from a number of saline and freshwater wetland studies (after Giblin 1985).

Metal	Accretion Rate ($mg/m^2/yr$)	Percentage Released
Cu	0.9 - 60	51 - 78
Cd	0.4 - 6.0	83 - 85
Cr	2.5 - 2.7	55
Mn	0.4 - 3,700	6 - 73
Fe	70 - 60,000	0 - 76
Pb	7 - 90	0 - 40
Zn	0.6 - 210	50 - 100

It is apparent that, if the objective is to increase metal retention in wetlands to promote their use in treating wastewater, more understanding of biogeochemical processes must be gained to develop management strategies. Giblin (1985) listed the following among the areas requiring research attention: 1) bed load movement; 2) the roles of storm flows and hydrologic fluctuations in metal cycling; 3) pore water chemistry; and 4) long-term interaction between nutrient and metal cycles. In the latter case she emphasized the effect of primary production, driven by nutrients, on pH and sediment redox potential, which in turn influence metal mobilization.

Mechanisms Affecting Organic Compounds

The transformations and fates of organic compounds in wetlands have received less attention than those of the metals. Principal mechanisms appear to be sedimentation, adsorption in sediments, plant uptake, and biodegradation (Clark and Clark 1979; Kadlec and Kadlec 1979). Residence time in the wetland has a substantial effect on, particularly, sedimentation and microbial decomposition processes (Clark and Clark 1979). Much of the specific knowledge of the fate of organics derives from extensive work on wetland wastewater treatment potential at West Germany's Max Planck Institute. For example, Seidel (1966) established that a *Scirpus lacustris* marsh was capable of reducing a variety of organic compounds (e.g., phenol, p-cresol, pyridine, aniline) to extinction in seven to fifty-two days. If excessive loadings are avoided, petroleum hydrocarbons also can be decomposed by wetland microbes. Pesticides represent a special case, because of their potential herbicidal quality and widely ranging degradability (Kadlec and Kadlec 1979).

Mechanisms Affecting Pathogens

The fate of pathogens in wetlands is determined primarily by sedimentation and rates of die-off. In a study of sources affecting sanitary conditions of water and shellfish in Minter Bay and Burley Lagoon (Puget Sound), Determan et al. (1985) noted a 52 percent decrease in rain-event fecal coliform loading as Minter Creek flowed through a swamp. They suggested that organisms settled out in the swamp but might still survive for long periods in the organic sediments and become entrained in the exiting flow later. The results of this study and others (Kadlec and Kadlec 1979) suggest that manipulating conditions to advance die-off is the key to preventing pathogen escape from wetlands.

Studies of Northwest Wetland Water Quality Functions

General State-of-the-Art

Comprehensive studies of Northwest wetland functions are scarce relative to those in other areas of the United States, especially the Upper Midwest and the Southeast. Nixon and Lee (1985) surveyed the studies on wetlands as sources, sinks, and transformers of N, P, and metals in seven U.S. Army Corps of Engineers regions. The Pacific coastal region, covering most of Washington, more than half of Oregon, and coastal California, has only 1.7 percent of U.S. wetlands. Fewer studies were located in this region than in any other, except the Desert Steppe area. None of the studies determined annual mass balances or fluxes at the sediment-water interface.

It is apparent that substantial research is needed to understand the functioning of Northwest wetlands and to guide their management in the coming years, during which time heightened development pressure is likely. This research could be guided by that completed elsewhere. If crucial differences in Northwest wetlands versus those elsewhere are recognized, some of the research effort could seek to confirm the applicability of conclusions reached elsewhere to this region. Such confirming studies are bound to be more efficient and less costly than those that start without a base of knowledge. The recent conference on Pacific Regional Wetland Functions considered the differences in regional wetlands and concluded that the following are important (Zedler et al. 1985):

- Drainage areas to West Coast wetlands are often smaller than on the East Coast; with some exceptions, the coastal plain is not as expansive.
- Soils in the region are often high in clay; partially because of relatively steep topography, substrates are often highly erosive.
- Precipitation varies more seasonally on the West Coast than east of the Rocky Mountains (although temperature seasonality is less pronounced than in much of the nation).
- Algae, particularly macroalgae, are prominent in coastal wetlands of the region.

Case Studies

An early Northwest study of wetland water quality functioning took advantage of the large releases of radioisotopes to the Columbia River by the Hanford nuclear weapons production activity. Renfro (1972) found that plants in a downstream riverine wetland took up Zn from river water, but that the isotope was swept away in the litter in the fall. Amphipods and perch inhabiting the wetland zone also assimilated Zn.

The most comprehensive functional study of a Northwest wetland yet completed was an investigation of primary production, detritus flux, and nutrient cycling in a Fraser River estuary (British Columbia) sedge marsh (Kistritz and Yesaki 1979). It was found that carbon and nutrients relocated from shoots to below-ground tissue during early senescence. Estimates were made of N and P translocation, root uptake, and leaching, the latter of which was identified to be a highly important process in nutrient cycling. Of the net annual detritus production, 38 percent was buried in sediments and the remainder was lost as dissolved and particulate organic matter.

Perdue et al. (1980) investigated the chemical and biological impact of the Klamath Marsh on the Williamson River, Oregon. Iron in suspended particulate matter weathered in the marsh yielded Fe-humus complexes, and the marsh was a source of amino acids and sugars. The humic-rich flow from the marsh ceased in the summer, and the flux of Fe and amino acids declined.

An Oregon coastal salt marsh has been the subject of several related studies. Gallagher and Kibby (1980) and Ragsdale and Thorhaug (1980) found some evidence that plants were mobilizing metals from the sediments and assisting their transport to adjacent waters. Gallagher et al. (1984) discovered that where marshes and seagrass beds meet in the estuarine zone, seagrass litter import to the marsh, and subsequent decomposition, block nutrient export to the ocean.

Herron et al. (1983) have performed nutrient and carbon budgeting work on a riverine marsh in the Bear Lake, Idaho, ecosystem. River flow through the marsh and then into the lake sometimes reverses. The marsh can be either a source or a sink for carbon and nutrients, depending on flow quantity and direction. Marsh periphyton were found to be important in nutrient cycling.

Bogs adjacent to Pine Lake (Pelletier 1985) and Liberty Lake (Funk et al. 1976), Washington, have been observed in connection with studies preliminary to lake restoration. In both situations the acidic bogs release P to the lakes and supply significant fractions of their P income.

Wetlands in the lower Coeur d'Alene River Valley, Idaho, have received massive sediment inflows from mining spoil banks in the Bunker Hill area over a 100-year period (R. Kreiger, Department of Veterinary Science, University of Idaho, Moscow, ID, personal communication). Wetland sediments contain 1,000 - 8,000 ppm of Pb (Kreiger et al. 1986). With several hundred swan deaths per year in the area, recent study has documented Pb tissue concentrations and specific sources. Sediments and horsetail ferns eaten by the swans are considered to be the most toxicologically significant sources.

Sampling Considerations

There seems to be general consensus in the scientific community that studies of wetland water quality functions should take a mass balance approach. To make such an approach effective, sampling programs must be carefully designed. Most basically, a number of system components must be monitored to determine mass fluxes. At a minimum these components should include water, sediments, and plants. In some instances other biotic components would also have to be sampled to obtain complete budget information.

Ideally, a continuous record would be kept of hydrologic, physical, and chemical events. Depending on inflow and outflow configurations, continuous flow gaging may be feasible. Almost certainly, continuous monitoring would not be feasible for most water quality constituents. Only temperature, pH, dissolved oxygen, specific conductivity, and salinity can be conveniently recorded continuously, although one's objectives may not warrant doing so. For many quantities, the strategies of composite sampling and stratified sampling can be applied to obtain the best possible record of water quality. In composite sampling, a number of samples are drawn over time into a single container. This technique sacrifices resolution for a more economically feasible cumulative record. Stratified sampling allocates effort with respect to actual temporal and spatial distributions of events of interest, rather than providing uniform coverage. This technique can reduce variances in the data, although the cost for an equal number of samples can be higher than for uniform sampling. Mar et al. (1986) recently covered these and other sampling considerations to improve the cost-effectiveness of environmental data acquisition.

Using Wetlands for Wastewater Treatment

Beginning more than 30 years ago at the Max Planck Institute, wetlands have been extensively investigated as sites for polishing municipal wastewater treatment plant effluents. More recently, their use for storing stormwater and improving its quality has received attention. These efforts have produced a very large literature, for which no attempt at a comprehensive review will be made here. Rather, this discussion will be restricted to a few summary points.

Experience has been gained with wetland wastewater treatment in a number of settings. Municipal effluents have been discharged for polishing to natural Michigan peatlands, Wisconsin cattail marshes, Louisiana and New Jersey tidal marshes, and Florida cypress domes and sawgrass (Sloey et al. 1978; Chan et al. 1982). Stormwater applications have been developed much less, but include a Minnesota peatland, Florida cypress wetland, California brackish marsh, and Lake Tahoe area wet meadow (Chan et al. 1982).

Wetland treatment examples are few in the Northwest. The City of Black Diamond, Washington, began discharging aerated lagoon effluent to a marsh in 1983. The marsh effluent has violated permit limitations on TSS, BOD, N, and P loadings, however, and the system is being redesigned (Beck and Associates, Inc. 1985). Cannon Beach, Oregon, opened an aerated/facultative lagoon and marsh treatment complex in 1984. The marsh is used only in the summer, when its natural inflow drops and the population of the resort community increases. The final effluent has met TSS and BOD standards during the two years of operation (Thompson and Minor 1985). A treatment system is currently being designed for Idaho City, Idaho, using an artificial wetland created years ago on dredge spoil (J. Nee, U.S. Fish and Wildlife Service, Boise, ID, personal communication.)

A large amount of data has been reported on the treatment efficiency afforded by wetlands. Table 4-3 summarizes some of these data. Substantial site-to-site variability is evident in the efficiencies. Despite the potential for nutrient releases discussed earlier, most systems reported efficient reduction of nutrient concentrations, especially of nitrogen. Negative efficiencies occurred in the cases of BOD, TSS, and total coliforms. Wetlands can generate these substances irrespective of inputs, making efficiency measures somewhat meaningless.

Studies of the effects of wastewater on wetlands are much scarcer than treatment efficiency reports. Uncertainties concerning these effects, particularly in the long term, and possible legal impediments to using natural wetlands for treatment, have stimulated consideration of artificial wetlands. The Max Planck Institute work led to the development of design strategies for artificial wetlands, and considerable experience with them has been gained in Europe and several locations in the United States (Chan et al. 1982). Artificial systems also offer the ability to design for specific objectives, operate with a high degree of control, and replace lost natural wetlands. Canning (1985) has summarized design principles pertinent to artificial wetlands receiving urban runoff in the Northwest. Sloey et al. (1978) presented numerous management strategies that could be applied to either natural or artificial wetlands to improve treatment performance.

Table 4-3

Typical results of tertiary treatment using freshwater wetlands (percentage removals based on concentration) (after Kadlec 1979).

Site	Loading Persons/ acre	Age (yrs)	BOD	Nitrogen NO_3^-	NH_4^+	TN	Total P	TSS	Coliforms Fecal	Total
Houghton Lake, MI	3	1	-	40	99	-	97[b]	-	-	-
Bellaire, MI	11	2	-	-	-	91[a]	97[b]	-	-	-
Mt. View, CA	1600	4	-19	54	39	-	3	-250	-	-
Hay River, N.W.T.	40	5	98	-	96	-	98	97	-	99
Wildwood, FL	6	20	-	99	99	90	98	-	99	-
Kincheloe, MI	15	20	-	95	98	-	-	-	-	-
Brillion, WI	7	55	80	51	-	-	13	29	-	86
Dundas, Ontario	-	59	30	83	96	88	87,98[b]	-47	66	-14
Great Meadows, MA	-	69	89	33	98	-	89	12	66	-1285

[a]Total dissolved nitrogen
[b]Total dissolved phosphorus

Conclusions

Interest in water quality and other wetland functions is growing rapidly at the present time. Fully understanding water quality functions requires detailed mass balance studies involving measurement of water flow and material fluxes to, from, and within wetlands. Among the various water quality constituents, nutrient cycles have been investigated most thoroughly. Results of nutrient and metal cycling studies indicate that wetlands accrete these quantities but do not, in general, serve as permanent sinks for all, or even the majority, of the influx.

Northwest wetlands have not received nearly as much study as those in certain other areas, but there is reason to believe that general conclusions formed elsewhere are also valid in this region. If the regional differences are taken into account, efficient confirming studies, based on the more complete record assembled elsewhere, could be conducted in the Northwest.

The fates of pollutants in wetlands have important implications for the effectiveness of wetlands in treating wastewater effluents and for the effects of wastes on wetland ecosystems. With full understanding of wetland processes and careful management based on this understanding, natural wetlands threatened with draining or filling could be used in storm drainage networks, instead of being lost to development. There is an even greater potential to design artificial wetlands for treatment on the basis of knowledge gained in studies of natural wetland functions.

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Carbon, Nitrogen, and Phosphorus Cycling in Pacific Northwest Wetlands

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Abstract

In this paper the available information on carbon (C), nitrogen (N), and phosphorus (P) cycling in Pacific Northwest wetlands is reviewed. The objectives include summarizing data on biogeochemical cycling of C, N, and P into a form useful to wetland managers, and identification of information gaps requiring further research. Major carbon fluxes include benthic primary production and exogenous sources (i.e., river and watershed inputs). A comparison of different Pacific Northwest wetlands demonstrates over 100-fold variations in total primary production between ecosystems, and the partitioning of that production among producer communities within wetlands of the region. Select studies reveal the importance of benthic plant- and microbiologically-mediated reactions involved in C, N, and P cycling within wetlands. Synthesis of information suggests relationships between primary production and phosphorus and nitrogen loading, and influences of water residence times. It also suggests how such functions can be integrated into management planning. Consumer trophic dynamics for these wetlands point toward the need to further delineate the pathways of benthic plant and microbe sources of carbon in consumer food webs. Other less detailed studies are cited for a variety of wetlands (i.e., freshwater marshes, riparian zones).

The available data for Pacific Northwest wetlands provide only limited insight into the functional aspects of carbon and nutrient pathways in these ecosystems. Information gaps are wide, indicating that research needs to be focused upon biogenic and chemical processes that are central to habitat and ecosystem maintenance. Detailed recommendations for research and management activities that will provide a better basis for understanding and managing the region's wetlands are described for the major biological, physical, and chemical functions.

Introduction

This paper reviews the state of our understanding of carbon, nitrogen and phosphorus (C, N, and P) cycling in Pacific Northwest wetlands. The objectives are to summarize information on biogeochemical cycling of C, N, and P in the region's freshwater and marine wetlands into a form useful to wetland managers, and to identify important questions on data gaps requiring further research. This synthesis of available information on the biogeochemistry of different wetlands in the Pacific Northwest, and of contrasting ecosystems of other temperate regions of North America, reveals the uncertainties in natural fluxes of C, N, and P.

In wetlands of the Pacific Northwest, as in other wetlands, limited knowledge of the biogeochemical cycles of C, N, and P almost precludes management that is sensitive to natural wetlands functions and to alterations induced by human activities. Research is needed on chemical and biological processes that affect the speciation of nutrients and their transfer within wetlands and to adjacent ecosystems. It should focus on how these processes are influenced by the morphologic and hydrodynamic properties of wetlands, and on how they may be altered in polluted ecosystems. This research is needed to provide baseline data for managers who must assess human influences. Detailed recommendations for future research and management planning are given at the end of this paper.

A major biogeochemical aspect of wetlands is the strong linkage of the carbon cycle to the N and P cycles (Morris et al. 1978; Naiman and Sibert 1979; Nixon and Pilson 1983). This cycling, which can also include sulfur and several other elements (Bolin and Cook 1983), is distinct from that in more open lakes and oceans. Wetlands are characterized not only by higher biomasses (i.e., seagrasses and marshes), but by short food webs, high turnover rates, and large transfers of organic matter and nutrients to the sediments. In turn, degradation of organic carbon in sediments plays an important role in recycling of nutrients that provides the basis for microbial, plant and animal production in wetlands (Figure 4-4A, 4-4B, and 4-4C).

Because of the biogeochemical features of C, N, and P, wetland ecosystems are not only highly productive, but also extremely sensitive to natural and human-induced disturbances. For example, increases in N and P in wetlands due to discharge by polluted rivers or other sources (i.e., groundwater and surface runoff) from heavily populated regions can lead to modification of plant production and composition, and of the capacity to cycle carbon and nutrients.

Overview of Primary Production and Carbon and Nutrient Cycling Studies

Primary production and the partitioning of that production among plant communities in wetlands are regulated to a large extent by nutrient inputs, hydrodynamics, solar radiation, and benthic substrate (Figures 4-4A, 4-4B, and 4-4C). Of these factors, nutrients have received considerable attention in the Pacific Northwest. Most of the available information concerns water quality in culturally eutrophic neritic plankton communities. Major studies of these systems can be grouped as follows: marine/estuarine ecosystems (Welch 1968, 1969; Winter et al. 1975; Stockner and Cliff 1979; Loehr and Collias 1980; Bell and Albright 1982; Albright 1983); and lake-stream ecosystems associated with wetlands, and riparian zones of forested watersheds (Luce 1974; Wissmar et al. 1977; Devol and Wissmar 1978; Welch et al. 1981; Jacoby et al. 1982; Wissmar et al. 1982; Pelletier 1985).

Almost all of the above studies deal with indices of carbon and nutrient cycling relative to planktonic production. In wetlands, however, the content and processing of carbon and nutrient in benthic habitats greatly exceed those in pelagic areas. For example, emergent and submergent plant production contributes most of the total primary production in wetland ecosystems (Naiman and Sibert 1978; Valiela et al. 1982; Long and Mason 1983; Thom 1984a, 1984b, in press). Available data on standing stocks and rates indicate that belowground plant components play the dominant role in exchanges of carbon and nutrients among plants, water, and sediments in Pacific Northwest wetlands (Phillips 1969, 1972; Eilers 1975; Disraeli and Fonda 1978; Kistritz and Yesaki 1979; Ewing 1982, 1983; Pregnall 1983; Seliskar and Gallagher 1983; Kistritz et al. 1983; Gallagher et al. 1984a, 1984b; Wissmar and Simenstad 1984a; Garber et al. 1985; Pelletier 1985). In summary, the majority of studies on Northwest wetlands have examined specific aspects of carbon, nitrogen, and phosphorus cycling, and minimal efforts have been made to place these details into the broader context of the morphologic, hydrologic, and biogeochemical systems.

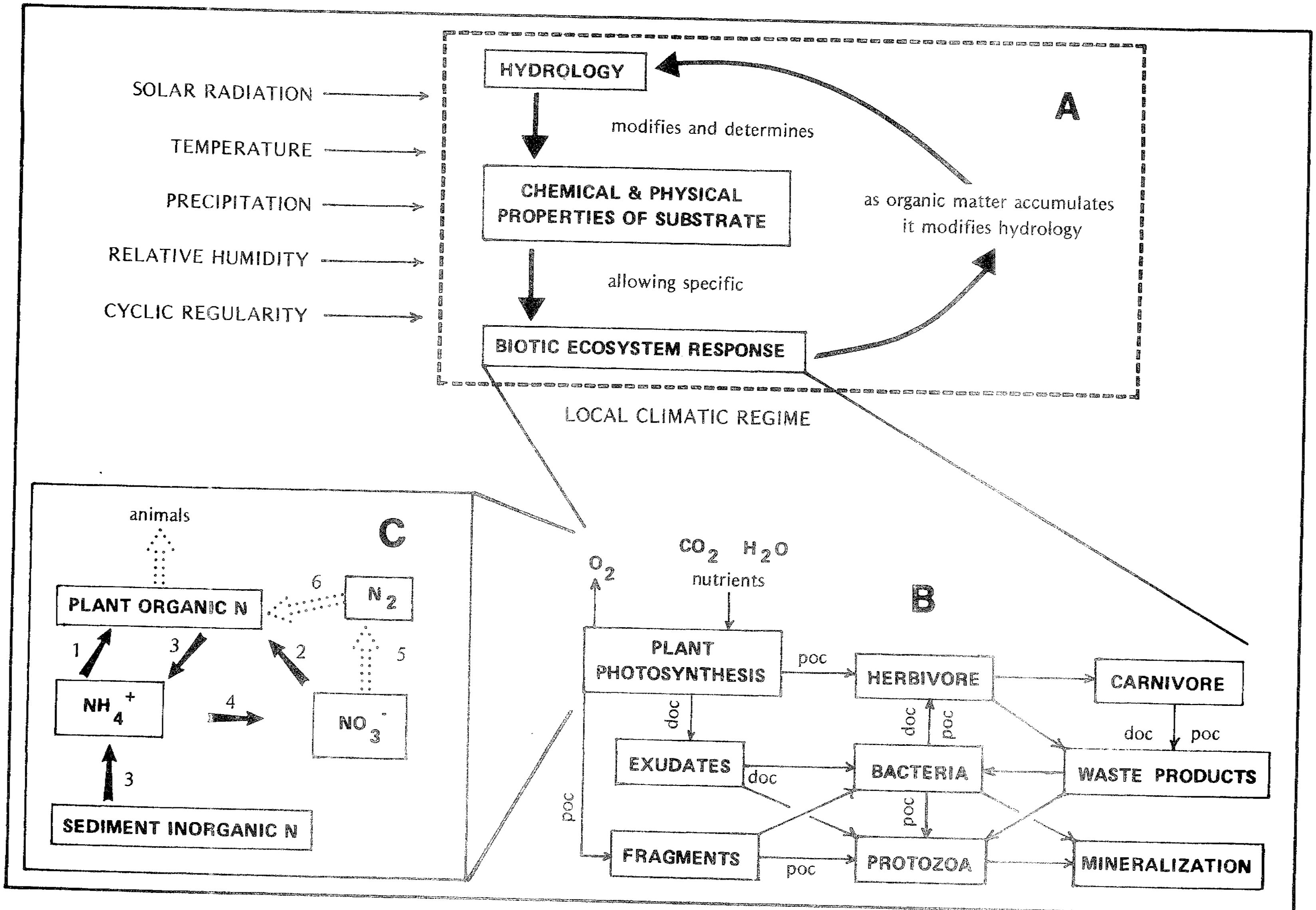

Figure 4-4. Conceptual models of hydrologic, physiochemical, and biotic interrelationships in wetland ecosystems. • (A) The role of hydrology in wetlands (after Gosselink and Turner 1978). • (B) The flow of organic carbon through wetland food webs. POC = particulate organic carbon and DOC = dissolved organic carbon (after Head 1976). • (C) Simplified example of nitrogen cycle depicting the fates of inorganic nitrogen species in wetland plants. Numbers 1 through 6 denote the following processes: 1) ammonium assimilation; 2) assimilatory nitrate reduction; 3) remineralization and release from sediments; 4) nitrification or ammonium oxidation; 5) dissimilatory nitrate reduction, i.e., denitrification; and 6) nitrogen fixation.

Table 4-4
Annual primary production rates (mgC/m²/yr) for different wetlands of the Pacific Northwest and representative wetland types of other temperate regions of North America.

Wetland Type	*Emergent* Marshes	*Submergent*** Macrophytes	Microalgae	Macroalgae	Phytoplankton	Total Production
Riverine/Estuarine						
Nanaimo, BC[a]	495	150	23	1	12	681
Grays Harbor[b]	4677	1209	124	2784	9	8803
Columbia[c]	390	-	33	-	55	478
Salt Marsh						
Great Sippewissett, MA[d]	1570	-	170	-	-	1740
Lake/Marsh						
Marion, BC[e]	-	32	43	-	5	80
*Lawrence, MI[e]	-	88	40	-	43	171
*Wingra, WI[e]	-	120	50	-	430	600
*Tundra Pond, AK[f]	96	-	8	-	1	105
*Bog, MN[g]	171	-	-	-	-	171

[a] Naiman and Sibert (1978), Vancouver Is., B.C.
[b] Thom (1984a, 1984b), WA
[c] Simenstad et al. (in press), WA and OR
[d] Valiela et al. (1982)
[e] Devol and Wissmar (1978)
[f] Hobbie (1984)
[g] Reader (1978)
* Representative wetland types in North America.
** Examples of macrophytes = sea grasses; microalgae = diatoms; macroalgae = *Enteromorpha.*

Comparison of Primary Production in Different Wetlands

Knowledge of primary production of plant communities in different wetlands can be extremely useful to managers involved in reclamation and mitigation projects. For example, spatial data on primary production rates of different communities can be essential in determining what types of plants might be transplanted to specific locations and whether existing wetlands may be suited for processing nutrient-laden wastes from human activities. A comparison of primary production in different Northwest wetlands, and of "representative wetland types" of other temperate regions of North America, shows the diversity of primary carbon sources in these ecosystems (Table 4-4). Total production varies over several orders of magnitude from 80 $gC/m^2/yr$ (Marion Lake, B.C.) to 8803 $gC/m^2/yr$ (Grays Harbor Estuary, WA). The importance of marsh primary production in both the Grays Harbor and Columbia River estuaries suggests that where reclamation and mitigation efforts are needed, they should be focused on marsh vegetation. The fact that the major portion of primary production occurs in marshes of the Columbia River estuary is of particular interest, given that only 22 percent of the original salt marsh habitats

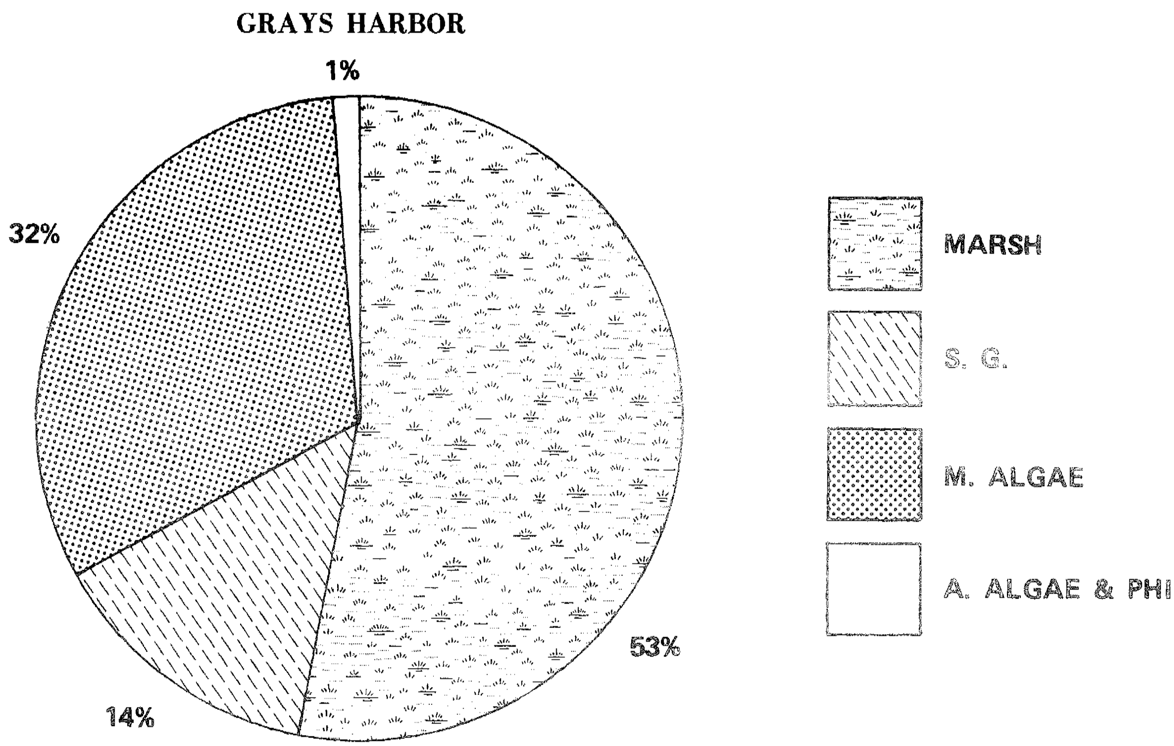

Figure 4-5. **Percentage of the total annual primary production rates attributed to different autotrophic components in Grays Harbor estuary, Washington. Data from Thom (1984a, 1984b).**

remain (Simenstad et al. 1984, in prep). The lack of seagrass production in the Columbia, compared to Grays Harbor, reflects the unstable riverine sediments that preclude the establishment of these plants.

In general, the comparison shows that a majority of the primary production in many wetlands occurs in benthic habitats (Table 4-4). Marshes account for 53 to 90 percent of the total primary production in the Nanaimo River, Grays Harbor, and Columbia River estuaries, compared to over 90 percent in tundra ponds of Alaska and bogs in Michigan. Seagrass and benthic macroalgal production in estuaries also appeared important. For example, these plants accounted for 45 percent of the total production in Grays Harbor (Figure 4-5; Thom 1984a, 1984b). Factors that might promote more vigorous seagrass and macroalgal growth in Grays Harbor than in the Columbia estuary include: more stable mud-sand sediments; shallower water depths and the resulting increased frequency of solar input to bottom sediments; and higher salinities (Shellem and Josselyn 1982) and higher tidal exchange rates. The influence of shallow depths on primary production is illustrated in the freshwater ecosystems of Marion and Lawrence lakes, where submergent macrophytes and attached algae contribute over 85 percent of total production. In summary, benthic primary production in these wetlands appears related to overriding influences of benthic morphology and processes involving sedimentology, hydrodynamics, and nutrient cycling.

Table 4-5
Comparison of major riverine and estuarine carbon sources and losses (gC/m²/yr) for the Nanaimo River (B.C.) and Columbia River (WA-OR) estuaries. DOC = dissolved organic carbon; POC = particulate organic carbon.*

Source	Nanaimo River Estuary	Columbia River Estuary
Riverine Inputs		
DOC	1960	~6706
POC	57	~817
Phytoplankton	-	~313
Total Input	*2017*	*~7836*
Estuarine Inputs		
Submergent/Emergent Plants	669	423
Phytoplankton	12	55
Total Input	*681*	*478*
Export		
DOC	-	~7260
POC	-	~885
Phytoplankton	-	~110
Total Export	-	*~8255*

*Data sources include Naiman and Sibert (1978) for the Nanaimo River estuary, and Neal (1972), Dahm et al. (1981), Hamilton (1984), Simenstad et al. (in press), and Jay et al. (in prep.) for the Columbia River estuary.

Riverine Carbon Inputs and Primary Production in Estuaries

The importance of riverine inputs in the carbon budgets of Pacific Northwest estuaries is evident in data from the Nanaimo and Columbia River estuaries (Table 4-5). Carbon inputs from rivers ranged from three- to sixteen-fold greater than total primary production (Naiman and Sibert 1978; Dahm et al. 1981; Simenstad et al. in prep.). The major fraction of riverine carbon consists of dissolved organic carbon (DOC) rather than particulate organic carbon (POC); DOC to POC ratios in the two estuaries were thirty-four and six, respectively. Although DOC and POC inputs from rivers exceeded carbon inputs from primary production, the amounts of carbon transferred to sediments, exported to the ocean, and used in food webs remain in question. The fate of carbon inputs in estuaries needs to be defined to better understand the impact of additional carbon loadings from cultural activities. Such uncertainties indicate that to properly manage estuaries, researchers and management agencies need to construct models of carbon budgets that can be used to estimate not only inputs from rivers but also the capacity of the ecosystems to biologically and chemically process carbon and nutrients.

An important topic needing further research is the importance of DOC in the trophic dynamics of estuaries. For instance, in the Columbia River high phytoplankton biomass appears to be caused by nutrient runoff from irrigation and fertilization of agricultural areas. Wissmar and Simenstad (1984a) suggested that a decline in chlorophyll *a* and an increase in DOC concentrations results from plasmolysis of riverine phytoplankton cells when they contact saline waters in the Columbia River estuary. Similar conditions have been noted in estuaries where DOC releases by freshwater phytoplankton enhance microbial activities, which in turn cause oxygen depletion and anaerobic biogeochemical reactions common to polluted waters (Morris et al. 1978).

Nitrogen and Phosphorus Loading, Water Residence Times, and Primary Production

In addition to the need for further research on carbon and nutrient loadings to wetlands, information is needed on the relationships of these fluxes to water residence times and primary production. Variations in N and P loadings from rivers and watersheds, and water residence times in different wetlands, are shown in Table 4-6. Total phosphorus loadings ranged from 0.01 $g/m^2/yr$ in tundra ponds to about 11.2 $g/m^2/yr$ in Marion Lake, while nitrogen loadings ranged from 0.04 $g/m^2/yr$ in a bog (Minn.) to 249 $g/m^2/yr$ for the Great Sippewissett Marsh, Mass. Both P and N nutrient loading rates generally increased with shorter residence times. Residence times, which reflect the rate of removal or flushing of water per ecosystem water volume, varied from approximately <365 days in Dingle Marsh (S. Idaho) to only 1.5 days in the Nanaimo River estuary (Vancouver Island, B.C.).

Nitrogen to phosphorus loading ratios for wetlands are useful to researchers and managers because they suggest potential nutrient limiting situations in these wetlands. In general, low N:P ratios of saline waters provide evidence of N limitation, compared to high ratios in freshwater where P is usually limiting (Devol and Wissmar 1978; Nixon and Pilson 1983). In this review N:P loading ratios varied from less than four (in a Minnesota Bog and in Dingle Marsh) to 44 (in Lawrence Lake, Mich.) (Table 4-6). In summary, nutrient loading rates and N:P ratios imply P limitation in lakes and marshes; N and P limitation in freshwater marsh, bog, and tundra pond ecosystems; and no apparent nutrient shortages in estuarine wetlands.

The possible influence of both residence times and nutrient loadings on primary production in wetlands can be examined by plotting total production per unit of phosphorus loading versus residence time (Figure 4-6). For ecosystems with long residence times (slow removal of water and dissolved nutrients), primary production apparently increases because of longer plant exposure to available nutrients. In general, such relationships for both N and P loadings suggest that more organic carbon cycles per year per unit of nutrient loading when waters of aquatic ecosystems have longer residence times. In summary, this brief synthesis of the available data demonstrates how nutrient loadings and water residence times influence wetland primary production. This type of information needs to be extended to a variety of wetlands so that managers can make better decisions when faced with plant production, nutrient and hydrologic questions.

C, N, and P Cycling Within Wetlands

Although the above primary production, nutrient loading, and residence time relationships are useful for comparisons of different lake/marsh and riverine/estuarine wetlands, they do not account for influences of storage and recycling of nutrients within wetlands. A major feature of wetlands is that P and N concentrations in sediments and belowground biomass are usually several-fold higher than levels in the overlying waters and aboveground plant tissues (Good et al. 1978; Valiela 1983). These features, along with microbial processing of carbon, nitrogen and phosphorus, support highly productive food

Table 4-6

Select physical, nutrient, and biotic functional characteristics of different wetlands in the Pacific Northwest and representative wetland types of other regions of North America. α = Residence time (days), the rate of removal or flushing of water per wetland water by volume. P = phosphorus loadings and N = nitrogen loadings, ($g/m^2/yr$); N:P = loading ratio. TP:P, TP:N = ratio of total primary production (Table 4-4) to P and N loadings.

Source	α	P	N	N:P	TP:P	TP:N
Riverine/Estuarine						
Nanaimo[a]	~1.50	2.1	12.7	6	324	54
Columbia[b]	~1.50	2.1	41.5	20	228	12
Grays Harbor[c]	~1.94	-	-	-	-	-
Salt Marsh						
Great Sippewissett, MA[d]	~1.80	-	249	-	-	7
Lake/Marsh						
Marion, BC[e]	4.80	11.2	-	-	8	-
Pine, WA[f]	183	0.4	-	-	-	-
Dingle, ID[g]	>365	0.1	0.4	4	-	-
*Lawrence, MI[e]	281	0.1	4.4	44	1710	39
*Wingra, WI[e]	174	1.0	24	24	600	25
*Tundra Pond, AK[h]	>365	0.01	0.06	6	10500	1750
*Bog, MN[i]	<365	0.03	0.04	1	5700	4275

a Naiman and Sibert (1978).
[b] Dahm et al. (1981).
[c] Duxbury (1979).
[d] Valiela et al. (1982), flushing by groundwater seepage and tidal exchange.
[e] Devol and Wissmar (1978).
[f] Pelletier (1985).
[g] Herron (1985, in press).
[h] Hobbie (1984).
[i] Richardson et al. (1978). Residence times for the Nanaimo, Columbia, and Grays Harbor estuaries derived from relationships of Duxbury (1979) and Neal (1972). Total P and N loadings were estimated from a C:N loading ratio of 10 and an inorganic N:P loading ratio of 20 (Park et al. 1972; Dahm et al. 1981).

webs for numerous animals. The following studies on both estuarine and freshwater wetlands indicate that managers need to integrate information about benthic C, N, and P cycles into management plans.

Estuarine Wetlands

The variety of nutrient cycling pathways that can occur in subtidal wetlands was highlighted in studies of the role of seagrass beds (*Zostera marina*) in cycling P and N (McRoy et al. (1972); Gallagher et al. 1984a, 1984b). Seagrasses were shown to absorb over 0.10 $gP/m^2/day$ from sediments, assimilate 0.10 in the production of seagrass, and excrete 0.06 into the water (McRoy et al. 1972). Sedimentation of detritus in the seagrass beds appeared rapid and presumably resulted in rather intense local recycling and flux of

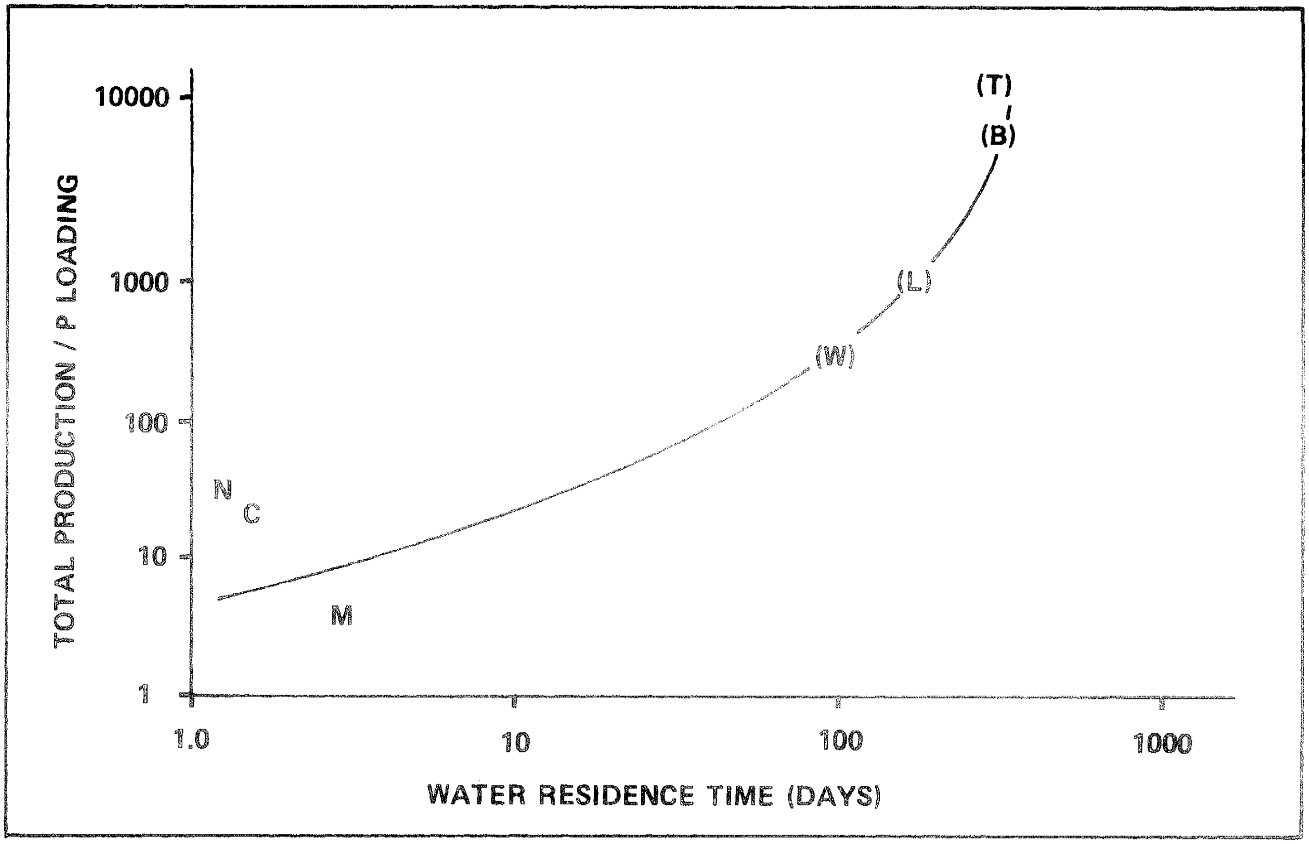

Figure 4-6. **Total primary production divided by phosphorus loading versus water residence times (days) for different wetlands. N = Nanaimo River Estuary (BC); C = Columbia River Estuary (WA-OR); M = Marion Lake (BC); W = Lake Wingra (WI); L = Lawrence Lake (MI); B = bog (MN); and T = tundra ponds (AK). (Data sources same as Table 4-6).**

P to other components of the system. Gallagher et al. (1984a, 1984b) showed that export of seagrass detritus to adjoining habitats also can be important. Their studies suggested that annual release rates of P and N from decomposing *Zostera* litter in a small Oregon estuary (Netarts Bay) of 0.04 to 0.13 $gP/m^2/yr$ and 0.40 to 1.10 $gN/m^2/yr$ were important to the growth of marsh plants.

Similar patterns of cycling of P and N were shown for sedge (*Carex lyngbyei*) marshes in the Fraser River estuary by Kistritz et al. (1983). As in east coast *Spartina* marshes (Valiela 1983), most of the biomnass of emergent plants exists below ground (about four times that above ground) where the principal nutrient cycling occurs. During the growing season, belowground uptake rates of 0.03 $gP/m^2/day$ and 0.10 $gN/m^2/day$ were followed by upward translocation of 0.02 $gP/m^2/day$ and 0.11 $gN/m^2/day$. Aboveground nutrient losses by leaching for the growing season were 66 percent (P) and 31 percent (N) of the peak aboveground standing stock of P and N. Tidal transport of leachates and detritus from the marsh appeared important to microbial activity and food webs in the estuary. Detritus, in which nutrients accumulated during the winter, appeared to provide a relatively constant and nutritious food source for much of the year. Large belowground reserves and rapid nutrient recycling rates also appeared to function effectively in regulating and conserving exogenous nutrient inputs.

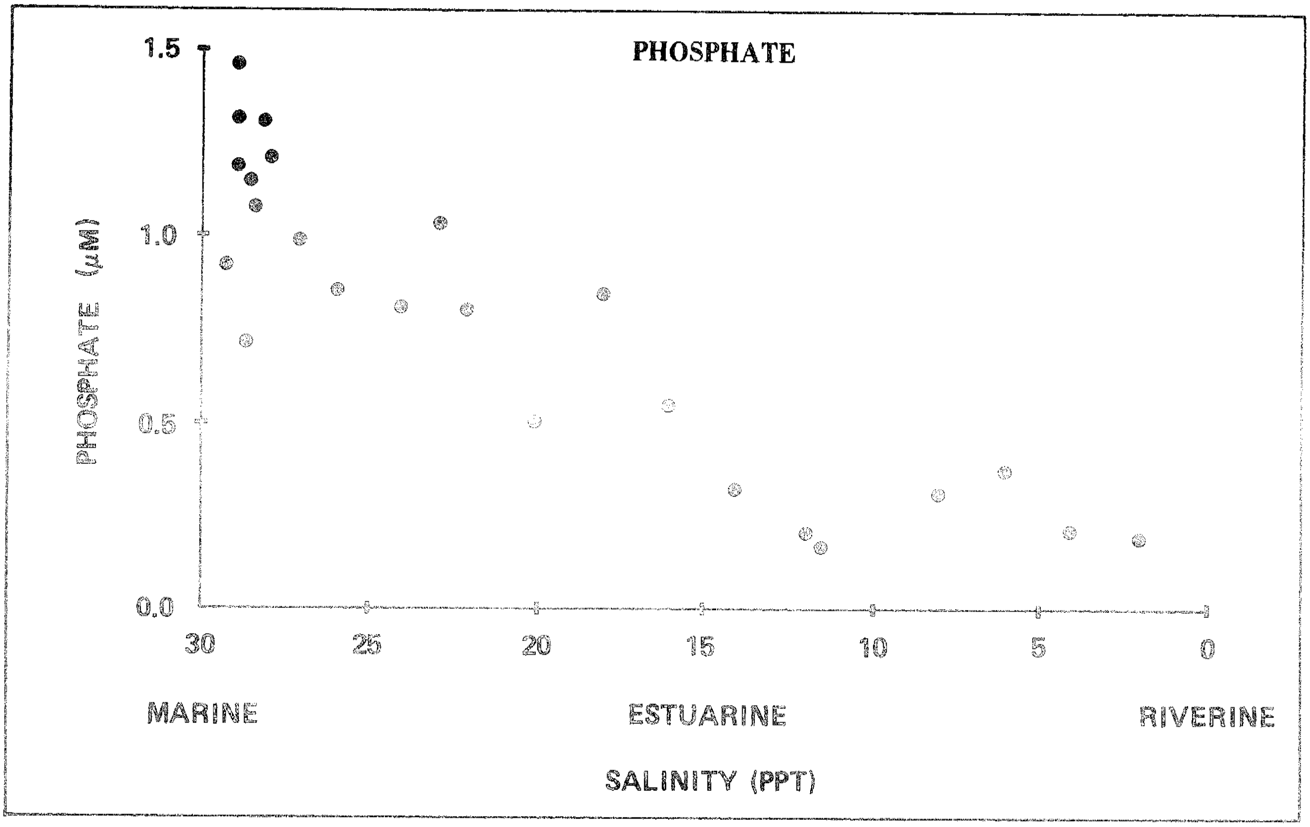

Figure 4-7. **Relationship between phosphate concentrations (micromolar) and salinity (parts per thousand) in Willapa Bay, WA. Representative summer conditions (Steve Hager, U.S.G.S., Menlo Park, CA, personal communication).**

The importance of benthic macroalgae in cycling P and N in Northwest estuaries has been shown by Garber et al. (1985). Comparisons of P and N sources and sinks in the Yaquina River estuary during the growing season indicate that macroalgae (*Ulva* and *Enteromorpha*) could remove from 0.4 to 58 times the amount of nitrate, and from 0.23 to 218 times the amount of phosphate supplied to the estuary by river discharge and sediment remineralization. However, the peak microalgal abundance of the summer-fall period was out of phase with high riverine inputs of nitrate during the winter and spring. Furthermore, N fluxes from sediments were low in comparison to what would be expected at the measured rates of oxygen fluxes. Nitrogen losses due to microbial denitrification appeared to be a likely mechanism for the loss of fixed nitrogen. P input to the estuary appeared regulated by temperature-dependent flux of remineralized phosphate from sediments.

Many of the above benthic influences on nutrient concentrations in estuarine habitats (i.e., seagrass and benthic algal beds, and marshes) can be evaluated by plotting water quality constituents against salinity. Examples are given for typical summer concentrations for P and N species in Willapa Bay, a large coastal estuary in Washington (Steve Hager, U.S.G.S., Menlo Park, CA, personal communication; Figure 4-7). The shapes of the curves suggest that phosphate originates in more saline portions of the estuary. Phosphate concentrations increase because of possible release from seagrass beds (McRoy et al. 1972) and sediments (Garber et al. 1985). Sources of inorganic nitrogen include

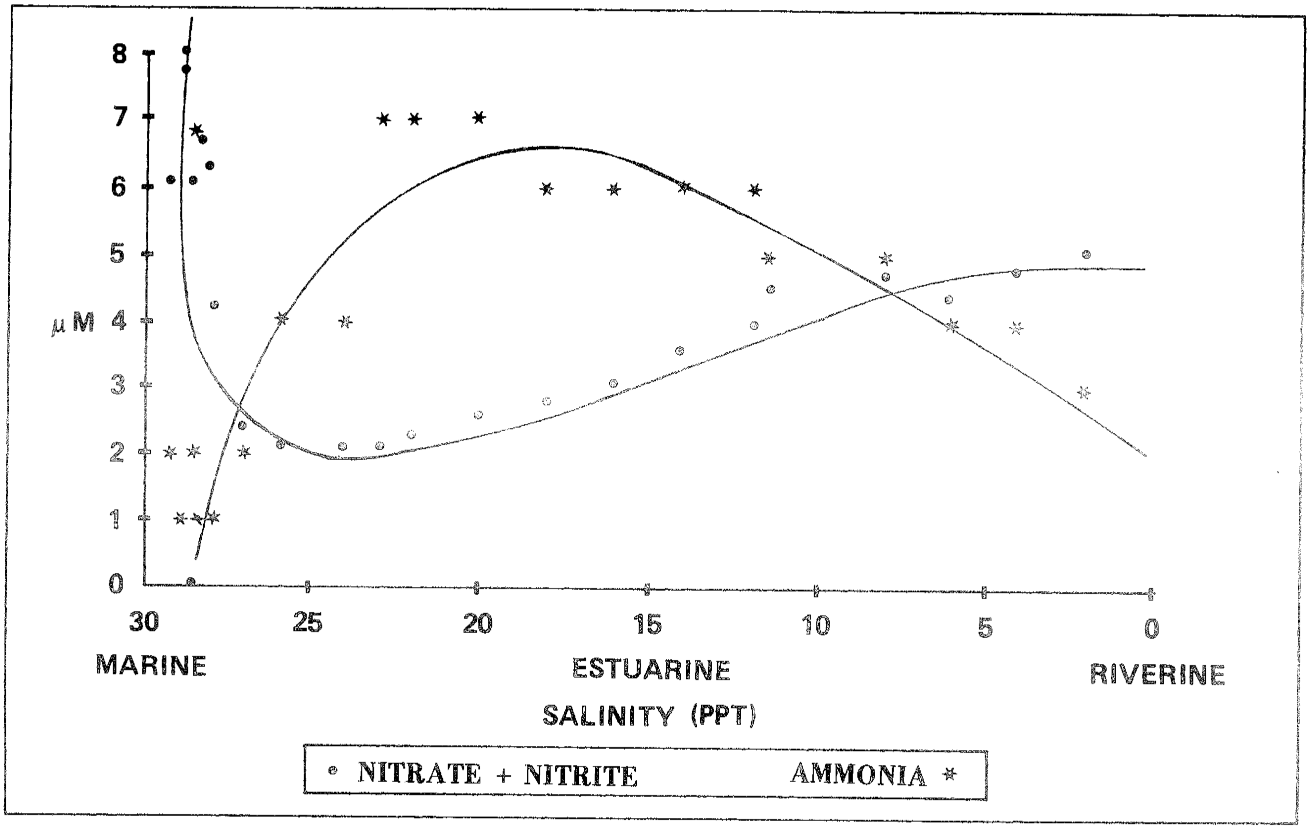

Figure 4-8. **Relationships between nitrate + nitrite and ammonia concentrations (micromolar) and salinity (parts per thousand) in Willapa Bay, WA. Representative summer conditions (Steve Hager, personal communication).**

nitrate from river inflows and release of ammonium via possible ammonification and animal excretion (Nixon and Pilson 1983) in estuarine sediments (Figure 4-8). Declining nitrate concentrations in more saline waters suggest dilution by marine waters and considerable biotic activity. Biotic uses of nitrate usually relate to uptake (i.e., algae and bacteria) and reduction via bacterially-mediated denitrification (Nixon and Pilson 1983; Garber et al. 1985).

Freshwater Wetlands

In contrast to estuaries and salt marshes of the Northwest region, carbon, phosphorus, and nitrogen cycles in freshwater marshes have had little study. The most intensive study to date has been done on the Dingle Marsh of southern Idaho, where nutrient mass balance studies show considerable variability among seasons (Herron 1985). Herron concluded that seasonal variability of nutrient cycling in such wetlands can be attributed to several factors, primarily: 1) timing and duration of water renewal; 2) sediment and water nutrient concentrations; 3) anaerobic conditions; 4) duration of ice cover; 5) death of vegetation; and 6) the length of the growing season.

An important finding of the Dingle Marsh study (Herron 1985) was that the annual P loading rate (0.30 gP/m^2) exceeded annual P retention (0.10 gP/m^2). Similar patterns were evident for annual N loadings (0.30 gN/m^2), with 0.17 gN/m^2 being used by plants and microbes or lost via bacterial denitrification. Nutrient export from the marsh appeared minor considering the long residence time of water in the wetland (Table 4-6).

An important aspect of these findings was that the daily nutrient recycling rates were equivalent to the annual loading rates. High recycling rates have considerable importance if freshwater marshes must be used for such purposes as water diversion and waste disposal. For example, if marsh production is adequately sustained by internal recycling of nutrients, increases in nutrient loading caused by human activities may alter the nutrient balance in these poorly flushed ecosystems. Such increased nutrient loadings could accelerate biochemical oxidation and reduction processes (i.e., oxidation of ammonia, reduction of nitrate, and loss of oxygen).

Additional information exists for specific aspects of carbon and nutrient processes in an array of Northwest freshwater wetlands, and it includes:

- biological and chemical influences of a marsh on an Oregon river (Perdue et al. 1980);
- macrophytes and nutrient cycles in small urban marsh-lake ecosystems of western Washington (Welch et al. 1979; Boston 1980; Boston et al. 1980; Boston and Perkins in press; Gabrielson 1978; Gabrielson et al. 1984; Pelletier 1985);
- marsh inputs of nutrients to a large oligotrophic lake in southern Idaho (Lamarra et al. 1983; Herron et al. 1984);
- classifications of Rocky Mountain-Great Basin marshes and bogs (Sturges 1967; Herron in press; Cooper in press; Foster in press; and Windell in press);
- mechanisms influencing salinity in marshes near Great Salt Lake (Kadlec 1982);
- carbon and nutrient cycling in mountain lake-stream riparian zones (Wissmar et al. 1977; Richey and Wissmar 1979; Triska et al. 1984; Corbett and Lynch 1985; Rhodes et al. 1985).

In summary, all the above studies on both estuarine and freshwater wetlands in the Pacific Northwest indicate that managers need to integrate information about benthic C, N, and P cycles into management plans. Furthermore, such benthic studies, along with measurements of primary production, carbon and nutrient loading, and hydrologic properties need to be coordinated with modeling efforts so that predictions can be made of wetland responses to natural and unnatural environmental changes.

Patterns of Carbon Cycling in Food Webs

The above studies provide dramatic examples of the importance of, and the need for information about, benthic biological processes in wetlands. Another benthic component that needs further research is the role of microbes (bacteria, algae, and fungi) in food webs. While some information is available about the role of such biota as remineralizers in converting organic matter to inorganics for use by primary producers (McRoy et al. 1972; Kistritz et al. 1983; Garber et al. 1985), little is known of the role as food resources for animals.

Most information on the role of microbes in food webs pertains to intertidal algal-seagrass, mud and sand-flat habitats in coastal estuaries in Washington and Oregon (Pamatmat 1968; Sibert et al. 1977; Wissmar and Simenstad 1984b; Simenstad and Wissmar 1985). These habitats are highly conditioned by physical (hydrodynamic and sedimentary) and biotic processing of organic and inorganic matter (Andrews 1965; Clifton and Phillips 1980; Kentula 1982; McIntire et al. 1983; Pregnall 1983; Davis and McIntire 1983; Gallagher et al. 1983; Wissmar and Simenstad 1984b; Garber et al. 1985).

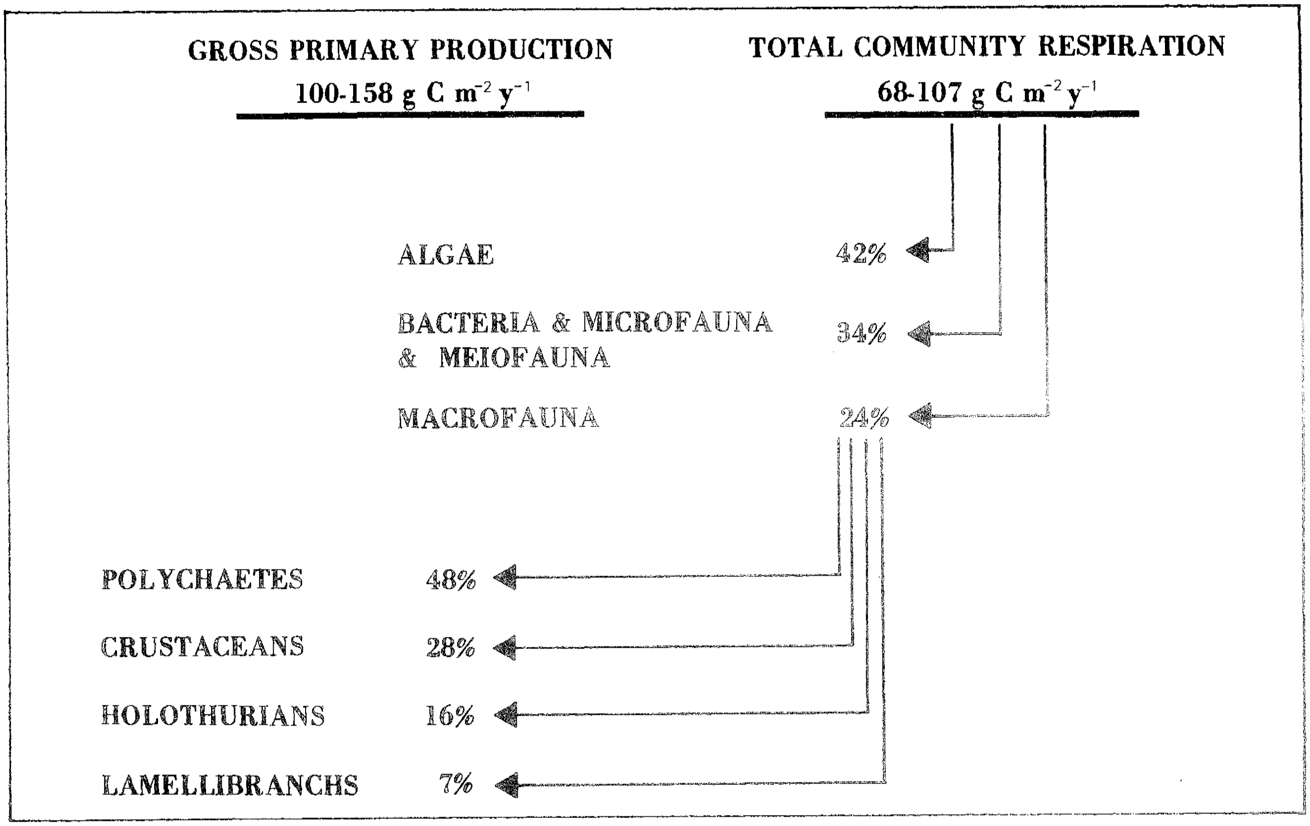

Figure 4-9. **Annual primary production, total respiration, and respiratory components of an epibenthic sandflat community, False Bay, San Juan Island, WA. (Data from Pamatmat 1968).**

A detailed study in False Bay, San Juan Island (WA) by Pamatmat (1968) demonstrated the importance of the microbe and consumer trophic pathways in epibenthic communities in an intertidal sandflat. Annual community respiration was estimated at 69 to 107 $gC/m^2/yr$, or 68 percent of the gross primary production (Figure 4-9). Of the total community respiration under submerged conditions, 42 percent was microalgal ("diatoms"), 34 percent bacterial + microfaunal + meiofaunal, and 24 percent macrofaunal. When the community was exposed at low tides, 30 to 51 percent of the respiratory processes were attributed to chemical oxidation of reduced substances.

Patterns of consumer uses of microbial food resources have been examined by stable carbon isotopic mapping of food webs in Hood Canal, Washington (Simenstad and Wissmar 1985; Figure 4-10). Seasonal isotopic ratios or compositions (^{13}C:^{12}C, or $\delta^{13}C$) of most epibenthic consumers in estuarine habitats (-10 to -22 for copepods, bivalves, and juvenile salmon) indicated that the major carbon sources were estuarine seagrasses, microalgae, and macroalgae (-8 to -22). Of minimal importance as food resources were mineralized carbon of sediments (-19 to -27), marine phytoplankton, and salt marsh and riverine-terrestrial carbon (-22 to -27). These stable isotopic studies and radioisotopic tracer experiments of Sibert et al. (1977) suggest the microbial-algal-epibenthic crustacean trophic pathways are extremely important to juvenile salmonids in the region's estuaries. Additional findings by Wissmar and Simenstad (1984b) and Simenstad and Wissmar (1985) for littoral habitats of a Puget Sound estuary further confirmed the existence of a

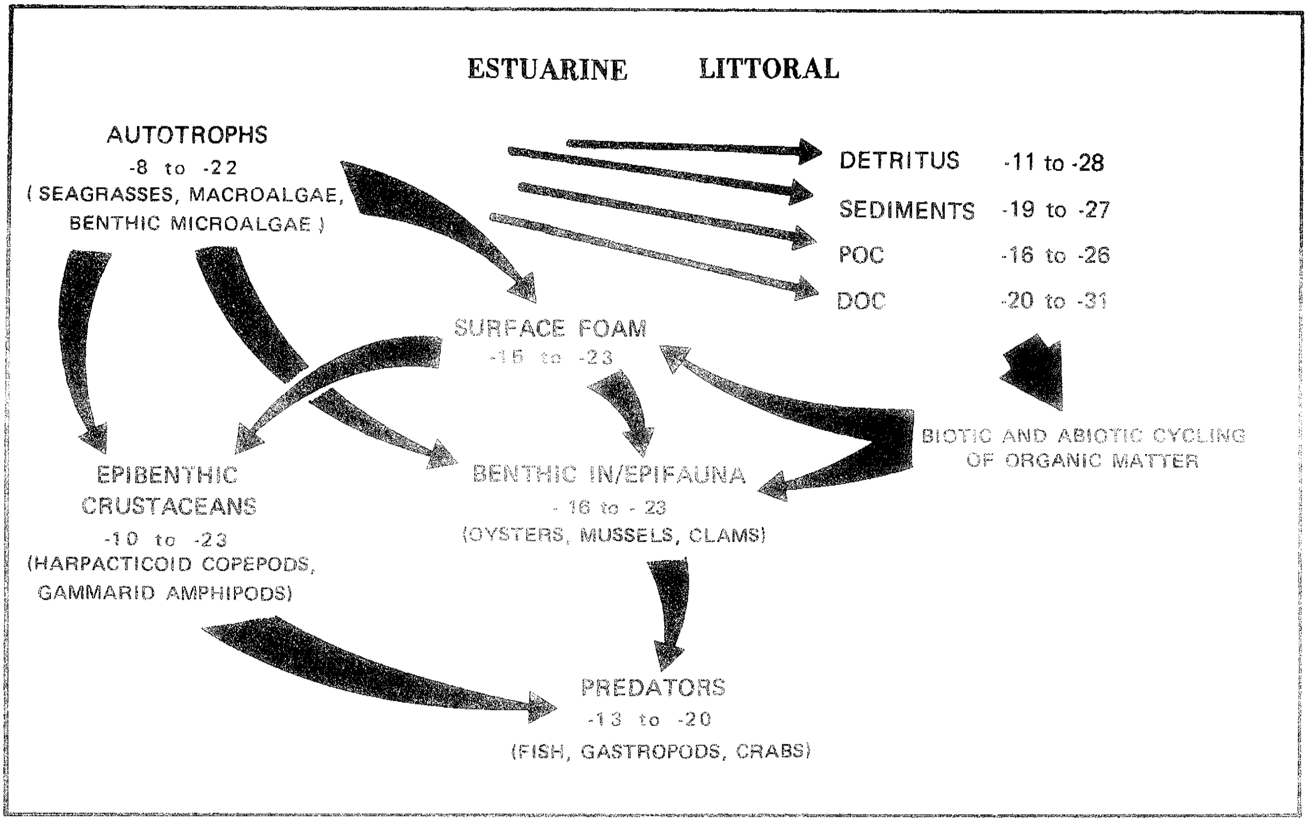

Figure 4-10. **Stable carbon isotopic evidence of the origins and fates of organic carbon in estuarine food webs in Puget Sound. Numbers refer to ^{13}C:^{12}C ratios. More negative values indicate depletion in ^{13}C isotopic content relative to ^{12}C. (Data from Wissmar and Simenstad 1984b, and Simenstad and Wissmar 1985.)**

dynamic epibenthic food web in which economically important consumers (i.e., mussels and oysters) use microalgae (Figure 4-10). Other studies measuring the natural abundance of stable carbon isotopes (Fry 1984; Fry and Sheer 1984) in seagrass habitats support these findings.

Recommendations for Future Research and Management Planning

Our knowledge concerning carbon and nutrient dynamics in wetlands of the Pacific Northwest is minimal compared to information about midwest freshwater ecosystems (Good et al. 1978) and East Coast estuaries (Nixon and Pilson 1983). For example, there are few studies on influences of morphometric and hydrologic properties, or on the seasonality of plant community production, nutrient recycling, or carbon use in a given wetland. From a management perspective, information is needed that will integrate these wetland functions into habitat and ecosystem perspectives. A major priority for future research and management planning should be focused upon understanding the role of benthic environments in cycling carbon and nutrients, and on how these features change in wetlands that are manipulated (i.e., by waste disposal), reclaimed, and constructed. Such benthic studies, along with other measurements such as primary production, carbon and nutrient loadings, and hydrologic properties, need to be coordinated with modeling efforts so that predictions can be made of wetland responses to natural and unnatural environmental changes.

Accompanying recommendations for future research and management planning include the needs:

- to define the ecological role of dissolved organic carbon (DOC) compounds, specifically the determination of which fractions (i.e., urea, amino acids) are useful to microorganisms.
- to define the importance of microbes as a food resource in food webs of animals.
- for additional information on the role of seasonal and temporal nutrient exchanges among plant components (above/belowground tissues) and possible losses (i.e., leaching) in the functioning of wetland plant communities.
- to define nutrient exchanges in surface sediments. (Specifically, the role of macrofauna through excretion and bioturbation).
- for nutrient inputs and outputs to be evaluated by putting increased emphasis on hydrology. Such information should include precipitation and rates of surface and groundwater flows.
- for management to make more extensive use of water quality data to document temporal and spatial sources and sinks of nutrients in wetland habitats. Such data can be used to evaluate relationships between dissolved nutrients and an index of conservative mixing (i.e., salinity). Consideration should be given to establishing salinity transects across major wetland habitats.
- for managers and researchers to develop a "biogeochemical concept of wetlands" because of the major importance of biological cycling of organic matter and nutrients in benthic environments. Considerable attention needs to be given to microbial, plant and animal activity in the cycling of C, N, and P. For instance, we need to determine the importance of denitrification in losses of nitrogen from wetlands.
- for research activities to be coupled to management questions by conducting manipulation studies at two levels: ecosystem and process. For example, ecosystem manipulations in mesocosms (with controls) are needed to better understand responses of community primary production to fertilization and influences of consumer populations. Smaller-scale process studies might include assessment of the effects of environmental factors — for example, influences of water renewal and inundation times upon benthic nutrient exchanges, activities of microbial and primary producer communities, and use by consumers.
- for government agencies, university, and private parties to designate **Intensive Study Sites** for wetlands where interdisciplinary research activities will provide a basis for acquiring background data pertinent to management questions and future research directions.
- to provide for **long-term sampling** of Intensive Study Sites. Long-term sampling will provide high quality data useful in identification of significant environmental shifts or perturbations in ecosystem dynamics.

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Working Group Report: Water Quality and Carbon and Nutrient Cycling

Richard Horner and Robert Wissmar, Moderators
Don Nichols, Rapporteur

"Trying to bridge the gap between ecology and bureaucracy."

Review of Plenary Papers

Group members felt that the plenary papers should have evaluated differences between wetlands in the Northwest and elsewhere with regard to such factors as photoperiod, insolation, temperature, and precipitation. They also suggested a discussion of sampling considerations, including spatial and temporal stratification of sampling (for example, sampling by sediment and habitat types), and a need for long-term and intensive study sites. The group suggested greater emphasis on the budget (mass balance) approach for both water and water quality constituents, and on the use of tracers that are less labile than nutrients (for example, conservative elements such as chlorine). They also would emphasize the importance of hydrology, and the need for baseline information on detrital food chains in most wetlands.

Discussion of Matrix

The group agreed that functional ratings were hard to arrive at because each wetland type has unique sets of system- and subsystem-level processes that operate on different time scales. Functional designations could be subdivided to permit more specific access to literature. For example, Biochemical Processing could be divided into cycling of carbon, of nitrogen and phosphorus, and of other dominant elements such as sulfur.

Definitions of wetland types also could be clarified, especially for freshwater impounded, riparian, and possibly mid-montane zones. (Does freshwater impounded include open water, for example?) New definitions should use objective qualifiers. For example, the mean depth of the euphotic zone during the growing season should be used to establish the limits of submergent plant growth in freshwater marshes and floodplains. Substrate should be more precisely defined by organic matter composition and particle size. Numerical ratings should be given specific meanings in specific wetland types, with examples, so that all respondents have a common basis for evaluating them. The group also wanted the geographic limitation removed so that pertinent national and global references could be cited in the matrix. Citations from outside the Northwest could be accompanied by a rating of their applicability to this area.

Discussion Questions

Outside or Site-specific Limiting Factors

Additional qualifiers for defining wetland types include accretion and sedimentation rates; age and successional stage; euphotic zone depth; geomorphology (e.g., area/depth ratio); and hydrological properties such as flushing rates. Some indicator of sensitivity or resiliency of systems would be desirable.

Also included in defining functional performance should be input, accumulation, and retention of organic matter and microbes; import and export of nutrients; and chemically and biologically mediated changes in wetlands. Presence or absence of certain functions such as denitrification should be indicated. Biological filtration occurs as well as physical filtration.

Interdependence of Functions

All of the major elemental cycles are tightly coupled and interdependent. The role of microflora and microfauna in water quality and chemical cycling functions may be underrated.

Additional Functions

Several water quality-related functions not represented in the matrix are important in wetlands: aesthetic and educational functions; public health functions (i.e., control of microbial contamination); functions as objects for scientific study; and the trend toward using wetlands for wastewater treatment, especially for stormwater runoff. The effects of the latter use on wetlands are poorly known, and it is difficult to purify wastewater before it enters wetlands.

Data Gaps and Research Needs

There are deficiencies in several sorts of water quality and chemistry data in Northwest wetlands. Data on ecosystem structure, and on abiotic (physical and chemical) and biotic processes are sparse. The lack of data is most severe for the remote wetlands, including mid-montane, alpine, and subalpine systems. There are no good physical filtration data indicated in the matrix for any wetland type, but it is known that some exist. The extent to which a wetland can be modified and still function is uncertain. The limitations on organic and nutrient loading, and the thresholds of responses to those loadings, are unknown. Wetlands can mineralize organic matter, but the point at which they are overloaded and become anoxic is unknown.

Long-term planned monitoring is needed, rather than haphazard "brush-fire" studies. This research should examine the importance of extreme events versus long-term mean conditions. Several quantitative methods might be employed in research, including computer analysis of statistical correlations and interactions between functional categories; mass balances; and testable mechanistic simulation models that use more complete data sets available for temperate wetlands in North America and Europe.

Linked submodels of processes including photosynthesis, respiration, retention, organic input, etc. need to be developed. Some useful models that can be used as prototypes already exist (for dissolved oxygen and sedimentation).

Some measures are also needed to facilitate the incorporation of scientific knowledge into management. It is uncertain how to write protective standards, and there is no satisfactory definition of unique wetland uses. As alternatives or supplements to the matrix used here, decision trees, procedurals manuals, or some combination might be developed. A Delphi process for incorporating expert opinion in developing new methodologies also could be tried.

Chapter 5 — Primary Production

Primary Production Functions of Wetlands in the Pacific Northwest

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Abstract

In the Pacific Northwest the structural characteristics (diversity, complexity) and functions of the primary producers in wetlands have only been the object of study for the last decade. Because virtually all published and unpublished sources deal with the structural and functional characteristics of estuarine wetlands in the region, and data for other wetland types are extremely meager, comparisons between wetland types and between sub-regions may be premature.

In general, however, the species richness of estuarine marsh plant communities declines to the north (other wetland types may exhibit a similar pattern); the small estuarine marshes of the region are as species-rich as their larger counterparts; and the species richness and relative diversity of marsh vascular plant communities increases towards their upland limits. No empirical research has yet been undertaken on the biotic or habitat complexity of these wetlands, or on the inter-relations between diversity and complexity.

Virtually all of the data on standing crop and net annual primary productivity (NAPP) of wetland plant species or communities of the region are derived from estuarine environments. The estimated mean (dry weight) peak standing crop for marsh phanerogams in these environments is 868 g/m^2 above-ground and 6067 g/m^2 below-ground, with a mean NAPP of 1071 g/m^2. Comparative values for impounded freshwater marshes are: mean above-ground standing crop = 929 g/m^2, and mean NAPP value = 1430 g/m^2. In contrast, subtidal kelp beds average 281 g/m^2 standing crop. Estimates of NAPP values for sediment microalgae and benthic macroalgae in estuarine environments vary considerably, but standing crops are usually <10% of NAPP values, indicating rapid turnover rates of organic matter in these communities. Rates of NAPP of 490 gC/m^2 thallus area for seven species of macroalgae growing in Grays Harbor, Washington, may be representative of the regional mean. The few estimates of production in estuarine eelgrass beds indicate an equal division of aerial and below-ground biomass. NAPP rates may be several-fold larger than standing crop values in these communities also. There are few productivity data for other wetland types in the region. The latitudinal gradient in radiation receipt exerts little influence on standing crop. Variations in the biomass and productivity of the coastal wetlands are apparently mainly related to changing community composition and local site conditions.

The meager available evidence suggests that productivity and diversity are inversely related, at least in the estuarine marshes of the region.

Introduction

Vegetated wetlands develop in geomorphic settings where water tables are maintained near, at, or above the ground surface for prolonged periods of time. Ecological classifications of wetlands generally differentiate between wetland types on the basis of the geomorphic, hydrological, sedimentological, and chemical characteristics of the physical template. Wherever seasonally or permanently high water tables exist, recruitment into a wetland plant community will be restricted to those members of the regional flora that are tolerant of the local inundation regime and the other conditions prevailing in the physical environment. Each wetland type therefore supports a more-or-less distinctive ecological community; wetland classifications may be based on indicator plant species as a differentiating criterion. What are rarely considered in such typologies are the structural characteristics of the wetland plant community (diversity and complexity), and the biomass functions of the primary producers.

As the physical characteristics of the major wetland types (marine, estuarine, freshwater impounded, riparian) in the Pacific Northwest region are likely analogous to those in similar geochemical and climatic environments elsewhere in the world, information on the developmental characteristics of wetlands from these other areas may be directly applicable to problems of wetland evolution and evaluation in the region. Similarly, some of the plants of the marshes and bogs in the Pacific Northwest have broad geographical distributions, and a few are cosmopolitan. Information derived from studies of the ecological amplitude, reproductive strategy, etc., of populations of these wide-ranging species growing elsewhere may also be applicable to their counterparts in the Pacific Northwest. Far less certain is the extent to which the structural and functional characteristics of wetlands elsewhere correspond with those of similar wetlands in our region; inter-regional variation in bioclimates and plant species assemblages likely make the wetlands of each region functionally unique. Furthermore, our scant knowledge of functional and structural characteristics of Pacific Northwest wetlands makes inter-regional comparisons premature. The meager data that do exist for Pacific Northwest wetlands are scattered in theses and agency reports, and only a few published sources are available.

This paper reviews the state of knowledge of the functions of primary producers of the wetlands in the Pacific Northwest, and the structural characteristics of wetland plant communities in the region as described in published and unpublished sources. In particular I address the following questions:

- Are some wetland types more ecologically diverse, complex, and productive than others?
- Is there regional variation in the ecological diversity, complexity, and productivity of a wetland type?
- Do large wetland areas possess a more diverse flora than small wetlands, and are they structurally more complex?
- To what extent is diversity, complexity or productivity influenced by environmental factors within wetlands?
- To what extent are structural characteristics and functional behavior interdependent or site-specific?

Definitions

Discussion of the **structural characteristics** of a plant community is limited here to an examination of diversity and complexity.

- **Diversity**: either the absolute number of taxa in some community (=species richness), or some measure of their relative abundance.

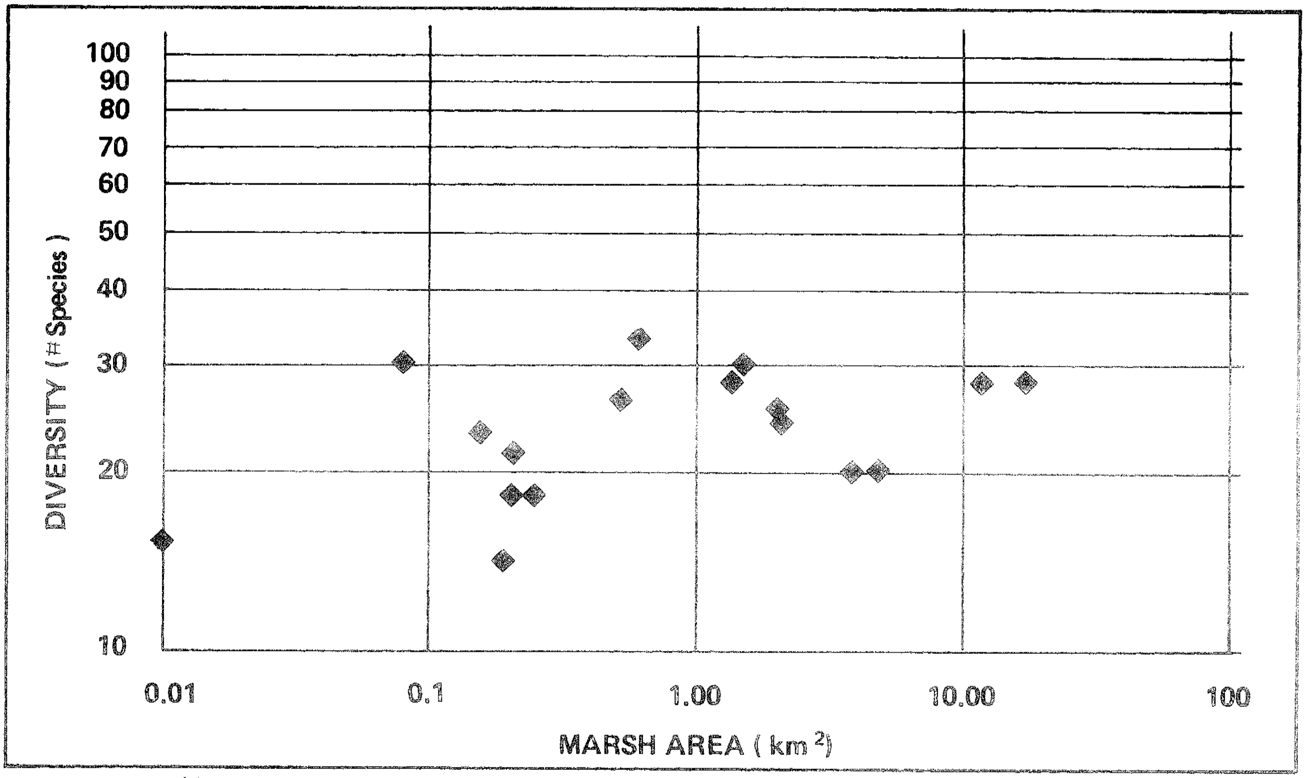


Figure 5-1. **Species richness of the plant communities of the foreshore intertidal marshes of seventeen deltas of the Puget Trough as a function of marsh area. Data: Hutchinson (unpub.).**

- **Complexity**: either structural complexity, which refers to the spatial and vertical architecture of aboveground plant structures, or habitat complexity, which refers to the morphological differentiation of the physical landscape. The term trophic complexity describes the feeding relationships in an ecological community, and is considered elsewhere in this volume.

The examination of the **functional characteristics** of a wetland plant community is limited here to a discussion of primary production.

- **Primary Production**: may denote either the mass of organic material or its rate of accumulation. Standing crop refers to the amount of aboveground plant material that can be harvested at any one time; biomass comprises the standing crop plus belowground structures. The weight of new organic matter formed over a period of time is known as productivity. Net annual primary productivity (NAPP) is the gross amount of productivity in one year less respiratory and predatory losses.

Diversity and Complexity

Floristic inventories are available for a large number of wetland habitats in the Pacific Northwest; however, the sampling effort and methods employed in these inventories vary greatly, and this severely limits the utility of these data for comparative purposes. A precise assessment of the between-wetland variation in diversity must await a more standardized sampling and recording procedure.

Only in the case of estuarine wetlands are data available that allow an investigation of the regional and local controls on species richness and relative diversity. On the basis of a

Table 5-1
Mean peak biomass and net annual primary productivity in Pacific Northwest wetlands (data summarized from Table 5-2).

Wetland Type and Plant Community	Biomass g (dry wt.)/m^2	NAPP g (dry wt.)/m^2/yr	Number of Habitats Sampled
Marine			
Kelp Beds	281	-	14
Estuarine			
Sediment Microalgae	-	392	2
	-	*62	2
	**5	**38	1
Benthic Macroalgae	-	*1404	4
	**123	**497	6
Eelgrass			
Above-ground	95	926	4
Below-ground	123	-	1
Marsh Phanerogams			
Above-ground	868	1071	111 (NAPP=53)
Below-ground	6067	-	40
Freshwater Impounded			
Marsh Phanerogams			
Above-ground	929	1430	8
Below-ground	-	-	-

- No data
* Units are in gC/m^2 of thallus area/yr
** Units are in gC/m^2/yr

limited number of floristic lists, Macdonald (1977) contended that the estuarine wetlands of the Pacific littoral exhibit a stepped gradient in species richness from south to north. He concluded that there are two phytogeographic sub-zones in the Pacific Northwest: 1) a region extending from northern California to the Canadian border, the latter marking the northern range limit for ten estuarine phanerogams; and 2) a region extending north from the Canadian border to 54-55°N, where a further five species are lost. Similar latitudinal gradients in diversity are likely found in non-estuarine wetlands of the Pacific Northwest; maps of the biogeographic ranges of wetland plants in regional floras indicate northern limits for several major species (e.g. *Scirpus americanus, S. maritimus*) around 52-55°N.

Within any phytogeographic sub-zone the species richness of the wetlands flora does not seem to be related to the size of the individual habitat units. Figure 5-1 shows the relationship between the richness of the vascular plant flora and habitat area for the estuarine wetlands of 17 deltas in the Puget Trough (Hutchinson 1986). Although all these foreshore marsh communities are floristically depauperate, the wetlands of the very small deltas are almost as species-rich as those wetlands several orders of magnitude larger. Wetland habitats essentially function as islands, isolated by intervening uplands and expanses of water. Biogeographic investigations of terrestrial habitat "islands" indicate that an increase in habitat area by four orders of magnitude should produce a three-fold increase in the species richness of the community (Gorman 1979). The uniform floristic richness of estuarine wetlands in the Puget Trough is therefore unexpected, and may indicate either 1) a rapid rate of immigration from a limited species pool, or 2) a habitat complexity of very small wetlands as great as that of their larger counterparts (perhaps as a result of more frequent or widespread disturbance in the smaller deltas).

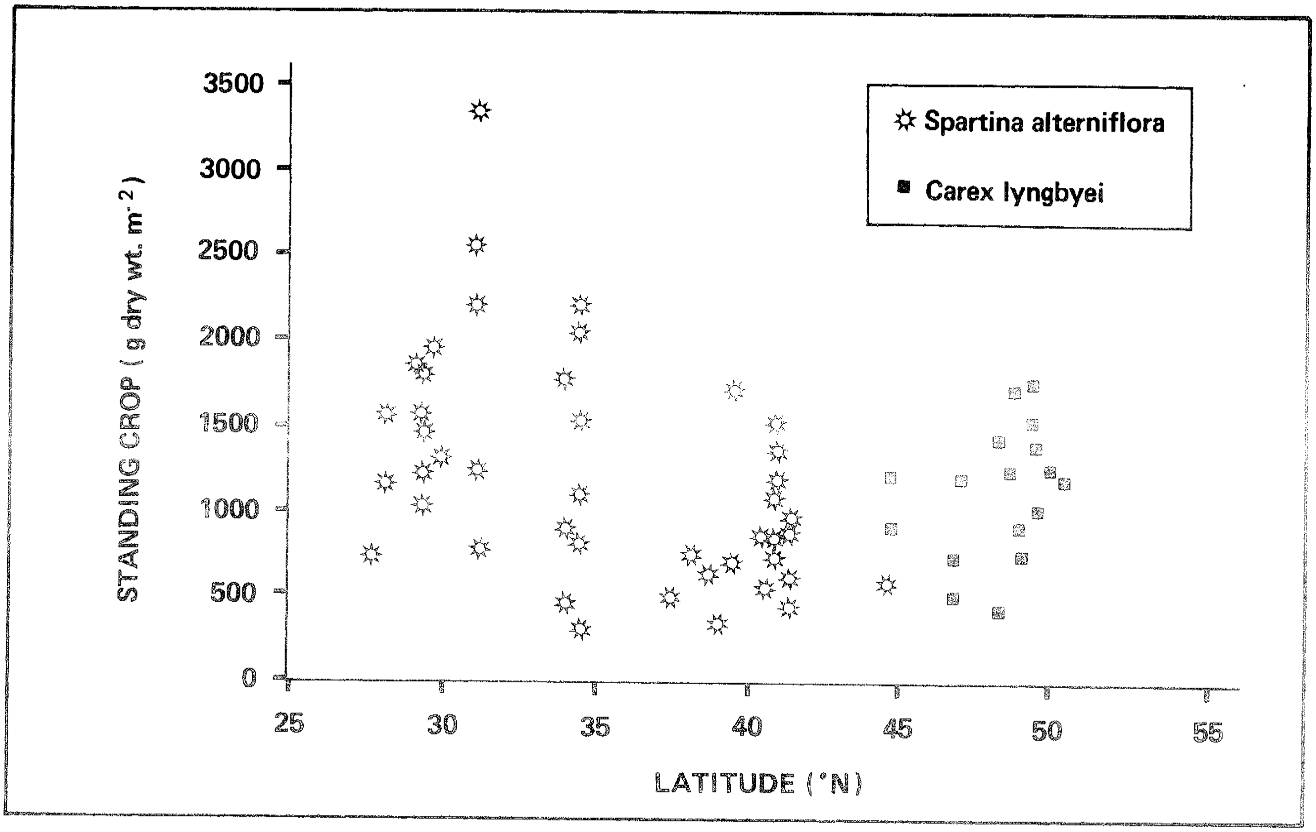
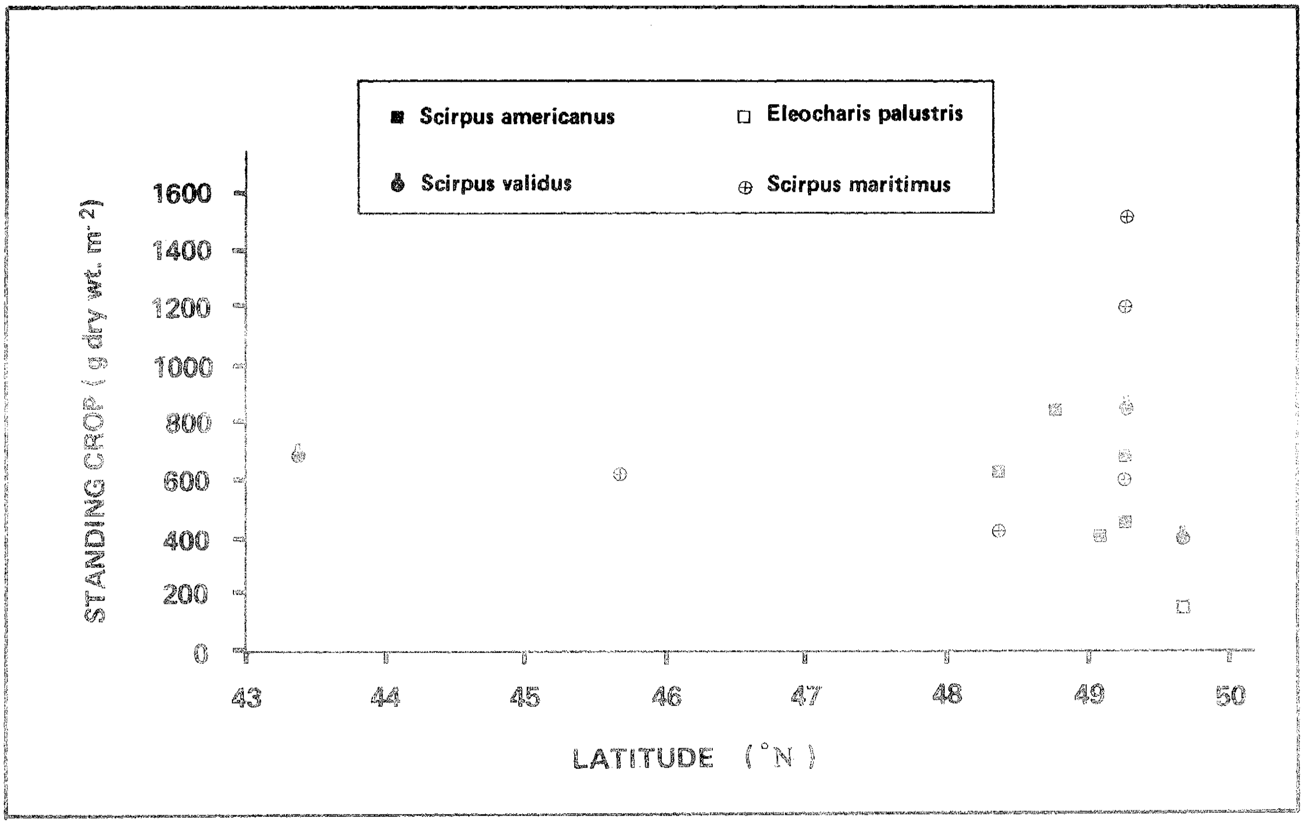
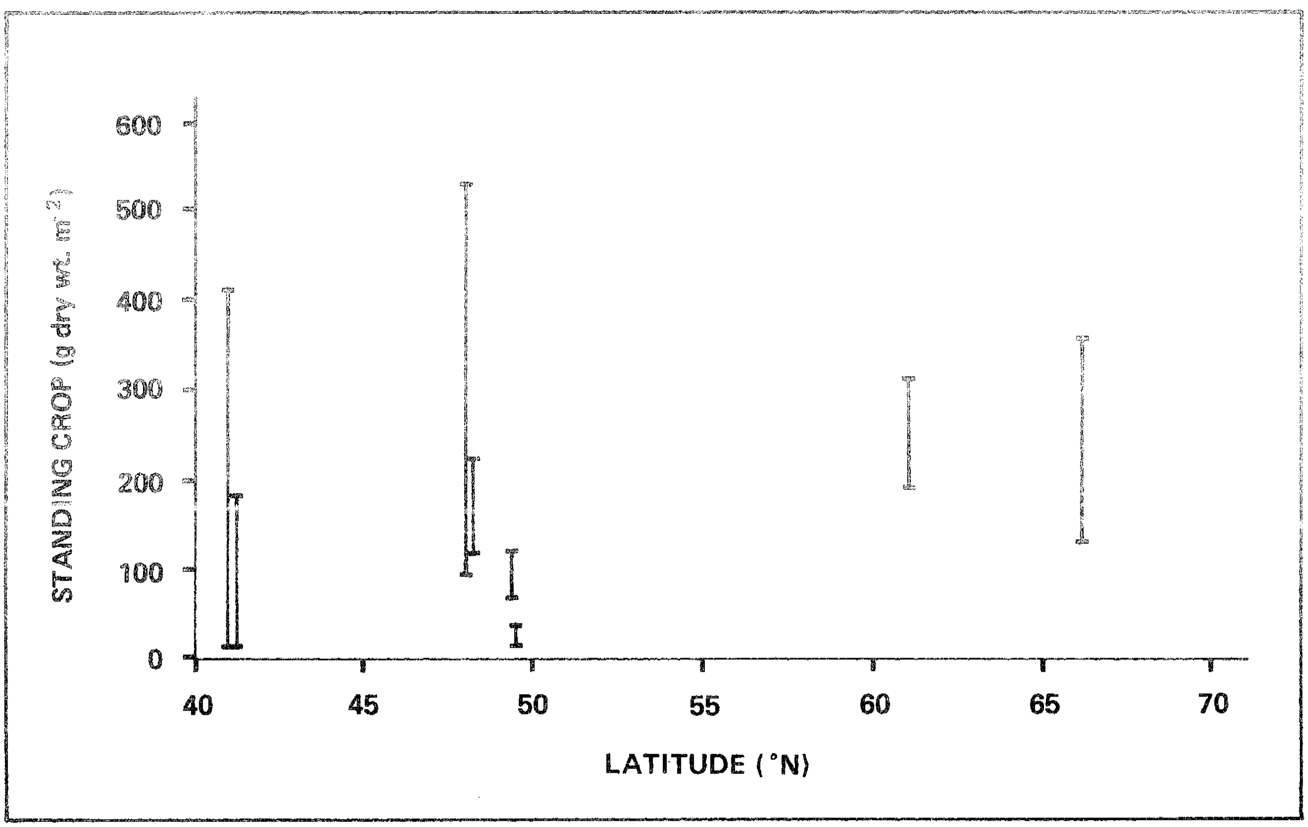


Figure 5-2. Mean peak standing crop of *Spartina alterniflora* Loisel. and *Carex lyngbyei* Hornem. as a function of latitude. Data for *Spartina* derived from Turner (1976), those for *Carex* from several sources.

On a more local scale the diversity of wetland vascular plant communities generally decreases with increasing frequency and duration of inundation. In the estuarine and deltaic littoral wetlands of the Pacific Northwest, low marsh communities are virtually monospecific, whereas high marsh communities are much more diverse (Eilers 1975; Bradfield and Porter 1982; Dawe and White 1982; Hutchinson 1982; Ewing 1983). Similar diversity gradients are reported by Frenkel (1986) for montane mires in the Cascade Range of Oregon. Obviously a great deal of research still needs to be undertaken on the diversity characteristics and relationships of various wetland types, and on the factors that control inter-wetland or inter-habitat variability.

In wetland ecosystems the development and scale of the habitat mosaic is mainly a response to the slope and structure of the underlying physical platform and to the morphology and evolution of the associated drainage network. These in turn are modified by the rates and patterns of accretion of inorganic and organic matter on the surface and by the nature of the accreting material. In some wetlands in the Pacific Northwest additional habitat differentiation results from wave and channel erosion, or from the scouring associated with the movement of drift logs across the marsh platform during storms. Variable microtopography may also result from the grubbing and burrowing activities of consumer organisms in the marsh. For example, flocks of snowgeese overwintering in some deltaic wetlands in the Puget Trough produce marsh surfaces pitted by large craters as a result of their grubbing activities (Burton 1977).


Scirpus americanus
Eleocharis palustris
Scirpus validus
Scirpus maritimus
STANDING CROP (g dry wt. m⁻2)
1600
1400
1200
1000
800
600
400
200
0
43
44
45
46
47
48
49
50
LATITUDE (°N)


STANDING CROP (g dry wt. m⁻2)
600
500
400
300
200
100
0
40
45
50
55
60
65
70
LATITUDE (°N)

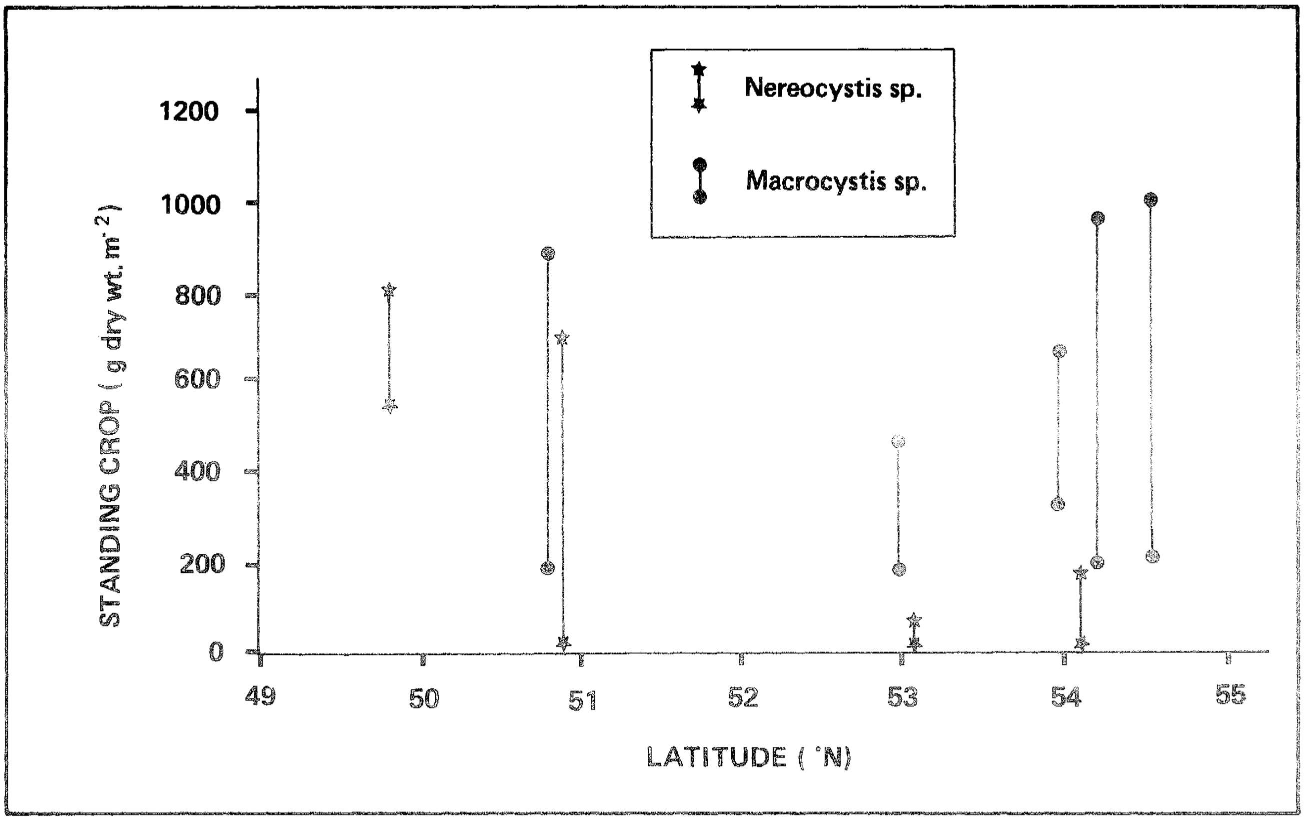


Figure 5-3. **Facing page: Mean and ranges of peak standing crop of a) estuarine sedges other than *Carex*, b) eelgrass (*Zostera* spp.).**

Above: c) Mean and ranges of peak standing crop of kelp, as a function of latitude. Data: Various sources.

As far as I am aware no attempt has yet been made to assess the variation in complexity of the physical habitat between wetland ecosystems, and no standard morphometric procedure exists to undertake such comparisons. Similarly, the comparative structural complexity of wetland plant communities has not been investigated in this region or elsewhere. Such studies should consider not only the vertical architecture of the plant canopy, but also its adaptive geometry, both for the plants themselves and for the consumers dependent upon them for food and cover.

Production

Regional variation in wetlands productivity has been examined by Turner (1976) and Keefe (1972) for estuarine and continental marshes in eastern and midwestern North America. Thom (1981) summarized the literature on the productivity of estuarine wetlands along the Pacific coast, but no corresponding review has been undertaken on non-estuarine wetlands in the western third of the continent. A compilation of the available biomass and productivity data arranged by wetland and community type (Tables 5-1 and 5-2) indicates that wetlands other than those occupying estuarine intertidal habitats have received very little attention; some wetland categories have been utterly neglected. The paucity of data for non-estuarine wetlands makes a formal

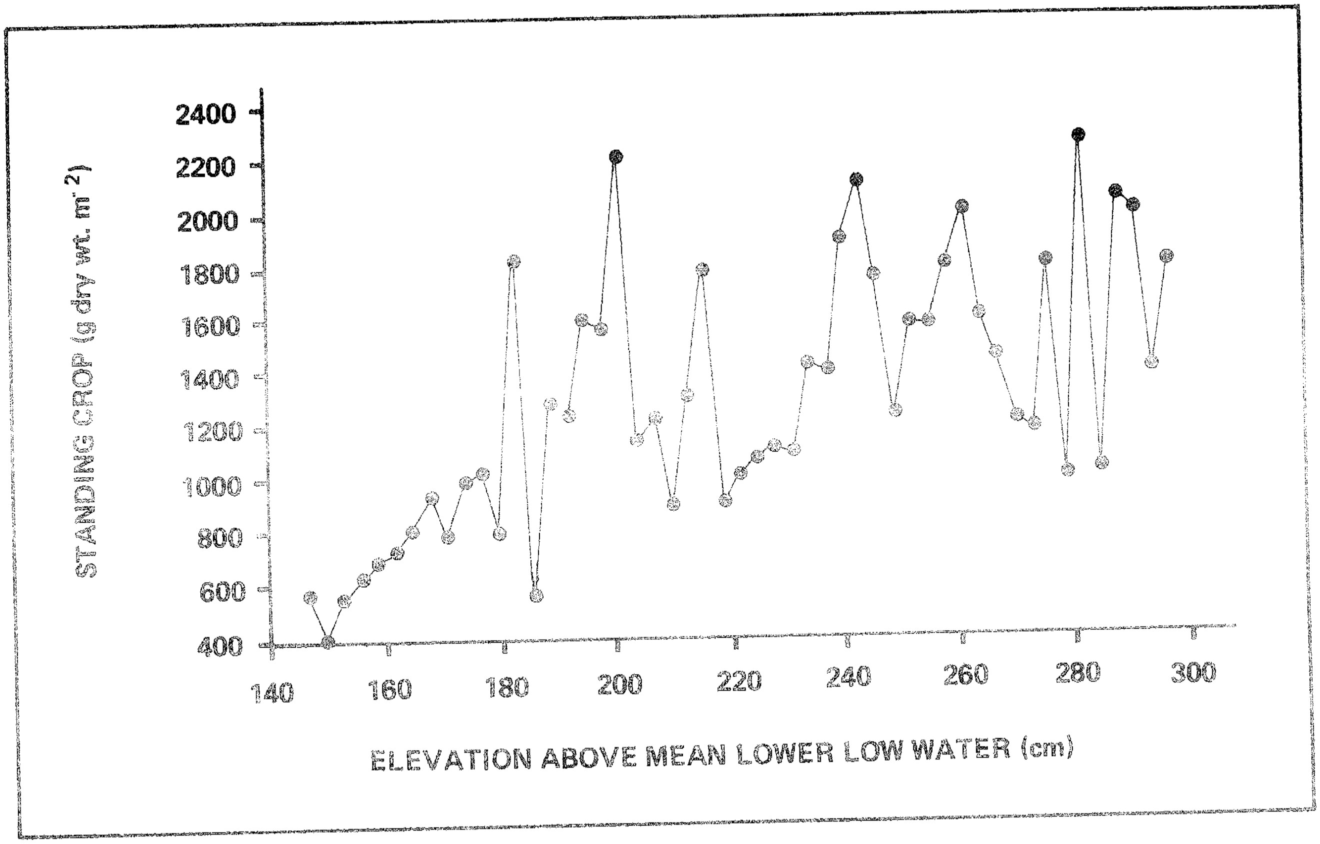


Figure 5-4. **Local variation of peak standing crop as a function of elevation and micro-relief in the marshes of the Nehalem River estuary, OR. After Eilers (1975).**

statistical comparison of inter-wetland variation in mean standing crop and productivity premature.

The study region encompasses almost 20° of latitude. As a result the frost-free season is almost twice as long, and the mean annual solar radiation receipt some 50 percent higher, in southern Oregon than it is in northern British Columbia (assuming that the stations being compared are the same distance from the coast) (Hare and Hay 1974; Court 1974). This climatic gradient does not, however, produce concomitant changes in wetland standing crop. The mean standing crop for stands of *Carex lyngbyei* Hornem., the dominant sedge in estuarine marshes of the northwestern Pacific, is uniform over that part of its biogeographic range for which biomass data are available. Standing crop values for this species are equivalent to those of *Spartina alterniflora* Loisel (the closest ecological counterpart of *Carex lyngbyei* in the coastal marshes of eastern North America), at its northern range limit (Figure 5-2). Similarly, the mean and range of standing crop values do not vary latitudinally for other estuarine sedge species (Figure 5-3a), eelgrass (Figure 5-3b), or kelp (Figure 5-3c). The effects of varying bioclimatic conditions on wetland productivity (as opposed to biomass) in the region remain unknown.

The importance of local site conditions in controlling wetland standing crop and productivity is demonstrated by the considerable range of values at particular geographic locations (Figures 5-2 and 5-3). Some of this variation is related to the frequency and duration of submergence of the plant, surface micro-relief, and associated variations in soil anoxia (Eilers 1975; Ewing 1983; Smythe in prep.). For example, the total net aerial

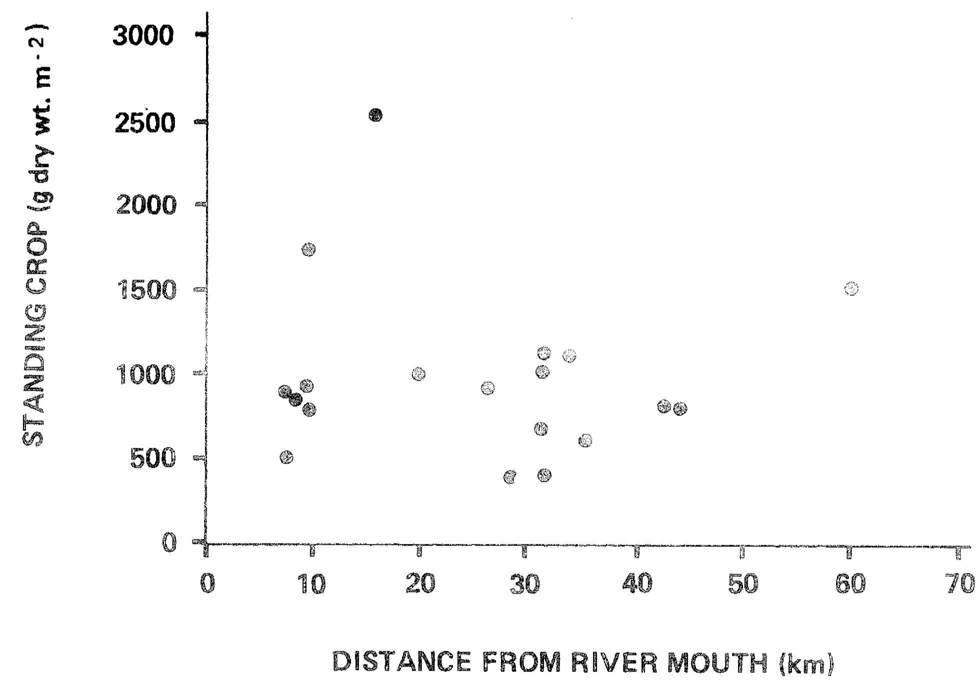


Figure 5-5. Mean peak standing crop of the intertidal marshes of the Columbia River estuary in relation to distance upriver. Data: Macdonald (1984).

production (primarily of *Carex lyngbyei*) increases four-fold along a transect from the low to high marsh limits in the Nehalem River estuary, Oregon (Figure 5-4). Superimposed upon this trend are dramatic variations in total standing crop which are related to the effects of microtopographic position and soil drainage. In contrast, estuarine salinity gradients seem to have little influence on marsh standing crop, at least in the case of the Columbia River (Figure 5-5).

Virtually no data exist on the production functions of the regionally important riparian, lacustrine, or bog wetlands. The role of non-vascular plants in wetlands productivity has also been consistently neglected; only Pomeroy (1977), Pomeroy and Stockner (1976), Thom (1981, 1984a) and McIntire et al. (1983) include information on macro- and microalgal production. We also know very little about the roles of specific environmental controls or biotic interactions on wetlands production. No manipulation of the biotic or physical environment to assess the effect of individual or interacting variables on wetlands production has as yet been attempted in the Pacific Northwest. Another area of ignorance concerns the effects of neighboring upland habitats on the productivity of lowland wetlands. No data exist, for example, on the extent to which detritus or dissolved nutrients exported from floodplain forest communities subsidize production in neighboring bogs or riparian marshes.

The extent to which the structural and functional characteristics of wetlands ecosystems are interdependent in the Pacific Northwest remains unknown. It might be hypothesized that any increase in the diversity of a community would bring about an increase in its

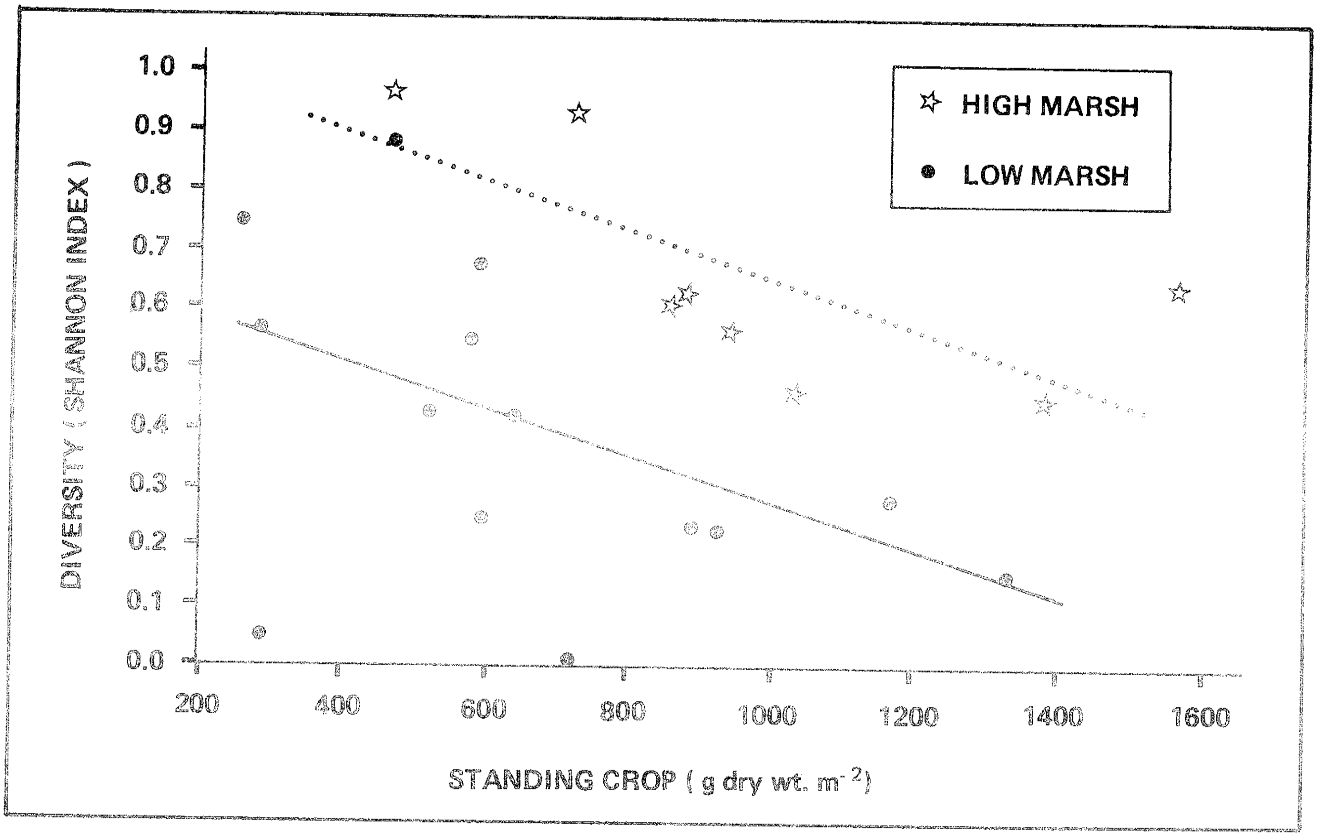


Figure 5-6. Relative diversity - standing crop relations in the intertidal marshes of the Columbia River estuary. Data: Macdonald (1984).

structural complexity, and, as a result of greater vertical resource partitioning, this would lead to a concomitant increase in production. Although the data are scant, there is reason to doubt that an increase in diversity produces corresponding increases in production. In the marshes of the Columbia River estuary, for example, there is an inverse relationship between production and diversity (Figure 5-6). Similar results were reported by Ewing (1982) for the marshes of the Skagit River delta, and by Auclair et al. (1976) for a freshwater wetland in southern Quebec.

Further research could profitably focus on the mechanisms by which niche segregation and resource partitioning occurs amongst wetland plant species, the ways in which dominance hierarchies are expressed on particular sites, and the roles that these factors play in determining the biotic diversity, structural complexity, and production of the local plant community.

Finally, it should be stressed that most wetlands ecosystems are highly dynamic entities, yet we have virtually no information on how constant the structural and production characteristics of a community are from one year to the next, how persistent successional phases are on particular sites, or what successional trajectories these communities will follow given different starting points. Yet all of these are critical if we are to understand how to manage these ecosystems and optimize their production functions.

Acknowledgements

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Table 5-2

Summary of standing crop and net aboveground primary productivity values for wetlands in the Pacific Northwest.

Wetland Type and Plant Community	Peak Standing Crop g (dry wt.)/m^2			NAPP g (dry wt.)/m^2/yr)	Locale	Source
	Below	Above	Total			
				Marine Wetlands		
Kelp beds						
Macrocystis integrifolia	-	800	-	-	BC, Barkley S.	Druehl & Wheeler 1986
	-	110	-	-	BC, Nootka S.	Coon et al. 1982
	-	24	-	-	BC, Estevan S.	Field et al. 1977
	-	60	-	-	BC, Dixon Ent.	Field & Clark 1978
		86	-	-	BC, Graham I.	Coon et al. 1979
	-	99	-	-	BC, Goschen I.	Coon et al. 1980
	-	29	-	-	BC, Hope I.	Coon et al. 1981
	-	355	-	-	BC, Pt. Hardy	Coon 1983
Nereocystis luetkeana	-	410	-	-	BC, Nootka S.	Coon et al. 1982
	-	350	-	-	BC, Estevan S.	Field et al. 1977
	-	405	-	-	BC, Dixon Ent.	Field & Clark 1978
	-	260	-	-	BC, Graham I.	Coon et al. 1979
	-	557	-	-	BC, Goschen I.	Coon et al. 1980
	-	393	-	-	BC, Hope I.	Coon et al. 1981
				Estuarine Wetlands		
Sediment Microalgae						
Sediment Microalgae	-	**5	-	**30	OR, Netarts B.	McIntire et al. 1983
	-	-	-	584	WA, Grays H.	Herrmann 1971
	-	-	-	*59	WA, Grays H.	Thom 1984a
Diatoms	-	-	-	*65	WA, Grays H.	Thom 1981
Vaucheria longicaulis	-	-	-	250	BC, Squamish	Pomeroy & Stockner 1976
Benthic Macroalgae						
Enteromorpha prolifera	-	**156	-	**2799	OR, Netarts B.	McIntire et al. 1983
Enteromorpha clathrata	-	-	-	*1257	WA, Grays H.	Thom 1984b
E. intestinalis	-	-	-	*826	WA, Grays H.	Thom 1984b
E. linza	-	-	-	*26	WA, Grays H.	Thom 1981
E. sp. - Blidingia sp.	-	-	-	*430	WA, Grays H.	Thom 1984b
Fucus evanescens	-	-	-	*729	WA, Grays H.	Thom 1984b
Gracilaria verrucosa	-	20	-	**8	OR, Yaquina B.	McIntire et al. 1983
Polysiphonia hendryi	-	-	-	*120	WA, Grays H.	Thom 1981
Porphyra sanjuanensis	-	-	-	*21	WA, Grays H.	Thom 1984b
Ulva expansa	-	412	-	-	OR, Yaquina B.	McIntire et al. 1983
Ulva - Monostroma	-	-	-	321	WA, Grays H.	Thom 1984b

Table 5-2 (Continued)

Wetland Type and Plant Community	Peak Standing Crop g (dry wt.)/m^2) Below	Above	Total	NAPP g (dry wt.)/m^2/yr)	Locale	Source
Eelgrass beds						
Zostera marina	123	128	251	+1843	OR, Netarts B.	McIntire et al. 1983
	-	-	-	806	WA, Grays H.	Thom 1984b
	-	120	-	-	WA, Puget S.	Phillips 1972
	-	110	-	-	BC, Boundary B.	Harrison 1982
	-	20	-	-	BC, Fraser R.	Moody, R. 1978
Marsh Phanerogams						
Agrostis alba - Festuca rubra- Juncus balticus	-	546	-	-	OR, Coos B.	Taylor & Frenkel 1979
Agrostis alba - Juncus balticus- Potentilla pacifica	1372	664	2036	1108	OR, Columbia R.	Macdonald 1984
A. alba- C.lyngbyei	1817	733	2650	1271	OR, Columbia R.	Macdonald 1984
Aster subspicatus - Potentilla pacifica - Oenanthe sarmentosa	-	-	-	1936	OR, Nehalem R.	Eilers 1975
Calamagrostis	7876	-	-	-	BC, Pitt R.	Ogwang 1982
canadensis	-	1982	-	-	BC, Pitt R.	Barnard 1975
Carex lyngbyei						
(streamside)	-	1200	-	2000	OR, Siletz R.	Gallagher & Kibby 1981
(backmarsh)	-	900	-	1200	OR, Siletz R.	Gallagher & Kibby 1981
	-	308	-	-	OR, Coos B.	Taylor & Frenkel 1979
(tall)	-	-	-	1746	OR, Nehalem R.	Eilers 1975
(short)	-	-	-	875	OR, Nehalem R.	Eilers 1975
(low)	2863	869	3732	1423	OR, Columbia R.	Macdonald 1984
(low)	1781	827	2608	1082	OR, Columbia R.	Macdonald 1984
	-	700	-	-	WA, Grays H.	Thom 1981
	-	491	-	-	WA, Grays H.	Thom 1981
	-	1180	-	1390	WA, Nisqually	Burg et al. 1980
(tall)	-	1422	-	-	WA, Skagit R.	Ewing 1982
(short)	-	393	-	-	WA, Skagit R.	Ewing 1982
(channel; "salt")	-	380	-	-	WA, Skagit R.	Smythe (in prep.)
(channel; "fresh")	-	302	-	-	WA, Skagit R.	Smythe (in prep.)
(backmarsh; "salt")	-	648	-	-	WA, Skagit R.	Smythe (in prep.)
(backmarsh; "fresh")	-	519	-	-	WA, Skagit R.	Smythe (in prep.)
(foreshore; "fresh")	-	279	-	-	WA, Skagit R.	Smythe (in prep.)
(foreshore; "fresh")	2200	1700	3900	-	WA, Nooksack R.	Disraeli & Fonda 1979
	-	1231	-	-	BC, Cowichan R.	Kennedy 1982
(channel; "salt")	-	508	-	-	BC, Nanaimo R.	Smythe (in prep.)

Table 5-2 (Continued)

Wetland Type and Plant Community	Peak Standing Crop g (dry wt.)/m² Below	Above	Total	NAPP g (dry wt.)/m^2/yr)	Locale	Source
Carex lyngbyei (continued)						
(channel; "fresh")	-	290	-	-	BC, Nanaimo R.	Smythe (in prep.)
(backmarsh; "salt")	-	42	-	-	BC, Nanaimo R.	Smythe (in prep.)
(backmarsh; "fresh")	-	538	-	-	BC, Nanaimo R.	Smythe (in prep.)
	-	909	-	-	BC, Fraser R.	Moody, A. 1978
	-	724	-	687	BC, Fraser R.	Kistritz & Yesaki 1979
	4992	-	-	-	BC, Fraser R.	Ogwang 1982
	-	1746	-	-	BC, Qualicum R.	Kennedy 1982
(streamside)	-	1518	-	-	BC, Qualicum R.	Dawe & White 1982
(tall)	-	1356	-	1322	BC, Squamish R.	Levings & Moody 1976
	-	1015	-	-	BC, Squamish R.	Lim & Levings 1973
(channel; "salt")	-	473	-	-	BC, Squamish R.	Smythe (in prep.)
(channel; "fresh")	-	532	-	-	BC, Squamish R.	Smythe (in prep.)
(backmarsh; "salt")	-	86	-	-	BC, Squamish R.	Smythe (in prep.)
(backmarsh; "fresh")	-	75	-	-	BC, Squamish R.	Smythe (in prep.)
(foreshore; "salt")	-	60	-	-	BC, Squamish R.	Smythe (in prep.)
(foreshore; "fresh")	-	60	-	-	BC, Squamish R.	Smythe (in prep.)
(levee; "fresh")	-	496	-	-	BC, Squamish R.	Smythe (in prep.)
	-	1223	-	-	BC, Campbell R.	Kennedy 1982
	-	1186	-	-	BC, Salmon R.	Kennedy 1982
C. lyngbyei -	2910	843	3753	1212	OR, Columbia R.	Macdonald 1984
Agrostis alba	346	900	1246	1511	OR, Columbia R.	Macdonald 1984
C. lyngbyei - *Aster subspicatus* - *Oenanthe sarmentosa*	-	-	-	1756	OR, Nehalem R.	Eilers 1975
C. lyngbyei - *Deschampsia cespitosa*	38232	205	38437	407	OR, Coos B.	Hoffnagle 1980
C. lyngbyei - *Deschampsia cespitosa*	414	64	1055	833	OR, Columbia R.	Macdonald 1984
C. lyngbyei - *Deschampsia cespitosa* - *Scirpus validus*	897	391	1288	754	OR, Columbia R.	Macdonald 1984
C. lyngbyei - *Deschampsia cespitosa* - *Juncus oxymeris*	2881	1093	3974	1193	OR, Columbia R.	Macdonald 1984
C. lyngbyei - *Deschampsia cespitosa* - *Triglochin maritimum*	-	-	-	1234	OR, Nehalem R.	Eilers 1975
C. lyngbyei - *Distichlis spicata*	15549	700	16249	625	OR, Coos B.	Hoffnagle 1980

Table 5-2 (Continued)

Wetland Type and Plant Community	Peak Standing Crop g (dry wt.)/m² Below	Above	Total	NAPP g (dry wt.)/m²/yr)	Locale	Source
C. lyngbyei - Distichlis spicata	-	908	-	908	WA, Nisqually R.	Burg et al. 1980
C. lyngbyei - Eleocharis palustris	-	800	-	-	BC, Squamish R.	Lim & Levings 1973
C. lyngbyei - Mixed grasses	1606	778	2384	1157	OR, Columbia R.	Macdonald 1984
C. lyngbyei -	2797	997	3794	1680	OR, Columbia R.	Macdonald 1984
Mixed herbs	1734	1104	2838	1437	OR, Columbia R.	Macdonald 1984
C. lyngbyei - Scirpus americanus	2916	847	3763	918	OR, Columbia R.	Macdonald 1984
C. lyngbyei - Scirpus maritimus	-	1302	-	-	WA, Skagit R.	Ewing 1982
C. lyngbyei -	1533	2528	4061	2706	OR, Columbia R.	Macdonald 1984
Scirpus validus	1413	576	1989	710	OR, Columbia R.	Macdonald 1984
C. lyngbyei - Typha latifolia	-	1500	-	-	BC, Fraser R.	Yamanaka 1975
C. lyngbyei - Umbelliferae	-	874	-	-	BC, Squamish R.	Lim & Levings 1973
Carex sitchensis	8440	-	-	-	BC, Pitt R.	Ogwang 1982
Deschampsia cespitosa	-	902	-	-	BC, Qualicum R.	Dawe & White 1982
	-	714	-	-	BC, Squamish R.	Lim & Levings 1973
D. cespitosa - Juncus balticus - Triglochin maritima	-	882	-	-	OR, Coos B.	Taylor & Frenkel 1979
Distichlis spicata - Juncus balticus	-	558	-	558	WA, Nisqually R.	Burg et al. 1980
D. spicata - Salicornia virginica	-	942	-	952	WA, Nisqually R.	Burg et al. 1980
D. spicata - Grindelia integrifolia	-	1420	-	-	BC, Chemainus R.	Kennedy 1982
Eleocharis palustris	-	149	-	-	BC, Squamish R.	Lim & Levings 1973
Festuca rubra - Carex lyngbyei	-	1086	-	1086	WA, Nisqually R.	Burg et al. 1980
Jaumea carnosa - Distichlis spicata	-	790	-	800	WA, Nisqually R.	Burg et al. 1980
Juncus balticus	-	425	-	-	WA, Grays H.	Thom 1981
	-	1155	-	-	BC, Cowichan R.	Kennedy 1982
	-	766	-	-	BC, Qualicum R.	Dawe & White 1982
	-	1098	-	-	BC, Squamish R.	Lim & Levings 1973
J. balticus - Agrostis alba	-	-	-	1512	OR, Nehalem R.	Eilers 1975

Table 5-2 (Continued)

Wetland Type and Plant Community	Peak Standing Crop g (dry wt.)/m^2 Below	Above	Total	NAPP g (dry wt.)/m^2/yr)	Locale	Source
Juncus effusus	1324	-	-	-	BC, Pitt R.	Ogwang 1982
Juncus oxymeris - *Eleocharis palustris*	930	364	1294	490	OR, Columbia R.	Macdonald 1984
Lathyrus palustris - *Potentilla pacifica*	-	774	-	-	BC, Squamish R.	Lim & Levings 1973
Phalaris arundinacea	-	2241	-	-	BC, Pitt R.	Barnard 1975
(pumped)	-	2515	-	-	BC, Pitt R.	Barnard 1975
Poa pratensis - *Agrostis alba* - *Potentilla pacifica*	-	1002	-	-	BC, Salmon R.	Kennedy 1982
Potentilla pacifica - *Agrostis alba* - *Juncus balticus*	934	771	1705	977	OR, Columbia R.	Macdonald 1984
Potentilla pacifica - *Eleocharis palustris*	-	868	-	-	BC, Qualicum R.	Kennedy 1982
Potentilla pacifica - *Eleocharis palustris*	-	613	-	-	BC, Campbell R.	Kennedy 1982
Salicornia virginica	-	704	-	-	OR, Coos B.	Taylor & Frenkel 1979
	-	730	-	730	WA, Nisqually R.	Burg et al. 1980
	-	2082	-	-	BC, Chemainus R.	Kennedy 1982
S. virginica - *Triglochin maritima*	7938	560	8498	821	OR, Coos B.	Hoffnagle 1980
S. virginica - *Distichlis spicata*	34474	689	35163	625	OR, Coos B.	Hoffnagle 1980
Scirpus americanus	-	622	-	-	WA, Skagit R.	Ewing 1982
	3000	850	3850	-	WA, Nooksack R.	Disraeli & Fonda 1979
(low marsh)	1093	673	1766	-	BC, Fraser R.	Karagatzides (in prep.)
(high marsh)	2740	463	3203	-	BC, Fraser R.	Karagatzides (in prep.)
	-	397	-	-	BC, Fraser R.	Moody, A. 1978
	3440	-	-	-	BC, Fraser R.	Ogwang 1982
S. americanus - *Eleocharis palustris*	1058	422	1480	580	OR, Columbia R.	Macdonald 1984
S. americanus - *S. maritimus* - *S. validus*	1163	-	-	-	BC, Fraser R.	Yamanaka 1975
Scirpus cyperinus	7464	-	-	-	BC, Pitt R.	Ogwang 1982
Scirpus maritimus	-	-	-	609	OR, Nehalem R.	Eilers 1975
	-	426	-	-	WA, Skagit R.	Ewing 1982
	-	606	-	583	BC, Fraser R.	Hall & Yesaki (n.d.)
(high marsh)	11635	1794	13429	-	BC, Fraser R.	Karagatzides (in prep.)
(mid marsh)	5030	1195	6225	-	BC, Fraser R.	Karagatzides (in prep.)

Table 5-2 (Continued)

Wetland Type and Plant Community	Peak Standing Crop g (dry wt.)/m^2 Below	Above	Total	NAPP g (dry wt.)/m^2/yr)	Locale	Source
Scirpus maritimus (Continued)						
(low marsh)	3195	1512	4707	-	BC, Fraser R.	Karagatzides (in prep.)
	-	565	-	-	BC, Fraser R.	Moody, A. 1978
S.maritimus - Carex lyngbyei	-	571	-	-	WA, Skagit R.	Ewing 1982
Scirpus microcarpus	-	1810	-	-	BC, Pitt R.	Barnard 1975
Scirpus validus	20915	687	21602	1201	OR, Coos B.	Hoffnagle 1980
	-	842	-	838	BC, Fraser R.	Hall & Yesaki (n.d.)
	-	400	-	-	BC, Squamish R.	Lim & Levings 1973
S. validus - Carex lyngbyei	13853	795	14648	1081	OR, Coos B.	Hoffnagle 1980
Spergularia marina	-	90	-	90	WA, Nisqually R.	Burg et al. 1980
Spirea douglasii	-	4216	-	-	BC, Pitt R.	Barnard 1975
(pumped)	-	3287	-	-	BC, Pitt R.	Barnard 1975
Triglochin maritimum	-	-	-	524	OR, Nehalem R.	Eilers 1975
T. maritimum - Deschampsia cespitosa	-	-	-	1468	OR, Nehalem R.	Eilers 1975
T. maritimum - Salicornia virginica	-	370	-	-	WA, Grays H.	Thom 1981
Typha latifolia	1686	1501	3187	1501	OR, Columbia R.	Macdonald 1984
	6664	-	-	-	BC, Fraser R.	Ogwang 1982
(pumped)	-	2051	-	-	BC, Pitt R.	Barnard 1975
	-	1203	-	-	BC, Pitt R.	Barnard 1975
	-	756	-	-	BC, Squamish R.	Lim & Levings 1973
	-	902	-	1204	OR, Columbia R.	Macdonald 1984
			Freshwater Impounded Wetlands			
Natural						
unknown	-	-	-	2872	OR, Daley L.	Boss 1982
	-	-	-	1837	OR, Fern Ridge	Boss 1982
"tall perennial"	-	-	-	1325	OR, Davis L.	Boss 1982
"prostrate perennial"	-	-	-	207	OR, Davis L.	Boss 1982
	-	-	-	889	OR, Lookout Ck.	Boss 1982
Man-made						
Phragmites australis	-	1447	-	-	ID, Raft R.	Breckenridge et al. 1983
Scirpus acutus	-	580	-	-	ID, Raft R.	Breckenridge et al. 1983
Typha latifolia	-	760	-	-	ID, Raft R.	Breckenridge et al. 1983

* Units are in grams Carbon per square meter of thallus area per year.

** Units are in grams Carbon per square meter per year.

+Includes epiphyte production (158 g/m^2)

Working Group Report: Primary Production

Ian Hutchinson, Moderator
Susan Smythe and Marc Boule, Rapporteurs

"Answers in search of a question."

Review of Plenary Paper

The working group discussed whether the generalization can be made that there is a gradient in wetland primary productivity (as indicated by standing crop) from high in freshwater to lower in marine waters. It is not clear that there are enough data to answer this question; data are mainly available for marine and estuarine systems, and few data are available for shrub and forest systems. It is also unclear whether the conclusion would be supported if belowground biomass were included in measuring standing crop. Finally, it is unclear that the available data are consistent with this hypothesis — for example, mudflats can be very productive. There may be an optimal salinity for primary productivity in estuaries of around five parts per thousand.

The group agreed that productivity may be regulated by site-specific factors other than salinity, including frequency, amplitude, periodicity, and duration of inundation in estuaries and freshwater impounded wetlands, and substrate in riparian wetlands.

Discussion of Matrix

The group critiqued definitions of several terms as used in the matrix. The definition of wetland boundaries is not considered. "Marine subtidal" (kelp bed) is not a valid wetland category and should be deleted. The use of the term "riparian" is confusing, and it was suggested that "palustrine" is more proper.

The group also struggled with several possible interpretations of the term "diversity." These include species richness (simple numbers of species), relative diversity (weighting species by an index of their abundance), alpha-diversity (diversity within a uniform community), and beta-diversity (diversity across environmental gradients within a habitat). For simplicity's sake, and because of a lack of data for calculating other indices, the use of simple species richness was recommended. Diversity should be used as an index of composition, to indicate vegetative conditions at a single site.

The term "complexity" also had to be clarified by separating it into physical/spatial and biological/trophic components. Complexity should be defined as the surface area per unit volume available as habitat for other organisms, as an index of structure. Physical/spatial complexity refers to spatial vegetative differences deriving from abiotic heterogeneity. (Often a mosaic of vegetation types is present in a wetland, making it difficult to classify). Biological/trophic complexity refers to support of numbers, varieties, and numbers of trophic levels of consumers.

The group felt that diversity and complexity are not actually functions of wetlands, like primary productivity. Instead they should be designated in a separate class as "evaluative criteria." Numerical indices of complexity and diversity are available in the literature, but it is not clear how they relate to functional parameters; ecological theory is not well suited for practical application. The group called these indices "answers in search of a question." The group also noted that both complexity and diversity are considered desirable properties, yet it is not clear that is true — for example, diversity can increase in response to disturbance, and decrease as the system recovers.

The group quibbled with a couple of other definitions in the matrix. The term "macrophyte" implicitly was used in the matrix to refer only to vascular plants, but technically it includes macroalgae as well. In addition, the importance of microalgae for primary production might be overlooked by classifying wetlands only in this manner. The group also was concerned that the distinction between "natural" and "disturbed" wetlands may be impossible to make, since they doubted whether any wetlands exist that have not been disturbed over the last century.

The group was concerned that oversimplification in the matrix could produce misleading results. For example, the preliminary output rated estuarine submergent vegetation as highly diverse, although this category is primarily monotypic eelgrass stands. Proper characterization of primary production may need to be done on a species-by-species basis rather than a community basis.

Discussion Questions

Outside or Site-specific Factors

Primary production is affected by many chemical and water quality parameters, including pH, salinity, redox potential, and alkalinity. These may be highly variable within a site as well as between sites. Even the identities of most of these parameters are uncertain, not to mention their numerical values. There also is a significant lack of autecological and physiological data on wetland plants relative to these parameters.

Primary production is also affected by the variability of the physical regime, especially flooding frequency, amplitude, periodicity, and duration, and especially in impounded wetlands. The system is driven by extreme events more than by average conditions.

Interdependence of Functions

Primary production depends critically on other wetland functions, especially the hydrologic and water quality functions.

Additional Functions

Two additional important properties of wetlands that affect primary production were identified. These might be considered functions, but are more appropriate as "evaluative criteria" like complexity and diversity. The first is **age or regeneration time**: functions and species composition of wetlands have successional components that change with time after a wetland is created or perturbed. The second is **index of scarcity**: high priority wetlands are usually defined by the presence of target organisms, without taking into account the rareness or uniqueness of the organisms or the wetland type.

Data Gaps and Research Needs

More data are needed in certain specific research areas. Riparian productivity estimates are almost non-existent, especially in small systems. Physiological/autecological data are needed as mentioned above. Study of several biological interactions is needed. These include relationships of algal productivity to that of emergent macrophytes; habitat characteristics important to juvenile salmonids; and effects of wildlife use on productivity.

Broader research priorities include long-term studies to examine productivity and changes in complexity and diversity over time. More study of impacts of the water regime is needed, especially in freshwater impounded systems. Study of such hydrologic relationships should include the influence of surface and ground water, and the effects of flooding regime variability on species interactions. More study of interactions of neighboring uplands with wetlands is needed, specifically on whether there is a minimum necessary wetland size, and on effects of buffer zones.

We need to keep in mind that the goal of this exercise is to provide a more objective basis for evaluating wetlands and justifying mitigation requirements. Scientists must try to sort out a balance among various priorities in wetlands, because agencies represent and defend only their administrative mandates, e.g., fisheries, wildlife, etc. Scientists may also contemplate the question of the needs of the wetland, versus the needs of humans.

Chapter 6 — Consumer Support

Consumptive and Non-Consumptive Uses of Vegetation in Pacific Northwest Aquatic Ecosystems

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Abstract

Wetlands in the Pacific Northwest support consumer organisms, and therefore tertiary producers, by providing food directly or as detritus. Vegetation and the substrates for the plant community also provide structure and cover in two or three dimensions, thus enhancing habitat variety in the water body. This attribute is probably at least as important as food, but is difficult to quantify.

In open coast habitats kelp (*Macrocystis integrifolia)* is one of the most important plants, with both local and distant benefits for consumers. Another kelp (*Nereocystis lutkeana*) has similar functions in sheltered waters including estuaries. In estuaries, microbenthic algae, sedges (*Carex* spp.) and eelgrass (*Zostera* spp.) are major suppliers of detritus and direct food, and also provide structure to these sedimentary habitats. In large estuaries (e.g. Columbia, Fraser, Skeena) riparian inputs from trees and food webs dominated by insects are probably unappreciated and few data are available. There is also a surprising lack of information on the role of vegetation in the ecosystems of large and intermediate sized rivers (about stream order 6 to 10) in the Pacific Northwest. More data on smaller streams are available and show riparian inputs from willows (*Salix* spp.), salmonberry (*Rubus spectabilis*), and alder (*Alnus* spp.) to be very important for aquatic insect consumers. The relative importance of riparian production (allochthonous inputs) compared to contributions from instream microbenthic algae is controversial. Dams and pools created by woody debris from shrub and forested vegetation are important offchannel and instream habitats. Shoreline vegetation on lakes and ponds is dominated by sedges (*Carex* spp.) and willows (*Salix* spp.), but in larger lakes and reservoirs submerged vascular plants (e.g. *Chara* spp.) are important to consumer communities.

The relative importance of this vegetation to consumers compared to phytoplankton is dependent on the relationship of a water body's surface area to its perimeter and flushing rates. Techniques for rehabilitation and creation of wetlands are available, but data are fragmentary on success to establish well-functioning and productive consumer communities. The production rate and availability of invertebrates to tertiary consumers such as fish is obviously closely linked with water levels, so when planning to reconstruct wetlands this parameter is very important. Methodology for using vegetation to build structure into habitats is also extremely relevant.

Introduction

Wetlands support consumers by providing habitats where vital life history links take place. Often the links are transition points where a species metamorphoses into a different life stage, reproduces, or migrates from one key habitat to another. Wetland management requires a rating or evaluation of various vegetation communities for breeding/rearing, feeding/foraging, refuge, and migration, but these terms actually describe interrelated or overlapping life history processes. The interaction of functions in wetlands has been well recognized by both applied biologists (e.g. Adamus and Stockwell 1983) and basic researchers in this field (e.g. Nixon 1980). Habitats for invertebrates, for example, often provide space, feeding and foraging, and refuge simultaneously. This fact may not always be obvious because comprehensive data are lacking for wetlands in the Pacific Northwest, as pointed out by Macdonald (1977), and therefore considerable judgement is needed before evaluation. In addition, the role of wetland plants in providing structure, cover, and refuge is at least as important as feeding, and should be emphasized as a major role of vegetation. Therefore I will review in some detail both consumptive and non-consumptive aspects of wetland function in the Pacific Northwest for marine, estuarine, riverine, and lake wetland habitats.

Consumptive Uses and Food Webs in Pacific Northwest Wetlands

Aquatic food webs are either autotrophic or heterotrophic (detritus-based). Heterotrophic bacteria also consume decomposing plant material and are then grazed by animals — the detrital pathway. Wetland and nearshore food webs in standing bodies of water, depending on depth and residence time of their water masses, are also supplied with organic material produced by phytoplankton. It is accordingly very difficult to separate and identify the ultimate source of elaborated carbon in wetland food webs. In fact there are few detailed data on these relationships in the Pacific Northwest, and this report reviews the available information, concentrating where feasible on the major studies.

Marine Wetlands — Kelp Beds

The majority of the organic matter produced in kelp beds appears to be used in detrital pathways (Srivastava 1982). Studies in the Strait of Georgia by Smith et al. (1985) indicated that the proportion of kelp biomass eventually processed into detritus may exceed that consumed directly by herbivores by three- to four-fold. Bacterial colonization may take place on organic exudates from the plant cells, on parts of the plants broken off by storms, or on the whole plant at the end of the growing season. Kelp bed material may be used some distance from the bed, either out to sea (as shown by studies off South Africa; Field et al. 1981) or on beaches on the nearby coastline. On sand beaches on the west coast of Vancouver Island, Richards (1984) showed that kelp bed debris, in addition to providing food for talitrid amphipods, also provided refuge from the amphipods' major predator, a staphylinid beetle. Detritus from seaweed in the Strait of Georgia was found to accumulate maximum biomass in late August (Figure 6-1) when it was used by a variety of gastropods, especially *Margarites coastalis* and *Lacuna marmorata* (Smith et al. 1985). A similar situation is likely to exist on the open coast, although the detritus could be transported and dispersed further from the bed because of greater wave energy and longshore currents.

Diverse local and distant communities of fish and invertebrates are supported by kelp production, mainly by the detrital pathways described above. These communities have not been well documented in the Pacific Northwest, but have been investigated in California by Leighton (1966) and in Alaska (Aleutian Islands) by Simenstad et al. (1977). The food web relationships of the Alaskan *Alaria* spp. system involve dozens of fish,

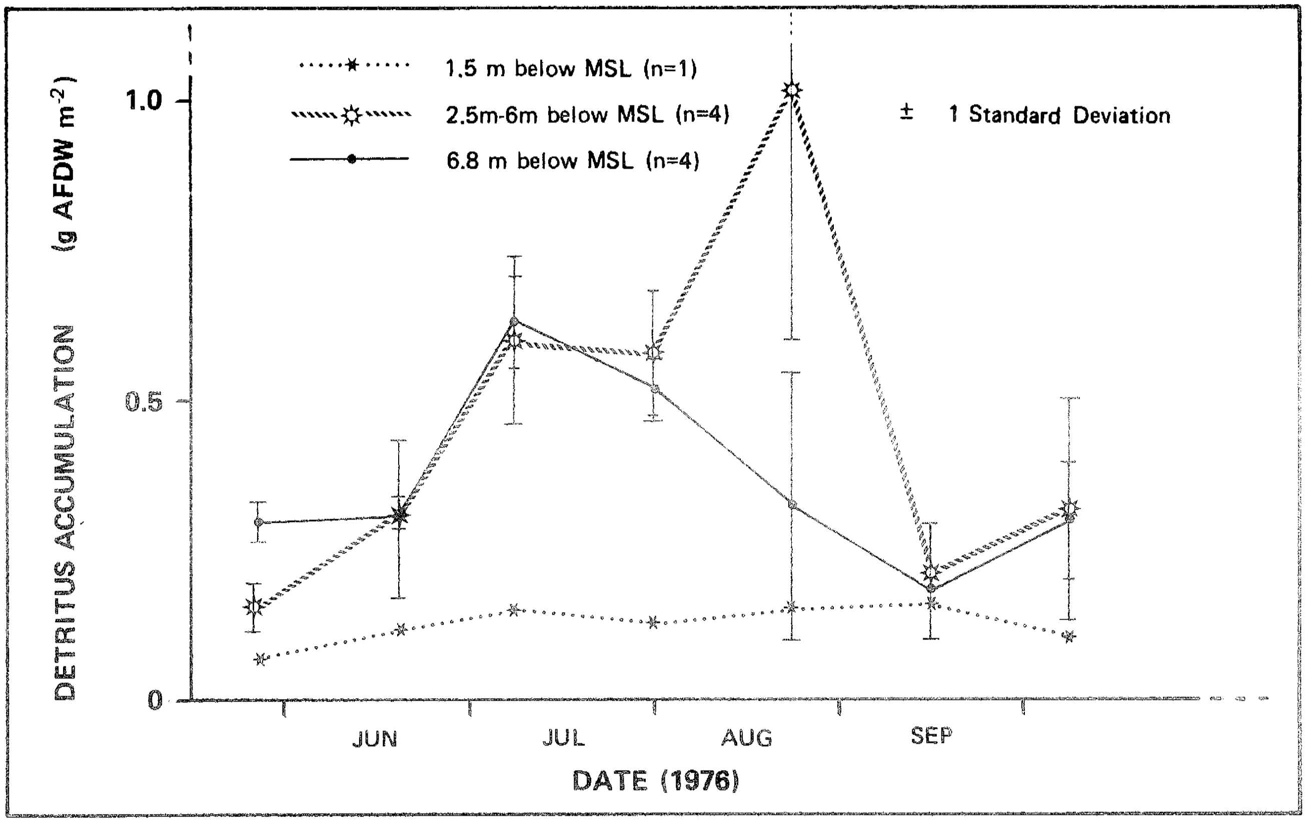

Figure 6-1. Detritus accumulation on cleared substratum in the seaweed zone at Bath Island, Strait of Georgia (n = number of quadrat samples) (after Smith et al. 1985).

including commercially significant species such as salmon, halibut, and cod. Supporting the fish are invertebrates which, in turn, use kelp detritus. Some of the more important taxa include gammarid and caprellid amphipods, mysids, isopods, euphausiids, cumaceans, decapod shrimps, lithoid crabs, brachyuran crabs, harpacticoid and calanoid copepods, polychaetes, and pelecypods.

Autotrophic pathways in kelp beds are those that involve direct grazing on the plants themselves. Direct grazing by urchins on *Macrocystis pyrifera* in California was documented by Harrold and Reed (1985). In the Pacific Northwest area, direct grazing by sea urchins (*Strongylocentrotus* spp.) on algae has been examined by Paine and Vadas (1969) and Foreman (1977). Sea otters consume urchins and abalone (*Haliotis* spp.) and the harvesting of the otters in the 1800s may have consequently affected the kelp bed community (Estes and Palmisano 1974).

Estuarine Wetlands

Research in British Columbia and Washington has investigated the linkages among the food webs of estuaries, and in the past decade this topic has received considerable attention. Direct consumption of estuarine vascular plants, e.g. brant feeding on eelgrass (*Zostera marina*) and snow geese on sedges (Rodgers 1974), has also been recognized for some time.

Vascular plants and microbenthic algae. Research at the Nanaimo River estuary in the early 1970s demonstrated that a complex food web involving vascular plants (primarily eelgrass, *Z. marina*) and sedge (*Carex lyngbyei*) debris, bacteria, and benthic algae was involved in providing nutrition that ultimately supported harpacticoid copepods (esp. *Harpacticus uniremis*) and chum salmon (*Oncorhynchus keta*) (Sibert et al. 1977; Brown and Sibert 1977). The harpacticoid-salmon fry link has been summarized by Simenstad et al. (1982) and Healey (1982), and clearly this detrital-based production system is of regional significance. Detrital feeders other than harpacticoids are also involved. For example, the suspension-feeding amphipod *Corophium salmonis* is the main prey for juvenile chinook (*O. tshawytscha*) in the Sixes River estuary, Oregon (Neilson et al. 1985). Further studies by Naiman and Sibert (1978) attempted to put together a budget for particulate organic carbon (POC) and dissolved organic carbon (DOC) for the Nanaimo estuary. These authors concluded that allochthonous input of DOC from the river's watershed was at least as important as that produced in the estuary itself (autochthonous production), at least in quantitative terms. This had been recognized earlier by Seki et al. (1969).

Studies in the Squamish and Fraser River estuaries in B.C. also investigated the pathways of energy flow, reaching slightly different conclusions and emphasizing autochthonous or direct pathways from algae to consumers. Pomeroy (1977), working at the Squamish estuary, found that direct grazing on microbenthic algae by the intertidal amphipod *Eogammarus confervicolus* could make significant impacts on standing crops of benthic diatoms such as *Pylaiella littoralis* and *Navicula grevillei*. Murphy (1984), working in an estuary in southeast Alaska, found similar results. Subsequent growth studies, although not with pure cultures, and hence including some component of detrital bacteria, showed that the amphipod grew and survived best on *Enteromorpha linza*, *P. littoralis*, *Porphyra* spp., *N. grevillei*, *Carex lyngbyei* debris, and *Ulva lactuca*, in that order (Pomeroy and Levings 1980). A recent study with the same amphipod, also at the Squamish estuary, demonstrated that *C. lyngbyei* detritus and *Fucus distichus* yielded better productivity compared to wood chips, a substrate relatively free of algae and bacteria (Stanhope and Levings 1985).

Another recent study, using the carbon-13 enrichment technique, appears to support the view that autochthonous pathways from localized sources of estuarine carbon are most relevant for estuarine food webs (Simenstad and Wissmar 1985). In Hood Canal, Washington, the finding that epibenthic crustaceans in estuarine littoral habitats were enriched in ^{13}C relative to sestonic particulate organic carbon, dissolved organic carbon, sediment, and most detrital carbon, indicated the prominence of nearby carbon sources (sandflat algae, eelgrass). Unlike the Nanaimo study, the importance of detrital carbon from allochthonous sources in the watershed of the rivers draining into Hood Canal was not shown in this study. Although considerable carbon is added to estuaries from rivers, it may be refractory and not utilized by consumers. Further investigations of the C:N ratio in detritus, which is only an approximate index of food suitability, are required to investigate this further.

The role of vascular plant detritus in estuarine food webs has therefore been fairly well established, but there are no doubt many subtle interactions, especially between microbes, algae, and vascular plant material, that are not yet understood. These interactions could be important for wetland management. Recent studies by Rieper (1985) showed that although harpacticoids can use bacteria directly, as shown by Brown and Sibert (1977), ciliates and other protozoans may be an intermediary trophic level (Figure 6-2) and some

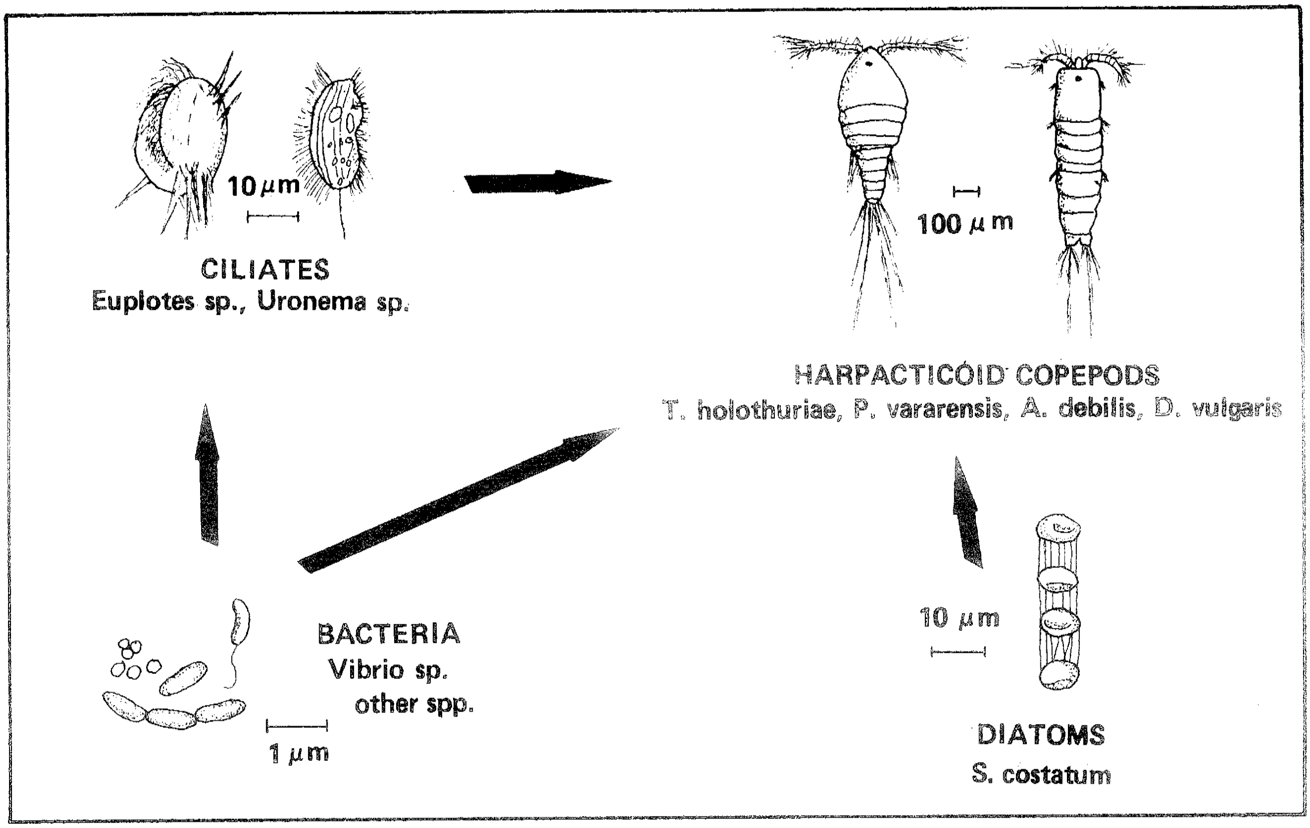

Figure 6-2. **Bacteria, protozoans, and diatoms involved in nutrition of harpacticoid copepods (from Rieper 1985).**

harpacticoids may need algae as a growth stimulant. These relationships need more investigation before ecosystem models can be considered comprehensive.

Kelp Beds. Kelp beds can develop in estuaries where salinities are not significantly reduced, and algae such as *Nereocystis lutkeana* and *Laminaria groenlandica* are important production sites in Puget Sound, the Strait of Georgia, and southeast Alaska. As described above, Smith et al. (1985), working in the Strait of Georgia (Bath Island) found that gastropods were consumers of kelp detritus, while the green sea urchin (*S. drobachiensis*) consumed the kelp plants directly (Foreman 1977). Levings et al. (1983; their Table 2) found that five faunal groups could be identified in the nearshore ecosystem near Bath Island, and the majority of species comprising the units were associated with kelp, foliose red, or "deep" algal communities. Direct grazing by urchins is an important controlling factor for both the primary kelp in the bed and understory species, as shown by Paine and Vadas (1969) in experiments near Friday Harbor (Puget Sound). Clearly, both autochthonous and allochthonous routes of consumption of the kelp are important in estuaries, as was the case for *Macrocystsis pyrifera* in offshore habitats.

Rocky substrates at the base of kelp beds or adjacent to these wetlands are important habitats for filter feeders such as mussels (*Mytilus edulis, M. californianius*) and barnacles (*Balanus glandula*), which may derive some of their nutrition from algal detritus (Wu and Levings 1979) but mainly use phytoplankton. These invertebrates, in turn, support avifauna such as scoters and other sea ducks that overwinter in coastal waters (Vermeer and Levings 1977).

Sand and Mudflats. Unvegetated areas deserve recognition as important habitats in estuaries, especially where river deltas are building out rapidly by settlement of mud and sand (e.g. Fraser, Skagit). Detritus from both algae and vascular plants is used by invertebrates on the flats, and there is significant use of autochthonous production as well (Pomeroy and Levings 1980; Simenstad and Wissmar 1985). Invertebrate communities — primarily assemblages of harpacticoids, amphipods, thallasidean shrimp and polychaetes — have been documented for the Fraser estuary by Swinbanks and Murray (1981), Harrison (1981), and Levings and Coustalin (1975); for the Yaquina estuary by Crandall (1967); and for the Columbia estuary by Higley and Holton (in Seliskar and Gallagher 1983) and Simenstad (1984). Tidal channel habitats that provide low water refuges for fish in mud/sand flats have been described by Levings (1982) and Simenstad (1983). Tidal flat invertebrates are used extensively by migrating dunlin and other shorebirds and for food during overwintering and migration (Rodgers 1974).

Riverine Wetlands

Food webs in streams and rivers derive their primary production from phytoplankton, and from plants (mostly algae) living in the stream bed and along their banks. All vegetation contributes to food webs which indirectly provide fish with energy (Mundie 1974). According to the river continuum hypothesis, allochthonous primary production is more important for invertebrate consumers (collectors, shredders, predators, and grazers in that order) in low order streams, whereas *in situ* and/or autochthonous material is used in intermediate-sized rivers and streams by a different community of invertebrates (i.e. collectors, grazers, predators, and shredders in that order) (Vannote et al. 1980). This concept emphasizes the importance of overhanging riparian vegetation as an energy source in smaller streams. In some circumstances (e.g. canopy opening by logging) autochthonous production by microbenthic algae can be important for invertebrates (e.g. Duncan and Brusven 1985). For non-forested interior rivers, autotrophy may be the dominant source of primary production, as shown by Minshall (1978) for an Idaho stream. Similar differences within the same geographic area (southeast Alaska) were in fact found by Duncan and Brusven (1985), who showed that leaf litter input into a stream where riparian vegetation had been regenerated was significantly higher than that into a stream in an old-growth forest or another in a recently logged area. In the latter, stream autochthonous production dominated, a post-logging response also documented at Carnation Creek on the west coast of Vancouver Island (Shortreed and Stockner 1983).

Much of our knowledge of the relative role of various vegetation types in supplying organic material for consumers in fact is only available for small streams in the Pacific Northwest. Large rivers (e.g., Columbia, Fraser, Skagit, Skeena, etc.) which support major populations of consumers, especially insects and crustaceans (the latter often in lower river habitats), are very poorly studied. Only qualitative descriptions of food webs and routes of energy flow are available (e.g. Northcote et al. 1979 on the Fraser River [Figure 6-3]; Simenstad 1984 on the Columbia River). According to the river continuum hypothesis, the larger rivers (stream order 8-10) function through a phytoplankton/zooplankton food web. Given the high turbidity and velocities in our major rivers, it is likely that such primary production is limited. In these circumstances, riparian and flood plain vegetation may in fact contribute to a detritus pool that is as yet unappreciated (e.g. Mulholland 1981) and that may be more important than *in situ* phytoplankton production.

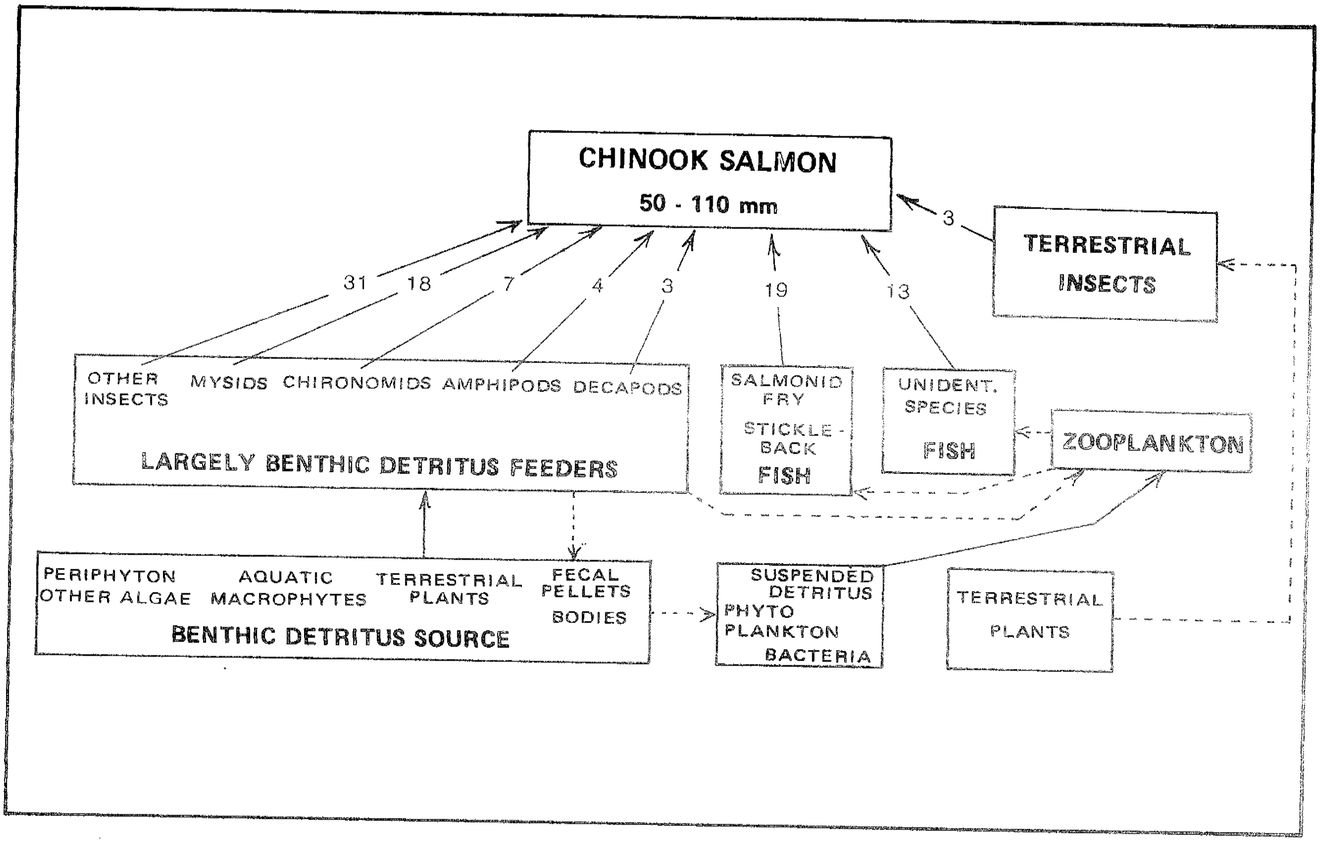

Figure 6-3. Food web supporting juvenile chinook salmon in the lower Fraser River, B.C. Numerals on lines leading from prey species indicate the percent contribution of the various taxa to chinook diets (after Northcote et al. 1979).

Although direct grazing on microbenthic algae was downplayed by earlier workers (e.g. Mundie 1974), it is clear from recent work that certain invertebrates are able to effectively use stream algae as food. In fact, grazing on algae by a herbivorous caddisfly (*Helicopsyche borealis*) in a northern California stream was found to stimulate algal production (Lamberti and Resh 1983). As explained above, the quality of detritus available to stream invertebrates, as well as physical factors such as temperature, substrate, and currents, can determine which community of invertebrates uses various types of plant material and the rate at which it is consumed. For example, Short et al. (1980), working in a Colorado stream, showed that 26 to 28 taxa of Ephemeroptera, Plecoptera, Coleoptera, Trichoptera, Diptera, Hydracarina, and Oligochaeta colonized alder, aspen, and willow litter, but only 22 were able to use pine. Duncan and Brusven (1985), who studied a stream in southeast Alaska, found that the processing rate (k) of allochthonous material for western hemlock was low (k = 0.0014) compared to alder (k = 0.0190), black cottonwood (k = 0.0218) and salmonberry (k = 0.0107). Insect larvae with the "collector-gatherer" feeding mode were the most important organisms using the leaf litter.

Lakes and Ponds

Vascular plants on lakes and ponds are used directly by waterfowl, especially dabbling ducks, swans, and geese (Rodgers 1974). Moose, deer, and bears also consume the shore

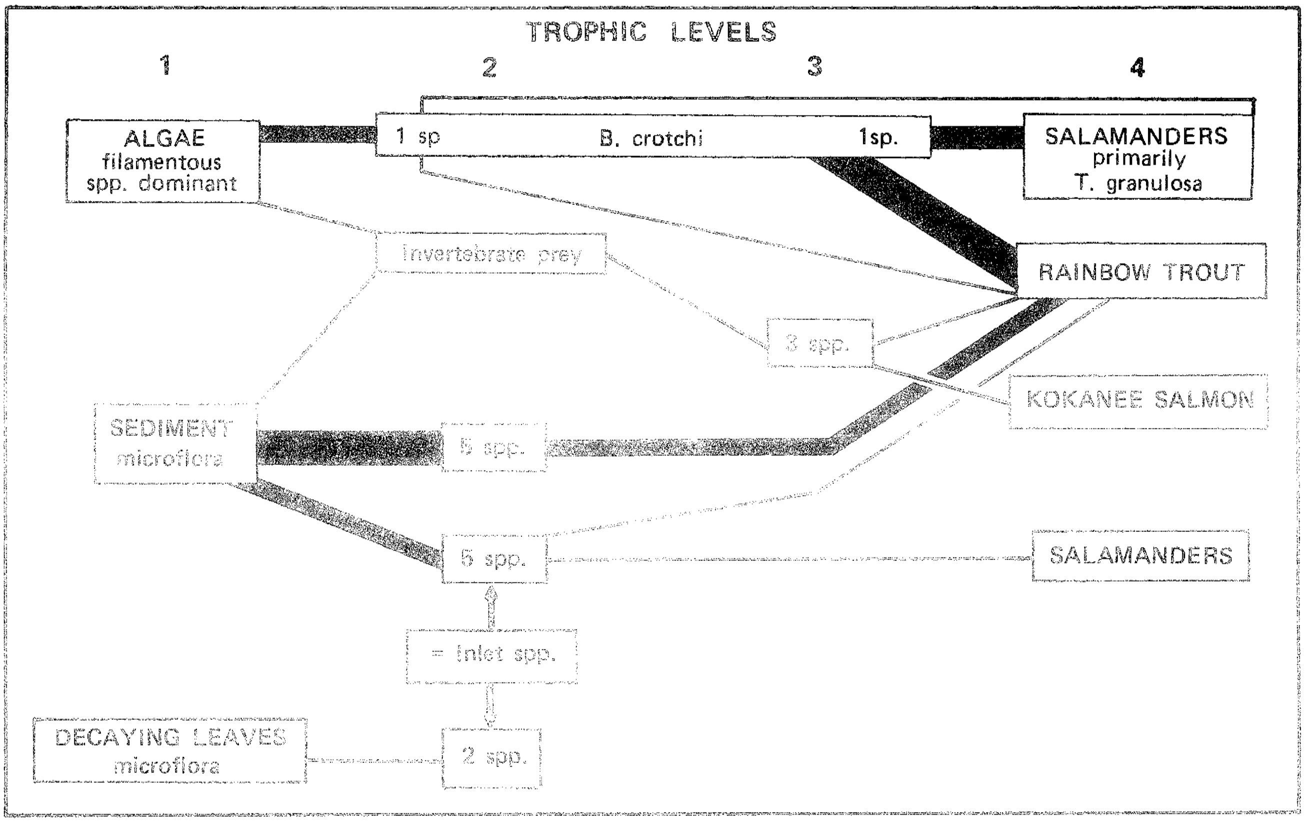

Figure 6-4. Food web summarizing the role of the Trichoptera in energy transfer through the Marion Lake community. The relative importance of the different pathways is indicated by the width of the lines (after Winterbourn 1971).

vegetation, and some herbivorous mammals (e.g. beaver) eat riparian vegetation (e.g. willow, alder).

In lentic habitats, the relative role of phytoplankton compared to shoreline vegetation and riparian communities for invertebrate consumers is dependent on the surface area/perimeter length relationship and also on the flushing rate of the water body (e.g. Efford and Hall 1977). Where the area/perimeter ratio is large and/or flushing rates are rapid, shoreline vegetation is likely to be more important in food webs, and detrital pathways for invertebrate consumers are likely to be emphasized.

In Marion Lake, B.C. (13.3 ha) for example, detritus input from the inlet stream and from decomposition of the shoreline plants (primarily *Potamogeton* spp., *Chara globularis*, and *Nuphar polysepala*; Davies 1970) contributed most of the carbon for benthic invertebrate communities (Efford and Hall 1977). Hargrave (1970) found that the epibenthic algae of the lake were important for nutrition of gammarid amphipods (*Hyallela azecta*). He also found that grazing by the amphipod could stimulate bacterial activity, which presumably was dependent on detritus supply. Winterbourn (1971) found that of nine species of Trichoptera found in the main lake, five were classified as detritus feeders using autochthonous material derived from decomposing vascular plants, as well as sediment microflora (algae, bacteria) (Figure 6-4). In a similar-sized (11.4 ha) but oligotrophic lake in Washington (Findley Lake), Wissmar and Wetzel (1977) found that most of the allochthonous input of litter from Pacific silver fir (*Abies amabilis*) and mountain hemlock (*Tsuga mertensiana*) provided sufficient carbon input to support the trichopterans of the lake. As was the case for detritus deriving from the Nanaimo River watershed (see above), the C:N ratios of detritus in sediments from the lake were quite high (11-18), and may have been refractory to some extent.

Non-Consumptive Uses

The non-consumptive role that vegetation fulfills for consumer species at various trophic levels is frequently part of the overall rationale used in wetland management. Typically, the concept of cover or refuge from predation is invoked, but data are much weaker than those for consumptive or trophodynamic considerations and are almost qualitative in many instances. The role of wetlands in providing habitat for endangered and rare animals (estimated 30 species in Washington state) may be related to provision of refuges. These species may have unappreciated functions in the wetland food web, but are virtually unstudied because they are not commercially significant.

For kelp beds, about the only quantitative data for cover and its relevance for fish from the Pacific Northwest are those from Leaman (1980). He showed that rockfish (*Sebastes melanops*) were more abundant on the outer edge of a *Nereocystis lutkeana* bed on the west coast of Vancouver Island compared to adjacent areas (Figure 6-5), including the interior of the bed. Benthic fish species were more facultative users of the kelp. Tube snouts (*Aulorhynchus flavidus*) spawned on the pneumatocysts of the kelp (Leaman 1980). Leaman (1976) showed that the cover aspect of a *Macrocystis* bed seemed to be important, as the rockfish also aggregated under a black plastic cover. Many other marine fish, including juvenile salmonids, are strongly associated with kelp beds. Whether this is cause and effect or a coincidence of shoreline orientation is yet to be investigated. A recent paper by Harrold and Reed (1985) from California demonstrated the interaction between cover and food for the red and purple urchin (*Strongylocentrotus franciscanus* and *S. purpuratus*). When the urchins were in a kelp bed (*Macrocystis pyrifera*), they used crevices within the bed as cover and fed on drift algae. In areas of food shortage ("barren grounds") the urchins left cover and actively grazed the substrate. The appearance of food (drift algae) stimulated the urchins to move into cover.

Estuarine plants seem to provide cover for invertebrates, as there is a strong relationship between plant debris and abundance and diversity of animals. This has been shown for the amphipod *E. confervicolus* by Levings (1974) (Figure 6-6), for another amphipod (*Hyale plumulosa*) and *Fucus distichus* (Nassichuk 1975), and for insects and pickleweed (*Salicornia* spp.) by Cameron (1972). Eelgrass provides a substrate for herring spawning (Haegele et al. 1981) as well as for invertebrates such as nudibranchs. The vertical structuring provided by eelgrass plants may be an important factor in the availability of harpacticoids for fish. The crustaceans use the epiphytes on the blade for food (Phillips 1984) and as a result are placed higher in the water column. Although extensively investigated on the Atlantic coast, the role of eelgrass as cover habitat for fish on our coast has not been experimentally demonstrated. Nevertheless it is widely recognized from survey data that eelgrass beds harbor much more diverse fish and invertebrate communities than adjacent unvegetated habitats (e.g. Miller et al. 1980; Gordon and Levings 1984). Sibert (1982) suggested that vegetation may function as a detritus trap in estuaries, increasing the availability of this carbon source to invertebrate consumers.

The importance of cover for fish in freshwater habitats has been better recognized (Figure 6-7), especially the cover provided by large woody debris in streams of the Pacific

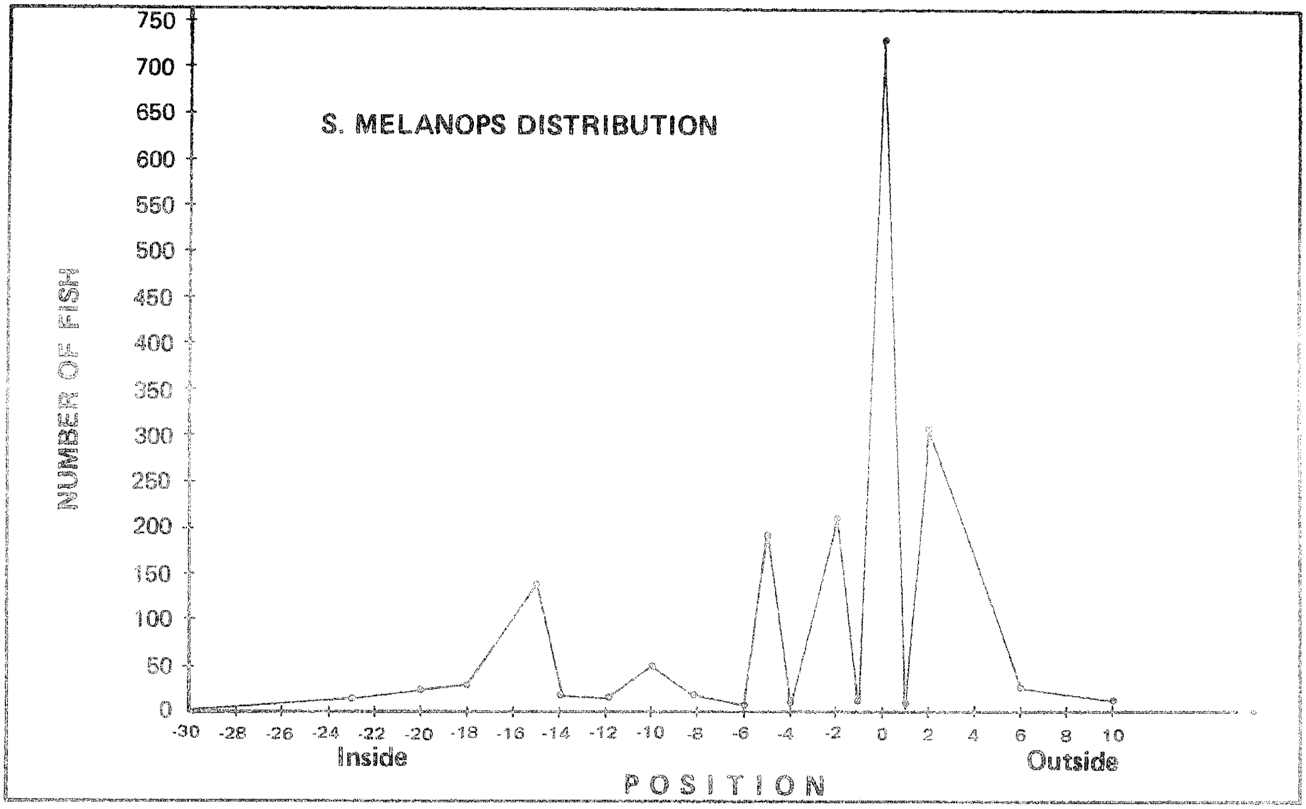

Figure 6-5. **Cumulative abundance of black rockfish (*Sebastes melanops*) inside and outside a *Nereocystis lutkeana* bed in Barkley Sound, B.C. Zero indicates the seaward edge of the kelp bed, negative and positive numerals on the abscissa indicate position (m) shoreward and seaward respectively (after Leaman 1980).**

Northwest (e.g. Bisson and Sedell 1984). Although not well investigated quantitatively, cover has been incorporated into habitat models (e.g. Binns and Eiserman 1979; McMahon 1983) that attempt to predict fish abundance from biotic and abiotic factors. Large woody debris is also an essential part of a river's mechanism to maintain a relatively high pool:riffle ratio (e.g., Lisle 1983). Since pools are overwintering habitat, especially for coho juveniles, maintenance of deeper water is important for good coho production (Bisson and Sedell 1984). Woody debris is also an essential component of beaver dams, which create vital on-and-off channel overwintering habitat (Bustard and Narver 1975; Swales et al. 1986).

Shoreline plants on lakes and ponds can consist of submergent, emergent, and riparian vegetation, and the importance of these wetlands types compared to phytoplankton production is of course related to the extent of the waterbody's littoral zone. Invertebrates such as gammarid amphipods (e.g. *Hyallela azteca, Gammarus lacustris*) are most abundant in the littoral zone around submergent plants such as *Chara* spp., at least in lakes of the Washington and B.C. interior (e.g. Rabe and Gibson 1984; Rawson 1934). The importance of *Chara* spp. as a refuge for gammarids being preyed on by rainbow trout (*Salmo gairdneri*) was pointed out by Johannes and Larkin (1961). The role of littoral vegetation as a habitat feature for salmonids and other fish in Pacific Northwest lakes, rivers and ponds has been poorly investigated. Surveys (e.g. Graham and Russell 1979;

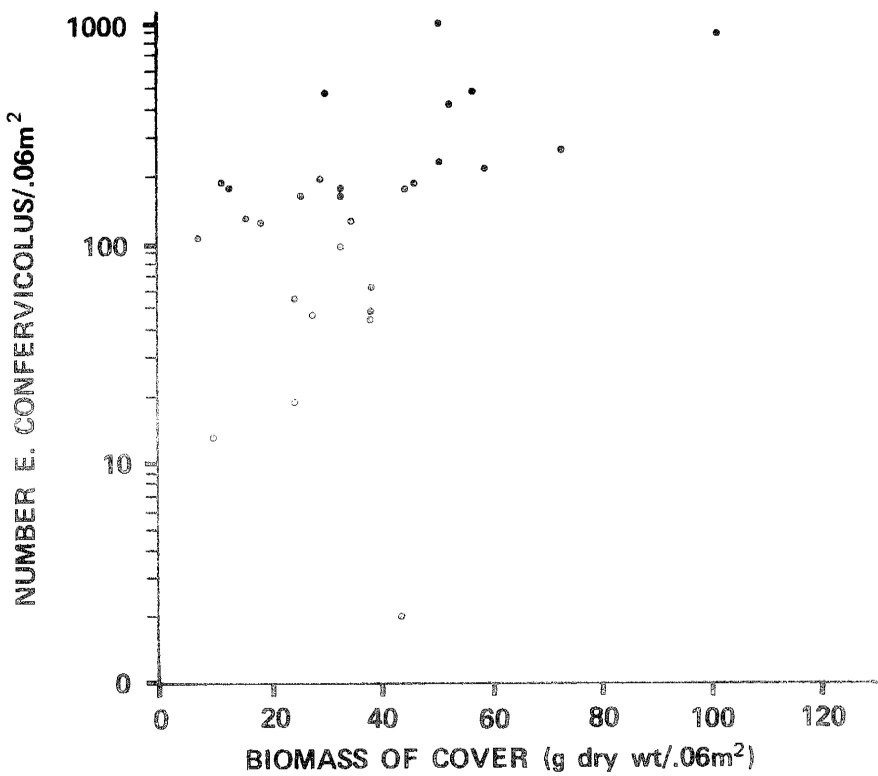

Figure 6-6. **Relationship between biomass of cover (sedge rhizomes and rockweed) and amphipod abundance (*Eogammarus confervicolus*) at the Squamish River estuary, B.C. (after Levings 1974).**

Shuswap Lake) show that juvenile chinook and coho are strongly shoreline-oriented in large lakes. This topic deserves more attention.

Waterfowl are major users of vegetation for nesting and roosting, especially in lakes, ponds and estuaries. Eagles, osprey, and great blue herons use trees on shorelines for nesting, and also build their nests from twigs and sticks from riparian vegetation. This structural use of vegetation is somewhat analogous to the use of tree branches by beavers building their lodges.

Prospects for Restoration and Creation

The success of recent wetland restoration experiments has been poorly documented, even for the basic parameters of growth and survival of the plant themselves. My review of the literature, which focused on consumer organisms and functions, showed that data are even scarcer for this topic. This is because we have an incomplete understanding of how intact wetland systems function.

The rationale for wetland restoration frequently involves the concomitant maintenance, restoration, or upgrading of consumer production — for example, landings of fish or hunter success for waterfowl. Perhaps because water fowl are more directly related to vegetation (e.g., nesting sites, grazing), production increases can be shown for this consumer group following restoration or creation (e.g. Ratti et al. 1982). Restoration of

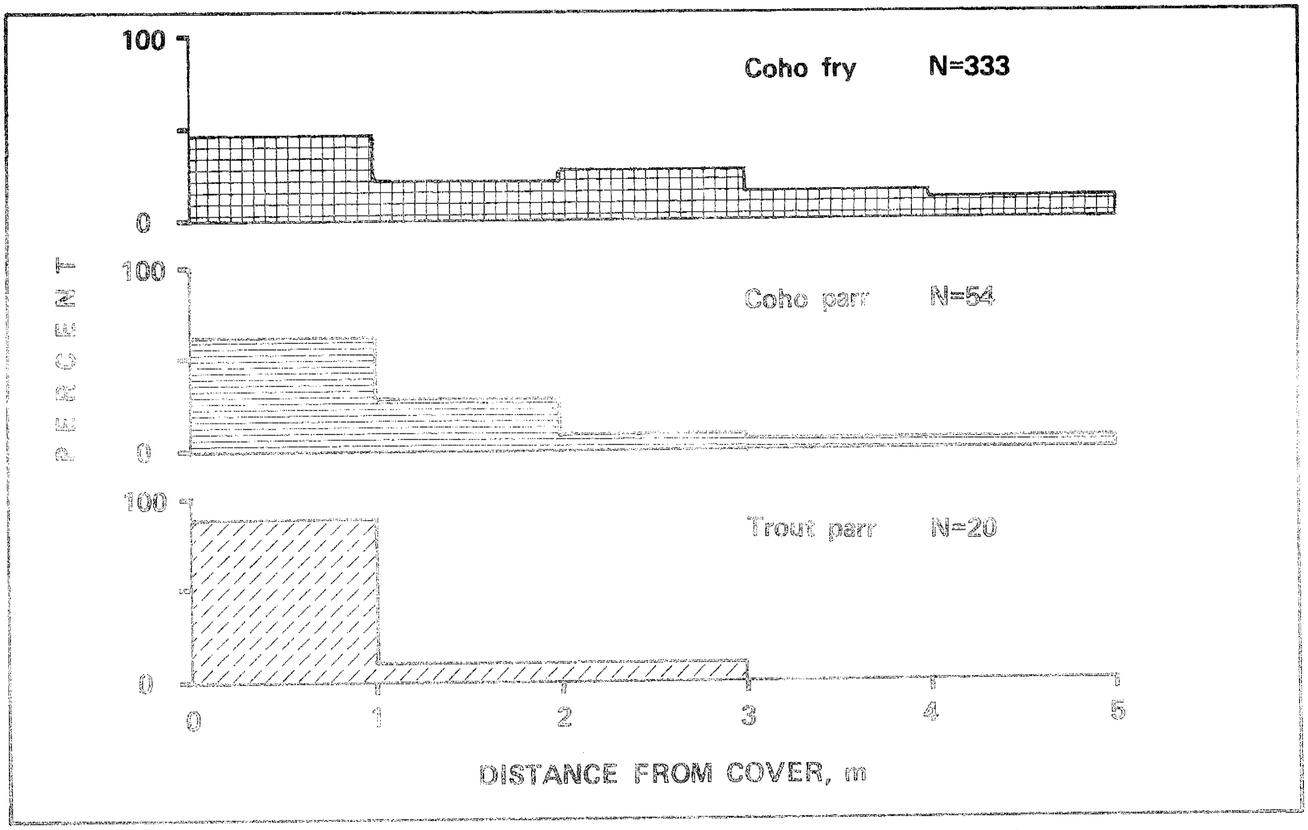

Figure 6-7. Abundance of coho fry and parr (*Oncorhynchus kisutch*) and trout parr (*Salmo gairdneri*) with respect to distance from cover, primarily woody debris, in a southeast Alaska stream (after Murphy et al. 1984).

lake, stream, estuarine, and marine wetlands is frequently used as a technique to try and increase fish production. Artificial reef developments are useful for "enhancing" marine fish populations (see below) but this technology cannot be considered proven for the other three habitats, especially for salmonids. More detailed research is required on the complex processes governing salmon production before relationships with wetlands can be shown. Before attempts are made to augment fish production through wetland restoration, managers should determine whether a particular stock's habitat is below, at, or above capacity.

Restoration of marine habitats in the Pacific Northwest has been documented in only a few studies. Gascon and Miller (1981), working in Barkley Sound on the west coast of Vancouver Island, showed that a very small scale artificial reef would be used by bottomfish. Miller and Hensel (1982) observed the colonization of cobble and riprap by kelp (*Nereocystis lutkeana*) in subtidal habitats off the Fraser estuary. They also documented the initial growth of small intertidal algae on riprap. The most extensive habitat restoration projects for marine fish communities are probably those of the artificial reef program established by Washington Dept. of Fisheries (e.g. Hueckel et al. 1983). These projects have been quite successful — the reefs do attract fish and are used for sports fishing. Their productivity and performance relative to natural rocky shorelines and reefs have not been documented.

As far as is known, restoration of wetlands in Pacific Northwest estuaries has been restricted to transplants of sedge, eelgrass, and pickleweed. Few studies have documented colonization by consumer communities. Transplants of sedge were first conducted by McVay et al. (1980), working on Miller Sands in the Columbia River. There did not appear to be any concurrent monitoring of invertebrates. Pomeroy et al. (1981) performed some small scale transplants of sedge on the Fraser estuary and found that gammarid amphipods were trapped in the algae entangled in the sedge stems, as also occurs in natural sedge meadows. During the six months in 1981 that a dredge-spoil sand island existed above high tide in the Fraser estuary, the sea rocket, *Cakile edula*, colonized the substrate. Sparrows and other passerines used these plants for roosting (Levings, unpublished data). The supratidal portions were also used as roosts for dunlin. Probably the most successful large-scale sedge transplant to date has been at the Campbell River estuary in B.C. (Brownlee et al. 1984). Chinook fry (*Oncorhynchus tshawytscha*) used these habitats extensively two months after they were built (Levings et al. 1986). Even before transplanting, gammarids and mysids colonized the low-elevation portions of the gravel islands at Campbell River. Harpacticoid populations were also very similar to those at reference sites within a few months (Kask et al. 1986). Further increases in secondary production and fish use might be expected as vegetation spreads, and this is under investigation.

Construction of sand and gravel islands seems to present some potential for habitat restoration in estuaries, but the technique should be used only in estuaries where normal accretion has been stopped, as was the case at Campbell River (due to a dam). The points made by Gonor (1979) should be heeded — since much of the wetland loss has occurred through filling, it is usually a better strategy to restore estuarine habitat by dredging and dike breaching. Recovery of low elevation habitats should be emphasized wherever possible. Studies in North Carolina (Cammen 1976) showed that creation of new marsh in areas that were previously subtidal actually may have reduced estuarine secondary production, by changing faunal composition from low elevation organisms (e.g. polychaetes) to species associated with emergent vegetation (e.g. insects). These are qualitative changes in consumer communities that should be examined if substrate elevation is being considered as part of a restoration project.

Restoration of freshwater wetlands and associated consumers appears to be very poorly documented in the Pacific Northwest. Colonization of restored riparian habitat by drift organisms might be expected to be fairly rapid, but whether insect communities will be as productive as those at natural sites remains to be investigated. A study in Wisconsin found that insect colonization of a relocated stream reach took about five and a half years. A lack of coarse particulate organic material, which resulted from removal of riparian material, was implicated as one of the reasons for delayed colonization (Narf 1985).

Summary and Research Priorities

Review of the available literature showing how Pacific Northwest wetlands support consumers has shown that knowledge of processes and relationships is slowly building, but several major topics need further substantiation to support inferences currently used.

For improving management criteria, perhaps the most important void is the almost absolute lack of data on long term changes in wetland fauna and communities. The value of decade-scale sampling for management has been recognized in San Francisco Bay, for example (see Nichols et al. 1986), but there are no comparable data in our region.

Long-term data are particularly relevant for wetland restoration and creation because of the temporal changes in consumer groups and process rates that may or may not occur as vegetation succession proceeds. In order to evaluate whether a developed wetland will support an equally diverse and/or productive community of animals, sequences of faunal change need to be documented. Although long-term studies appear to be difficult to set up and support, there is no alternative to this approach if scientifically supportable management decisions are to be made.

Both natural and developed wetlands are modified and shaped by physical forces such as currents, wave action, and water quality. These can in turn affect the faunal composition of the vegetation units, but such interactions are poorly known for wetlands. Micro-scales of measurements are involved, such as modifications in eelgrass beds and wave action around kelp beds. There are virtually no data on these topics in the Pacific Northwest, but such data are needed for properly siting wetland restoration and development projects and for understanding how natural systems operate. This is an area of research where laboratory flume tests (e.g. Muschenheim et al. 1986) combined with field observations would be extremely fruitful. Data on the trophodynamic aspects of wetland function appear to be best for estuaries and small lakes and streams, but even these habitats require further attention to re-examine concepts developed in the past 10-15 years (e.g. bacteria vs. protozoans, and algae in detritus). Energy or carbon flow budgets of wetlands ecosystems can be constructed (see Wissmar, this volume). For scientifically defensible decisions, further quantification of the importance of refuge is needed; the "refuge" aspects of wetland function cannot easily be measured or accounted for in the present models. This issue may be particularly important for rare or endangered species and non-commercial animals that use wetland habitats.

For wetlands that support commercial or game species, as either adults or juveniles, there is a continuing need for research to document how wetlands affect the survival of the species of interest. As pointed out above, for many management agencies production values provide the justification for wetland protection. Carrying capacity data are available for large herbivores such as moose and deer, and for waterfowl (e.g. Ratti et al. 1982). For species that have invertebrates as an intermediate link in food webs (fish, for example), measuring the carrying capacity of specific wetland habitats is much more complex and requires further development of new methodology.

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Working Group Report: Consumer Support

Colin Levings, Moderator
Ralph Rogers, Rapporteur

"The major consumer of wetlands is the bulldozer."

Review of Plenary Paper

The plenary review in this working group entailed elaboration of data gaps and research needs, which are presented under Discussion Questions below.

Discussion of Matrix

The group felt that definitions of certain functions were ambiguous and could be interpreted in multiple ways. For example, numerical values for the "Feeding and Foraging" function could be based on: total number of animals using a site; number of different types of animals using a site (diversity); diversity based on a density-weighted index; number of trophic levels supported; or specificity (importance or scarcity of a given habitat for particular species). These functions should be more precisely defined, and criteria should be developed to help determine numerical values for performance of functions by a wetland. The group also considered it essential that functional categories should be stratified by taxonomic groups: fish, mammals, birds, "herps" (reptiles and amphibians), and invertebrates.

A significant minority of the group felt that salmon and shellfish experts were poorly represented in the working group, relative to the economic importance of those faunal groups. (Such experts were invited but declined to attend the conference).

Discussion Questions

Outside or Site-specific Factors

Performance of consumer support functions can be affected by adjacent land use, geographic location, seasonality (seasonal habitat uses), extremes in habitat conditions (e.g., drought, flooding), and proximity to and local abundance of similar habitats.

Interdependence of Functions

The interdependence of consumer functions with other wetland functional values is very strong. In vegetated systems consumers are obviously closely linked to primary production, which in turn is closely related to certain abiotic functions.

Additional Functions

Consumer support criteria and functions not considered in the matrix include: trophic complexity (i.e., number of trophic levels); structural diversity and interspersion of habitats; physical and chemical water quality factors that affect consumers; consumers as biological indicators of pollution and health of environment; and agricultural and aquacultural production of food and fiber. They also include social amenities such as aesthetics, recreation (consumptive and non-consumptive), and education and research.

Data Gaps and Research Needs

Data adequacy for each of the four consumer support functions in the matrix, stratified according to five types of consumers, is presented in Table 6-1.

Knowledge of consumer support functions depends in part on research in hydrology, sedimentology, water quality, and primary production. Wetlands and riparian management zones should be studied on a broad geomorphic scale, using a localized watershed approach. Biologically-based research should be conducted on the dependence of wetland integrity on adjacent upland habitat. Criteria for buffer zone sizes in riparian zones and adjacent to wetlands should be established.

Habitat use by many species is relatively well known, but the correlation between given species and their habitats requires more study. Little is known about the amount of space needed by species, or about temporal patterns of habitat use by species throughout their life cycles. Improved sampling techniques for wetland fish are needed. A complete inventory of critical spawning habitats for littoral-zone fishes is needed, along with research on reasons for their extreme specificity of habitat selection. Freshwater impounded wetlands and ponds need similar habitat inventories. Animal communities that use riparian systems need to be better defined, especially west of the Cascades. The dependence of consumer production rates on habitat properties should be explored, especially for rare and non-game species. There is a general need for more data on life histories and environmental interactions of rare, threatened, endangered, and non-game species.

Wetlands science is ripe for studies of relationships between species, instead of just species inventories. These relationships include energy transfer and food chain production, processes that need to be quantified. The dependence of consumers on primary production and its regulating factors, and the capacity of wetlands for supporting consumers, are high priorities for further research. Models should be developed for groups of species relative to specific communities. Emphasis should be placed on production available to and consumed by salmonids, on the possibility of increasing food supplies for salmonids, and on the effects of competition from non-salmonids.

Research should be conducted on a long-term and interdisciplinary basis, and correlated with specific management needs. The responses of wetlands to human perturbations must be better defined, in part through use of cause-and-effect studies for predictive purposes. More basic research could be focused on habitat protection, such as identification of sensitive species as indicators of early changes in habitat quality. The "value" of wetlands should be evaluated, especially for non-game production. Statewide wetland inventories are needed, based on area, type, ownership, and quality. They should be accompanied by surveys of ordinances related to wetland protection.

Table 6-1

Data Adequacy for consumer support by function and faunal group.

Function	Faunal Group: Birds	Faunal Group: Mammals
Breeding & rearing	Data adequate, especially for game species, but needs to be synthesized. Relationships between species and habitats less well known. Information on management techniques not available to managers.	
Feeding & foraging	Few quantitative data for most species (not unanimous). Even if prey known for certain species, energetics unknown. Insufficient data for both game & non-game species for managers.	Some game species well known. Few quantitative studies for non-game species.
Refuge	General data available but not compiled. Infrequent/critical refuge needs less known.	Adequate data available for game, not for non-game species.
Migration	Most major roosts & wintering areas known. Staging areas less known — lack systematic quantitative studies.	Adequate studies on large game movements. Riparian corridors known to be important travel routes less studied. Small and non-game species less known.

Fish	Invertebrates	Herps
Game & some non-game species' life stages & habitat needs are adequately known. Relationships to habitats are less well known for most species.	Very little known except in streams. Most known about commercial species and pests. Marine studies increasing.	Habitat needs generally known. Less known about management & limiting factors.
Little knowledge of food preferences & energetics. Less known than about breeding & rearing. Best knowledge is of stream inhabitants. Game & commercial species prey studies adequate for estuaries.	Few data except in streams.	Some data on food types, but less on foraging habits.
Use of aquatic beds important, but few data to distinguish refuge from feeding or other needs. Little known about freshwater refugia.	Substrates and edges known to be important in upper streams. Macrophytes more important in lowland streams & wetlands.	Few data — hard to separate refuge from other habitat needs.
Many tagging studies on some game species. Relationship to environmental factors (e.g. water quality) not well known.	Patterns known, but stimuli unknown. Game species best known but still sparse.	Sparse data in Northwest.

Chapter 7 — Creation and Rehabilitation

Wetland Creation and Rehabilitation in the Pacific Northwest

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Abstract

The practice of creation and rehabilitation of wetlands in the Pacific Northwest is in its infancy. The oldest, best documented project is the Army Corps of Engineers Miller Sands Marsh and Upland Habitat Development project on the Columbia River, completed in 1977. Most permitted projects in the region are less than five years old. In Oregon and Washington, the majority are located west of the Cascade Mountains and near urban centers. In Oregon, most have been small (<10 acres), typically one acre or less.

Types of wetlands being created and rehabilitated are intertidal mudflats, seagrass beds, salt marshes, fresh water ponds and associated wetlands, and riparian and in-stream habitat. Most available information relates to the creation or improvement of habitat functions in fresh water ponds and associated wetlands, tidal fresh water and salt marshes, and riparian and in-stream areas.

The permitting and mitigation process, e.g. Section 404 of the Clean Water Act, has an impact on the creation and rehabilitation of wetlands. Difficulties in involving a wetland scientist early in the planning process, and in completing the construction as planned, hinder efforts to evaluate the ability of agencies to condition permits. When projects are monitored, that monitoring is primarily observational, not quantitative. To evaluate the success of a creation or rehabilitation project its goals must be clearly stated, its construction plans given, the proper incorporation of design features verified, and a quantitative monitoring program established.

Introduction

Research and experience in the creation and rehabilitation of wetlands in the Pacific Northwest are limited. In this region it is a relatively new endeavor, with most projects less than five years old; the median age is two or three years.

In a recent review of the creation and rehabilitation of Pacific coastal marshes, Knutson and Woodhouse (1982) presented guidelines "based on perhaps five field planting experiments, twenty years of first hand experience by the authors, and a great deal of conjecture." Of the 54 references cited, only one dealt with the creation or rehabilitation of coastal wetlands in the Pacific Northwest, i.e., the U.S. Army Corps of Engineers' Miller Sands Marsh and Upland Habitat Development project (Clairain et al. 1978). Miller Sands, on the Columbia River, is the oldest, best documented wetland creation project in the region.

Wetland creation or rehabilitation is commonly proposed as mitigation for wetland losses permitted under Section 404 of the Federal Clean Water Act and state removal-fill laws. Since the science of wetland creation and rehabilitation in the Pacific Northwest is

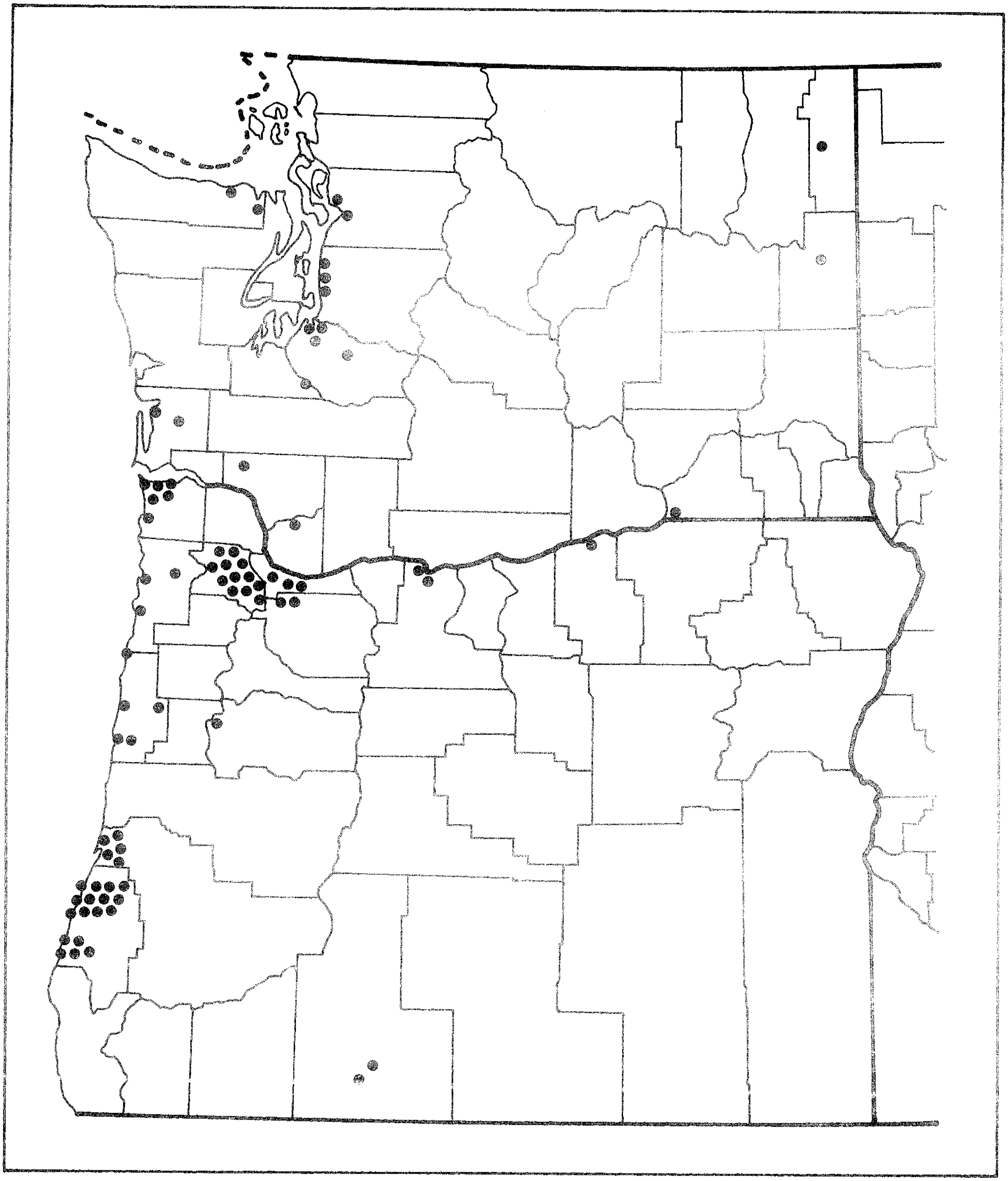

Figure 7-1. General locations of mitigation projects in Oregon and Washington. Each dot represents one project. For Oregon the entire permit record of the Division of State Lands from 1980 to the present is represented. For Washington the record of the U.S. Fish and Wildlife Service for Fiscal Year 1983 to the present is represented.

in its infancy, there is a great need to continue documenting what is known, to identify information gaps, and to initiate research.

Documentation of Wetland Creation and Rehabilitation in the Pacific Northwest

The Permit Record

The occurrence of wetland creation and rehabilitation as mitigation for permitted wetland alteration was examined. The entire permit record of the Oregon Division of State Lands (1980 to the present) and a partial record for the State of Washington (Fiscal Year 1983 to the present), provided by the U.S. Fish and Wildlife Service, were analyzed.

In Oregon and Washington most projects (>80 percent) are west of the Cascade Mountains near urban centers (Figure 7-1). Analysis of Oregon records revealed additional patterns. About 50 percent of the projects are in fresh water systems and about 50 percent are in saline systems. Projects have been small (<10 acres), typically one acre or less. Of the permits granted between 1980 and 1985, 67 percent were issued in 1985 (Table 7-1). Consequently, two-thirds of the projects permitted in Oregon either were just recently completed or are in some stage of construction.

The Scientific Literature

The readily accessible literature on creation and rehabilitation of wetlands in the West, and especially the Pacific Northwest, is limited. A computer search of three databases to identify publications on the creation and rehabilitation of wetlands located 277 items; 22 applied to California, Idaho, Oregon or Washington (Table 7-2). Nine of these were publications from the Army Corps of Engineers' Dredged Materials Research Program.

Most of the information presented in this paper was obtained through interviews with people in the region. They shared their personal experience and their knowledge of printed resources not generally available.

Other Sources of Information

Many wetland creation and rehabilitation projects are not recorded in the permit record. For example, wetlands are created in the management of wildlife refuges, and the Soil Conservation Service oversees farm pond development across the nation.

Most of the wetland creation and rehabilitation projects in Oregon and Washington not recorded in the permit record have been of riparian and in-stream systems. Both states have programs to restore salmon and trout habitat. In Oregon's Salmon and Trout Enhancement Program, Department of Fish and Wildlife biologists supervise the work of volunteers to increase fish habitat. Concurrently, the program educates the public on the importance of riverine wetlands. The Bonneville Power Administration has an

Table 7-1

Number of permits issued yearly by Oregon's Division Of State Lands that required mitigation under Oregon's removal fill permit program.

1980	1
1981	0
1982	3
1983	7
1984	6
1985	35

active program of stream enhancement. A Bureau of Land Management research program focuses on the prevention and restoration of stream damage caused by grazing. As part of their continuing research on the ecology of streams, the Forest Service's Intermountain Research Station recently initiated research to develop restoration techniques for riparian systems in arid regions.

Creation and Rehabilitation of Specific Wetland Types in the Pacific Northwest

Coastal

Salt Marshes. Sedimentation and the construction of dikes, landfills, and jetties have significantly modified the salt marshes of the Pacific Northwest. Almost no areas of old, high marsh remain undiked in Oregon (Jefferson 1974); dike removal is commonly proposed to restore this habitat.

A diked wetland in the Salmon River Estuary (Lincoln County, Oregon) was breached in 1978 (Mitchell 1981). During the first year after breaching the upland, pasture-type plant species suffered almost 100 percent mortality. Wetland plant species invaded the area. However, since the land had subsided 0.3 - 0.4 meters with diking, an intertidal to low transitional salt marsh developed. The high transitional marsh that probably existed before diking was not restored. The new marsh was compositionally and functionally different from the pre-dike marsh.

Knutsen and Woodhouse (1982) described techniques for growing the salt marsh plants *Carex lyngbyei* Hornem. (Lyngby's sedge), *Deschampsia cespitosa* (L.) Beauv. (tufted hairgrass), and *Triglochin maritimum* L. (seaside arrowgrass). Seeding has often been a failure. Transplanting sprigs is most common and successful. Plugs with soil and pot-grown seedlings, although awkward to transport and handle, are typically successful.

Seagrass Beds. Attempts to create eelgrass (*Zostera marina* L.) beds in the Pacific Northwest have been limited. Phillips (1982) stated that the best results are obtained using plugs. He reported 100, 100, 87 and 50 percent success for four plantings in Puget Sound. Plantings using seeds have had little or no success.

As a result of their experience in the southeastern United States, Thayer et al. (in press) stress the need to consider the site history. If a seagrass bed chronically has a low density of vegetation, attempts to increase density with transplants will result in a short-term pulse. The system will quickly return to its natural configuration. Planting a site that naturally lacks seagrass carries a high risk of failure.

Tidal fresh water. The Army Corps of Engineers' Dredged Materials Research Program attempted to establish fresh water marsh and areas of upland vegetation on Miller Sands, a dredged spoil island in the Columbia River. The 2.5 year study was conducted from March 1975 to August 1978. Pre- and post-project inventories monitored changes in chemical and physical conditions, vegetation, and animals. Zooplankton, invertebrates, fish, birds, and mammals also were studied. Results pertaining to marsh creation (summarized by Clairain et al. 1978) are presented below.

Plant propagation was generally successful in the intertidal areas. Planted areas were fairly well established by August 1977 and the plants were beginning to invade bare areas. *Deschampsia caespitosa* and *Carex obnupta* Bailey (slough sedge) were successfully established from sprigs at elevations >67 cm above mean lower low water. Application of fertilizer had no significant effect on the establishment or production rates of *Carex obnupta*. Intertidal mixed plantings of transplants of *Carex lyngbyei*, *Scirpus validus* Vahl (American bulrush), *Juncus effusus* L. (common rush), *Iris pseudacorus* L. (yellow flag) and *Alisma plantago-aquatica* L. (water plantain) were successful. Almost no plants were established by seeding any of the species.

Colonization of animals in the planted areas reflected the early stages of succession during which the animal populations were sampled. Plantings seemed to have no detectable influence on the aquatic biota. Fish distribution and abundance were the same before and after habitat development. The marsh developed by July 1977 had little influence on the benthic community. Bird use of the intertidal areas slowly increased as development of the marsh progressed. Avian species composition changed in the intertidal areas from those preferring bare, sandy areas to those preferring vegetated areas.

More recently, Brian Lightcap (Army Corps of Engineers, Portland, OR, personal communication) documented the self-establishment of tidal fresh water marsh vegetation on dredged spoil in the Columbia River.

Intertidal mudflats. Intertidal mudflats are being created as mitigation projects in the Pacific Northwest, but little is known about their status. The development of an invertebrate community is desired. Sampling to characterize these communities is difficult and time consuming; no documentation was found for such projects in the Pacific Northwest.

Fresh Water Impounded

Literature on the creation and rehabilitation of fresh water wetlands in the Pacific Northwest is becoming more available. There is considerable expertise on the construction of fresh water ponds and associated wetlands to increase habitat functions. However, no information was found on bogs and fens.

Fresh water wetlands are typically constructed in urban areas. Virtually all such projects in Oregon are in the Portland metropolitan area. The work of Milligan (1985) and Milligan and Raedeke (in press) describes how to integrate wetlands for wildlife habitat into urban development projects. Shallow ponds and associated wetlands with year-round water are of particular value to waterfowl, since natural wetlands often dry up in the summer (G. Herb, OR Dept. of Fish and Wildlife, personal communication). Nesting islands are a common feature of these pond systems. A combination of open water with emergent and shrub-scrub wetlands is desired for maximum potential for wildlife use. Emergent vegetation for spring nesting habitat is particularly important. However, the ability to create such areas is often constrained by the small size of the typical urban project and the availability of adequate funding (D. Milligan, Raedeke Associates, Seattle, WA, personal communication). The challenge for the resource agencies is to maintain habitat in urban settings that supports wildlife for non-consumptive purposes, e.g., bird watching, photography, and educational use (Herb 1986).

Riverine

Restoration of riparian and in-stream habitat is occurring on both the east and west sides of the Cascade mountains. Activities supervised by the Oregon Department of Fish and Wildlife were reported in *Oregon Wildlife*. Claire's work on Murder's Creek and the

South Fork of the John Day was described by Gladson (1983). Newton's (1981) work on Fifteenmile Creek, south of The Dalles, is summarized below.

The Fifteenmile Creek area, like many others in the Pacific Northwest, suffered deterioration due to grazing, agriculture, timber harvest, and irrigation withdrawals. The area had been averaging two severe floods per ten year period. A restoration and stabilization project, initiated in 1974, involved an eight- to ten-mile reach of the stream. Results are encouraging: Where the plantings were protected, recovery of streamside vegetation was noticeable within four years (Newton 1981). However, Meehan and Platts (1978) cautioned that although many western rangelands have improved through management and revegetation programs, many riparian habitats have responded slowly to treatments.

Monsen (1983) listed the conditions that influence restoration of riparian wetlands in the intermountain region:

- Protection for the vegetation;
- Accessibility by mechanical equipment;
- Variation in plant communities and site conditions;
- Serious alteration of the site, e.g., erosion, lack of vegetation or topsoil, lowered groundwater;
- Competition with "weeds;"
- Fluctuating water levels, i.e., high runoff and flooding in the spring, drought in the summer.

He also stated that willow (*Salix*), dogwood (*Cornus*) and cottonwood (*Populus*) are easy to propagate from local cuttings.

In-stream restorations are primarily directed toward upgrading salmonid habitat. However, some improvements can serve the dual purpose of raising the water table in areas of former wet meadows (Bowers et al. 1979). The favored in-channel treatments are current deflectors, overpour structures (dams and wiers), bank covers (structures to create streamside covers) and boulder placements. Digger logs, trash catchers, simple gabions (rock filled wire structures), substrate manipulations, pool excavation, channel blocks and barriers, and beaver management are less common (Wesche 1985).

Gabions currently are receiving attention because the Bonneville Power Administration plans to place a large number of them in the John Day system. Use of gabions has been criticized for aesthetic reasons (U.S. Forest Service 1952). Their susceptibility to damage and need for frequent repair also has been cited as a problem. However, low-profile gabions have been described as effective, easy to install, fairly inexpensive and strong enough to withstand high discharge (Wesche 1985).

Summary and Conclusions

Most of the easily accessible literature on wetland creation and rehabilitation in the Pacific Northwest is specific to the habitat functions of fresh water ponds and associated wetlands, salt and tidal fresh water marshes, and riparian and in-stream areas. Information that can be extracted from the permit record is uneven. For some projects site descriptions and detailed construction plans are provided, but usually few specifics are available. What detailed information might exist must be "tracked down" by contacting the agencies that reviewed the permit request, and the biological consultant for the project, if one was contracted. Therefore, it is often difficult to gather enough information to evaluate both the design of the projects and the conditions imposed on the permits.

Even when detailed information on the plans and goals for creation and rehabilitation projects is readily available, evaluation of project design is often hindered because the construction was not done as planned. Many times a wetland scientist is not involved until late in the process. Monitoring of projects, when it does occur, is primarily observational, not quantitative.

To effectively evaluate the success of creation and rehabilitation efforts, documentation is needed. The goals of the project should be clearly stated and the construction plans given. When the project is completed a representative of the agency in charge should visit the site to assure that the design features proposed were properly incorporated. This reconnaissance should include the project biologist, if one was employed. Finally, a monitoring program that produces quantitative information and provides for its analysis should be implemented.

However, the potential for evaluating existing projects by viewing them as "experiments in progress" should not be ignored. Since there is much to learn about the process of creating and rehabilitating wetlands, a systematic appraisal of projects and follow-up reporting would greatly augment the existing body of knowledge.

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Table 7-2

Lterature on the creation and rehabilitation of wetlands in Oregon, Washington, and California identified through a computer search of three literature databases. The National Technical Information Service database consists of government-sponsored research, development, and engineering, plus analyses prepared by federal agencies or their contractors or grantees. The COM PENDEX database provides coverage of the world's significant engineering and technological literature. CAB ABSTRACTS is a comprehensive file of agricultural and biological information published in journals, reports, books, and other publications.

The key words used were wetland OR marsh OR riparian OR lacustrine OR palustrine OR riverine OR shallow vegetated area AND artificial OR create OR creation OR construct OR restore? OR enhance OR design OR reclaim? OR reclaim OR planting guideline? OR habitat develop? AND Washington NOT DC OR Oregon OR Pacific coast OR West coast OR Pacific Northwest; question mark (?) indicates all possible forms of the word. Bogs and fens were not used as key words in this search because an earlier effort indicated they added no new information.

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Working Group Report: Creation and Rehabilitation

Mary Kentula, Moderator
Diane Mitchell, Rapporteur

"Just let the bulldozer driver go."

Review of Plenary Paper

To the question, "Can you create or restore wetlands?" this group responded: it depends. The question can be answered only in terms of a goal that is defined for a particular project. If a goal is simplistic, unidisciplinary, and/or easy to measure (for example, obtaining plant regrowth or fish return), a yes/no answer is possible. If multidisciplinary goals are set (a better way to proceed), then the answer is more difficult and ambiguous. The evaluation of success also depends on the training and knowledge of the person judging it. The more you know about wetlands, the easier it is to see shortcomings in a creation or restoration project.

The ability to create or restore may depend on the age of the natural system that is being emulated. Full functioning may not be realized for the length of time required for the natural system to repopulate, especially in slow-growing systems such as forested wetlands with large old trees. The hardest systems to create or restore are bogs, swamps, and large rivers. There is a good ability to restore fish habitat in streams west of Cascades, and in low-gradient streams in Idaho and Montana.

Techniques, criteria for success, and problems for wetland creation and restoration schemes are presented in Table 7-3. Common elements in creation and restoration schemes include: bulldozers to modify substrate, elevation, and drainage; a natural, diverted, or restored water source; and a plan for natural or artificial revegetation.

The degree of improvement or enhancement of a wetland that results depends on the initial condition of the system being restored. The most significant incremental or relative improvement is possible with severely degraded wetlands, but the most successful restorations (returning the system closest to a natural state) are possible with lightly impacted wetlands. Improvement is not necessarily synonymous with restoration, unless the natural state of the wetland is disregarded. The ability to create or restore might be mostly a matter of having adequate time and resources. It is not known whether creation or restoration failures are caused by a lack of knowledge, or by intrinsic difficulties that may apply to certain systems regardless of the level of knowledge.

Discussion of Matrix

The group had difficulty interpreting the matrix results. They did say marine waters should not be included in the definition of wetlands.

Table 7-3
Techniques, criteria for success, and problems in creation and rehabilitation of wetlands.

Wetland Type	Situation	Techniques
Riverine	Degradation by cattle usage (both sides of Cascades)	Fence exclosure; revegetation; natural recolonization by vegetation west of Cascades
	Stream straightening or channelization	Create new meander; replant native vegetation.
	Logging impact (removal of large stream logs)	Place gabions in channel
Freshwater impoundments	Creation of wetland from scratch, or restoration from various types and degrees of degradation	Excavate ponds and secure water source; develop water recirculation systems; create non-uniform topography and vegetation.
Estuarine vegetated wetlands	Degradation from diking of wetland	Breach or remove dike; allow natural plant recolonization.
	Degradation from wetland filling	Grade fill down; add new substrate in some cases; replant sprigs of multiple species; protect with rip-rap when necessary.
	Loss of wetland	Add fill to create an island; replant plugs or allow natural recolonization.
	Degraded or destroyed eelgrass beds	Locate appropriate site, change substrate and elevation and reduce wave energy if necessary, employing oceanographer or engineer; plant eelgrass, using nets for anchoring or even plastic grass if necessary.
Estuarine unvegetated wetlands	Lack or loss of habitat	Create shallow substrate by filling and/or adding cobbles.

Criteria For Success	Problems
Plant growth for shade and bank stability; reduced sediment and clean stream gravel; increased stream depth and pooling; narrower channel profile; reduced coliform contamination; return of fish. Time frame: improvement in 1-5 years; up to 50 years for full recovery.	Original vegetation may not be reestablished; reed canary grass may become dominant.
Improved sediment; renewed fish and bird usage; revegetation.	
Aesthetic improvement; waterfowl and wildlife usage.	Lack of year-round water flow; contamination by fertilizers and pesticides; monotypic vegetation; lack of data for comparison.
	Failure to return to original state due to land subsidence while diked.
Plant growth; faunal recolonization.	Erosion of substrate before plants can stabilize site.
Vegetative growth and cover; faunal recolonization.	Erosion; lag time of up to 5 years for regeneration of plant cover; grazing by geese.
Presence of regenerated eelgrass.	Finding site with suitable substrate and energy characteristics; failure of herring to spawn on regenerated eelgrass.
Algal diversity; production of epibenthic invertebrate prey for juvenile salmonids.	Designing adequate sampling schemes for monitoring, and interpreting results.

Discussion Questions

Data Gaps and Research Needs

The most important need in new creation and restoration projects is for improved follow-up monitoring oriented to the specific project goals to be included in the project design. For example, eagle or juvenile salmon usage should be monitored if those are mitigation objectives. Effort should be made to develop a full suite of standardized monitoring procedures. For example, standard vegetation sampling techniques should be used, such as Braun-Blanquet measures. A photo record should be kept of all projects. Consultants should promote projects in which thorough monitoring is assured.

In addition to prospective monitoring of new projects, retrospective studies of past projects should be undertaken to compare their development with natural systems. Does natural colonization yield desirable vegetation or undesirable species? How well do consumers return once desired vegetation is established? Monitoring of present and past projects should also be supplemented with microcosm and manipulative experiments to verify and improve creation and restoration techniques.

Another critical need for enhancing our creation and restoration abilities is for more research and data on natural wetlands — we can't create wetlands we don't know anything about. These studies should include some variables not directly related to the criteria monitored for evaluation of success of creation/restoration projects; such multidisciplinary studies are needed to learn more about how natural systems function. For example, large riverine systems are poorly understood. There is little knowledge of the cumulative impact of alterations along the length and the history of a river. The original condition of many major rivers is not known, so what should be restored also is not known. Also, little is known about how to restore bogs and swamps.

The approach of understanding cumulative impacts could be applied to wetlands in general. Quantitative studies are needed. An understanding of cumulative impacts could reveal which restoration projects are most needed, and could help to get needed restoration projects underway. It would also be valuable to have a knowledge of temporal trends in wetlands, rather than simply snapshots of data at a single time. A literature survey of the historical record of wetland loss and creation/restoration should be done.

A "landscape" approach could be applied to studying wetlands. This approach would encompass study of surrounding lands and their interactions with the wetland. For freshwater wetlands, the entire watershed should be considered, both upstream and downstream. For marine and estuarine wetlands, the landscape is less obvious, but may include both the watershed and the local marine waters or basin. The biological picture of a wetland also should be expanded beyond single target species to include ecological linkages.

"How-to" handbooks should be written to provide uniform systems of measurements and data for evaluation of project success, and to serve as a guide for private owners in maintaining wetlands. A new EPA wetlands program is being initiated that includes followup of past creation and restoration projects, cumulative impacts assessment, and preparation of regionalized creation/restoration handbooks.

Slide Show Excerpts: "Best and Worst Experiences in Wetlands Creation and Rehabilitation"

[Editor's note] To give some examples of the types of wetland creation and restoration projects that have been conducted in the Pacific Northwest, several attendees at the conference were asked to show slides and talk about their experiences. This show amounted to a "Hall of Fame, Hall of Shame" presentation of successes and failures. The slide show stimulated a great deal of debate and provided material for reference later in a panel discussion session. The session was moderated by Kathy Kunz of the Environmental Protection Agency in Seattle.

The following is a summary of the major points brought out by each of the speakers, prepared from a transcript of the session. These were informal presentations. The text has been shortened and the grammatical errors corrected, but much of the original language and many anecdotal or unsupported statements have been retained. Editorial clarifications and additions to the text are indicated by brackets [ ].

Rex Van Wormer, of Independent Ecological Services, in Olympia, Washington, showed slides of his company's work at the future Koll Business Park on North Creek in Bothell, Washington [a suburb north of Seattle]. The site was an old farm where a stream had been channelized for drainage. The project was designed to recreate a meandering stream and to create a backwater wetland, a difficult task on a property over 3000 feet [923 meters] across with only six feet [1.8 m] of fall. The wetland was designed on a computer by a company in Montana and constructed by the Watershed Company of Kirkland, Washington, with the cooperation of the Washington Departments of Fisheries, Game, and Ecology, as well as officials from King County and the City of Bothell.

The site began with mixed vegetation, mainly reed canary grass. Two small areas of buttercup sedge marsh had to be mitigated for, and a 200-foot [61 m] setback had to be created on each side of the stream. Plant species were selected after determining the frequency and duration of flooding and the types of soils. A diverse assemblage of three seed groups and seven different types of plugs was planted. High areas were planted in bentgrass. In the middle low areas, a spike-rush/bentgrass mix was selected. Low areas received combinations of rushes and aquatic smartweed, and the lowest flowing-water area was planted with northern manna grass, among other plants.

The entire site was underlain by heavy peat, making special features for load-bearing necessary. A rock-crib channel was built to regulate streamflow and create fish habitat. Hundred-year flood dikes were built around the stream. The area designated for the marsh was too low for water to [drain] through, so 360,000 cubic yards [275,000 m^3] of peat were brought in to raise the area. The peat then was cut and filled to create the desired stream configuration, including an [adjacent] surface water detention pond. The surface water running off the site, which was contaminated by dairy waste from the original farm and additional runoff from nearby Interstate-405, was diverted to keep it out of North Creek. Surface runoff is now carried by underground pipes to a 3 1/2-acre [1.4 hectare] open-water pond with 1 1/2 acres [0.6 ha] of marsh. It then flows into a one-mile [1.6 km] grass-lined swale before it enters a nearby stream, Sammamish Slough. The lowest estimated flow rate through the site is 25 cfs [0.71 m^3/sec.]. Any time the streamflow exceeds 40 cfs [1.13 m^3/sec.] it will back into this pond. At 150 cfs [4.25 m^3/sec.] the entire wetland is inundated, which is [predicted] to occur 76 times a year.

During the first half year in operation (winter 1985-86), a dry season reduced that rate by 60 percent.

The project was designed to provide stream shading as rapidly as possible, because a riparian border with a high probability of stream shading was needed before the Fisheries Department would permit diversion of the stream. Two hundred eighty major trees and shrubs were moved and planted by helicopter. The area was overseeded with blends of grasses. The wetland portion was plugged with soft rush on three-foot [0.9 m] centers. An overstory of annual rye was used, which was later regretted, because 15 months later much of it was still present. A monitoring program and a contingency plan are included in the design. Independent Ecological Services has a 45-minute presentation, which they will present to groups, that provides greater detail on the North Creek project.

Neil Dawe of the Canadian Wildlife Service, Qualicum Beach, British Columbia, showed slides of an estuarine restoration project in the Campbell River estuary where it empties into the Strait of Georgia on eastern Vancouver Island, B.C.

The Strait of Georgia supports Canada's largest winter population of waterbirds because of its mild winters and its estuaries. These estuaries are considered critical waterfowl habitat because destruction of such habitats results directly in the death of the birds. Estuaries are the only places the wintering birds can go when the inland areas freeze. Neil made the philosophical point that land developers should consider such sites already fully developed.

The Campbell River estuary, about 240 km north of Victoria, had been a log booming site since 1904. In 1980, British Columbia Forest Products (BCFP) acquired the site and proposed to dredge it for construction of a dry-land sorting operation. They approached the Canadian Department of Fisheries and Oceans, which assembled a broad spectrum of professionals to evaluate the proposal.

One of the mitigative measures ordered by Fisheries and Oceans was the creation of four intertidal islands within the estuary, to which some of the vegetation destroyed by dredging a holding pond would be transplanted. Of about 4200 m^2 of vegetation lost during dredging, about 700 m^2 of donor stock were saved. The stock had to be overwintered because the collection was done in November. The transplanting was done in February, 1982 by unemployed loggers hired by BCFP, following a plan provided by Fisheries and Oceans. The planting was done at low tide, which took place at night and so required artificial lighting. They put out 23,302 plugs, 15 cm^2 by 20 cm deep. Three planting schemes were used: intervals of every one m^2 and every 0.5 m^2, and control plots where no vegetation was planted. In March the site was inspected, and about 30 percent of the plugs were planted upside down. BCFP sent a crew out to turn them over. Neil felt this was unbelievable cooperation, and had never seen anything like it. He attributed the success of the program to BCFP.

By the end of April growth was evident, and by July some of the species were propagating away from the plugs. The dominant species were *Carex lyngbyei, Heliocarex pelosporus, Juncus arcticus*, and *Potentilla pacifica*. *Heliocarex* was a very good colonizer, spreading quite rapidly. *Potentilla* also colonized rapidly — stolons went out the first summer, and by the following summer, new plants were stabilizing the soil. Some new colonizers, *Scirpus cernuis* and another *Scirpus* species, were observed the first year. Grazing by wildlife, notably Canada geese, also was observed the first summer; interestingly, the most productive plot to date was one that geese grazed.

Slides of the one m^2 block planting taken in July, 1985 still showed some bare soil. Coverage by the 0.5 m^2 plantings was much more rapid — the 0.5 m^2 plots one year after transplant resembled the one m^2 plantings four years after transplant. By 1985 coverage in the 0.5 m^2 plots was total. In a control plot in 1983, one year after transplant, a bit of stock was coming in on its own, possibly contaminants from the plugs. This observation suggested that, in the presence of a stable substrate, a marsh may be able to regenerate on its own. Some loss of plants occurred during the second year where they had been transplanted too low on the islands. The island elevations ranged from subtidal to four m above zero mean tide. Salinities at these tidal elevations were 25 parts per thousand [ppt], compared to 8-10 ppt at higher levels. However, the main cause of the mortality was probably the longer inundation period.

Adjacent Nutts Island was also used as a control site for comparison of rates of plant growth. Aboveground biomass (specifically, the relative lengths of the plants in different plots) was used as an indicator of growth rate. The first year the growth rate on the experimental plots was about 50 percent of that in undisturbed plots. By 1985 the growth rate was about 60 percent that of the natural vegetation. During that period the total vegetative cover of the estuary expanded from 4200 m^2 (the area of vegetation prior to development) to about 1.5 ha. This represented a net increase in productivity of the system over those four years.

Bob Zeigler of the Washington State Department of Game, Olympia, showed examples of the best and worst projects he has observed that tried to mitigate loss of scarce habitat. The first project, in the Duwamish River estuary near Terminal Three in Seattle, was an attempt to replace some shallow, sloping, intertidal lands, a scarce habitat in the Duwamish. Some subtidal land was filled and lost as a result of the project, but this is not a scarce habitat in the Duwamish. The intertidal land was to be created by making mounds, a design that came about through changes late in the permit process. The design, however, was not followed during construction. Sediment sizes used to create the mounds were different from those in the original plan. A number of other features that were really needed also weren't incorporated into the project. Only monitoring could reveal whether benefits will be realized from this effort, but it was felt that little could be lost from trying a project in an estuary as severely degraded as the Duwamish.

Bob felt that the next project, on North Creek [discussed previously by Rex Van Wormer], had tremendous success with riparian vegetation, some of the best he had seen. He had expected greater mortality from the helicopter transport of the plants. There are some problems, as Rex pointed out — the wetland is not wet enough to function as intended, so quite a bit of additional work must be done to obtain a high value wetland. A lot of low-value non-wetland plants, such as a monotypic stand of reed canary grass, are found in the wetland area instead of some of the species that were planted. Another problem arises from the limited ability of regulators to supervise projects. One of the conditions agreed to in the North Creek project was a 100-foot [30.5 m] setback to be replanted in native riparian vegetation. Bob confessed that he had not realized during his review of the plans that a footpath through the wetland would be paved and rest atop an eight-foot [2.44 m] dike. The vegetation on the far side of the path and dike doesn't function as riparian vegetation because it has no interaction with the stream.

Another outstanding mitigation project is one being conducted by the Port of Tacoma and the Fisheries Research Institute of the University of Washington [see subsequent slide presentation by Ron Thom]. The design was excellent, a series of "fingers" or dead-end channels to increase habitat diversity. Some problems were encountered, though. Some heavy rains occurred, and the people that were digging the channels had to do it blind. Rather than having an area in which there was a gradual decline in elevation, this produced some erratic depths where restoration should be done. Bob reflected that working in aquatic environments where everything shifts around is not as easy as building in a terrestrial area.

One of the worst projects Bob had seen was on a tributary of Tibbits Creek in Issaquah, Washington. It was a stream relocation and wetland creation project to replace a wetland that was [partially] filled. A parking lot and an office park come right up to the edge of the stream channel, so Bob felt it has [limited] value. The wetland was not developed as designed, is collecting a lot of trash, and in Bob's opinion is basically unfunctioning. The most Bob was able to do with the permit authority available to him was keep the stream open, to require 25 feet [7.6 m] of riparian vegetation on each side, and to retain a portion of the wetland. There was use of the stream by coho salmon fry and adults in this area as recently as three years ago [but Bob did not characterize its current use by salmon]. The stream channel upstream of the site is still in its original state, and the waters there are much cleaner.

Another project was a mitigation for about ten acres [4 ha] of wetlands that were filled by Port of Tacoma for Sea-Land. This project initially appears successful, but it takes four to six years until these areas really become productive, and sometimes further losses occur over time. Seldom is there more than a one-to-one replacement of wetlands, which in Bob's opinion means that the Department of Game is not really doing its job as mandated — preserving, protecting, and enhancing the public's fish and wildlife resources.

Bob's final example was of a salt marsh creation site in Oak Bay; a self-guided tour to this site in the vicinity of Port Townsend was recommended to conference attendees. This marsh developed over time as a result of both human alterations and natural processes. In 1916 the Corps of Engineers dredged a navigation channel between Indian Island and the Oak Bay shoreline, and sidecast the spoils. Eventually the hydrologic processes of the area reworked the sediments, allowing the establishment of salt marsh vegetation and a return of some wetland functions.

Gene Herb of the Oregon Department of Fish and Wildlife showed slides of wetland creation sites around Portland and other urban areas. The first was a condominium project where the original plan was to completely channelize the stream, take all the vegetation off both sides, and replant it with grass. Oregon Fish and Wildlife had them leave the vegetation next to the stream and replant detention basins around the perimeter of the area with willow. When Gene first saw the area in 1980 he expected poor results. However, grass began coming back in 1981, and willow growth, stream healing, and reduced siltation were evident in 1982. By 1984 and 1985 the site was beginning to look like a successful restoration, demonstrating the important point that these processes take time. Gene estimated this project achieved close to 90 percent of the compensation that was hoped for.

The next project was one with some plusses and minusses. It was about a 3/4-acre [0.3 ha] wetland that was filled by a developer for an industrial site. As compensation a wetland was built next to a little stream, but it lacked the one thing a wetland needs — water. The water source, a little spring with rushes and a gurgling stream, was about 40 feet [12.2 m] above the wetland. The developer put in a corrugated collection pipe, but placed it upside down (with the collection holes on the bottom), so as soon as the water entered the pipe it flowed out again. It took two years to get it turned around, but when it was, the water came out, and the wetland began taking on typical wetland characteristics.

One successful thing the developer did was to use a frontloader to scoop mud from the bottom of the pond that was destroyed. A lot of smartweed was growing in that mud, and it grew well when it was put into the new pond. It was by then a woodland-type wetland that Gene felt was probably about as good as the one that had been lost. However, there was a problem with buffering and keeping people out of it. A motorcycle path came down a hill to the wetland from Interstate-205, where the public could gain access. Bikers would see how far they could jump their cycles into the wetland. A chainlink fence at the top would have prevented that problem. About a hundred yards downstream the developer did some bank alterations and removed all the vegetation, but the state got a good contractor to replant it. After 1983 the riparian vegetation came back very well, reaching nearly the size of the vegetation upstream, with cottonwood in the overstory and red osier dogwood in the understory.

One of the better projects was on the Sunset Highway outside Portland. A wetland was filled, one that Gene characterized as not very valuable and not well buffered. The spoil for the fill came from a slope pasture above an existing cattail marsh. The plan was to grade the slope down to the level of the marsh, put in some ponds, and create essentially a new wetland. The project was completed in August of 1984 and the resulting grade was close to what had been planned. Spring [flow] filled the ponds immediately. Later that fall the site was seeded with grasses, which grew well. By 1985 the scar had healed fairly well. The plan also left a nice fence row as a riparian border. In 1986, Gene visited the site a couple of weeks before the conference, and felt it was getting to be a pretty good wetland again — a muskrat was swimming in the first pond, a pair of mallards was in the second one, and there was a Virginia rail back in the cattails and some redwing blackbirds nesting. The newly created wetland acted as a buffer for the [existing] cattail marsh. There was tremendous development around the site (superhighway on three sides), but that development acted as a very protective sort of buffer, because there was so much traffic that people were afraid to stop and get out. The developer was extremely good at cutting back and making minor modifications. At one spot the berm was raised about one foot [0.3 m] higher, which allowed the water to flow back and create additional shallow wetland to the rear, where soft rush and cattails are now coming up. They were very careful [with the hydrology of the site] to keep from draining the wetlands.

An example of a poor project was a stream called Golf Creek in Beaverton, once a real nice riparian stream. The stream is now completely gone and underground. Herb asked how you replace riparian vegetation in such a case — by using plastic trees? He felt the resource agencies got involved way too late into the game.

An example of a good project was one on Beaverton Creek. On one side there was a loss of one wetland where material was taken out and replaced. A 40-foot [12.2 m] buffer of trees and shrubs was created; Gene will be interested to see how well those have come up in about four or five years. On the other side was a cut and fill, where material was taken out and smooth sedge and rush were replanted. A series of four ponds also was created to compensate for a road going in on the upper end. The ponds and buffer vegetation around the perimeter of the site were intended to ensure no net loss of fish and wildlife values. There may possibly be a gain, although the mudflat areas might be taken over by reed canary grass. A completely new channel was dug to provide additional open water. On adjacent Hedge Creek, formerly a mass of reed canary grass, a pond with islands was created, and the contractor was really artistic in making an irregular shape. This was a combination of mitigation and enhancement.

The final site was a sewage treatment plant that originally sprinkled all its water on about 200 acres [81 ha] of reed canary grass, doing nothing but permitting mosquitoes to breed. With about four hours of tractor work a series of ponds was created and filled with secondary-treated sewage water. Gene felt the site has a lot of potential and would be a tremendous research project. He called it a great improvement compared to the stand of reed canary grass, but said it still had a long ways to go.

Diane Mitchell of J & M Land Restoration in Bakersfield, California, showed slides of a project on the Salmon River estuary on the north-central coast of Oregon. The site was originally a high marsh and had been diked to convert it to horse and cattle pasture. The dike was removed in 1978 to restore the wetland. At the ends of the site two control marshes, which had been disturbed but were still flushed by tides, provided an idea of what the entire property looked like before being diked. The tidal creek channels on the diked side were degraded compared to the continuations of the same channels on the undiked side, as visible in the difference in channel profiles. Thus the test site was expected to have altered hydrologic properties, especially since diking had caused it to subside one foot below the undiked areas, which remained high marsh.

Bulldozers leveled the dike, tidal creeks were reconnected with the Salmon River, and a culvert was pulled out at the tide gate. The first winter it looked very soggy (although probably not much different than it had with the dike up, because it was a soggy place). Before the dike was removed tansy ragwort covered the site. About a year later lot of bare mud areas could be seen close to the main tidal creek. Upland areas seemed less impacted and were covered by *Agrostis alba* and *Potentilla pacifica*, which were on the site when the dike was intact. After two years the upland showed the effects of intruding tidal water: large woody debris, thatch from other areas, and an early transient colonizer, saltbush (*Atriplex patula*). A lot of the pasture closest to the upland really didn't show much change the first few years. Dike removal took out velvet grass, (*Holcus lanatus*), but left the *Agrostis* and *Potentilla*, which were tolerant of the initial flooding. Four years after removal *Carex lyngbyei* began to invade those areas. Two years after that it was getting thicker. Closer to the tide gates (in 1984) there was still a rapidly changing situation on the bare mud flat, and *Carex* densely covered much of the dike removal site. Diane hopes in the future to recheck changes in tidal creek channel profiles, and the relative elevations of the test and control sites.

John Thilenius, of the Forestry Services Lab in Juneau, Alaska, showed slides of the Copper River Delta. The area was tidal marsh before 1964, when an earthquake measuring 8.6 on the Richter scale lifted most of the area about two meters, but some places as much as 14 meters. The wetland area covers about 110 square miles [285 km^2] and is backed by relatively small local glaciers that supply all of the sediment and are very important in the development of the marsh. The sediments are very fine gray glacial silts that pack very tightly and support the weight of a walker, except along the edge of the creek. Maximum tidal range is about five meters. The tidal water is very fresh because of the 90 to 100 inches of annual rainfall, about 60 percent of which falls in summer between May and September. The immense outflow of the Copper River keeps the ocean surface very fresh several kilometers offshore during the summer. Very strong onshore winds are common even in summer. Especially in winter, however, low pressure centers from the Gulf of Alaska cause storm surges, during which sea level rises as much as three meters in addition to the five meter tidal rise, bringing seawater far inland. Thus nearshore areas are much more saline in winter.

John showed a transect from seaward to landward. From other evidence he determined that vegetative trends in this landward direction resemble the temporal development of the marsh after 1964. The offshore edge of the marsh and the earliest stage of succession are characterized by circles or rings of a near monoculture of *Carex lyngbyei*. The first colonization of the sedge is along the tidal bank, where head-cutting takes place in the continuous development of small side channels. The sedge rings coalesce along the creeks, then move into the inner levee basin between drainage creeks. The tidal meadow was totally covered by *Carex* by about 1978, 14 years after the earthquake. A line of alder and willow shrubs still marks the edge of the marsh prior to 1964. Since 1978 the meadow has become more species-rich and there has been an increase in shrubs, following the normal successional pattern in this area. The channels are deceivingly deep (two meters) in the meadow, and the sedges are as tall as a man — John gave them the name "megafauna." The area is used by brown bear and occasionally by moose.

The last speaker was **Ron Thom** from the University of Washington, who described the Lincoln Street marsh re-creation project in the Puyallup River estuary [which Bob Zeigler discussed previously]. Ron acknowledged other contributors to the project, including Ernie Salo, Rick Albright, Si Simenstad, Trish Dahlberg, Linda Kunze, Kathy Kunz, Mary Burg, Fred Weinmann, Marc Boulé, John Armstrong, Diane Mitchell, Colin Levings, and many others. He gave special mention to Dave Stout of the U.S. Fish and Wildlife Service in Olympia, Washington, who developed the criteria for designing the marsh — "the guy who has no mental blocks about playing God." Dave called for 50 percent of the area to be devoted to juvenile salmonids, 20 percent to shorebirds and waterfowl, 5 percent to small mammals, and 5 percent to raptors. Of course Ernie, wanting to do the will of God, said, "Sure, we can do that." But Ron asked the audience to consider the question that faced him as a result — "What do you build?".

The project was mitigation for filling Parcel Five at the Port of Tacoma, Washington, about ten acres [4 ha] of wetland habitat that generated controversy between resource agencies, Indian tribes, and the Port. The initial design included "fingers" of shoreline to increase the area of exposure of juvenile salmonids to the marsh. It also included a mudflat, an existing grassland and cattail marsh, and a shrub forest. A later design augmented the fingers with offshoot side channels, called "Si's papillomas" after their creator. The redesign also included moving the mouth of the wetland to the upstream end, and pinching it down as small as possible (on the advice of a hydrologist) to increase flushing and minimize sediment deposition from the Puyallup. Because the former wetland had been diked and filled with garbage, they took cores to test for toxic chemicals, but no serious contamination was found. During initial construction they tried to excavate down to the elevation of the former wetlands sediments. On the average there was about 20 feet [6.1 m] of dirt to remove from a six- or seven-acre [2.4 - 2.8 ha] area. A new dike had to be built to Corps specifications. There were many delays, including some caused by breakdowns in equipment. A lot of groundwater was evident on the site during the winter before the dike was breached, and birds sat on the ice after it froze. Lots of garbage was uncovered, such as bottles 46 years old.

The dike was breached just this spring (1986), and Ron showed slides taken at the end of March, one month before the conference. They showed a low marsh, a steep berm, a pre-existing upland, a V-shaped cattail marsh, and a wet swampy area below that. Some of the poor-quality construction that Bob Zeigler mentioned was evident, and was to be fixed. Planting had been under way for about three or four weeks. On the main flat they had planted about 15,000 culms of *Carex lyngbyei*, of the total 18,000 culms in the plan. The planting process was a back-breaking, dirty, muddy, job, for which Ron requested additional volunteers. They planted at half-meter intervals, two or three culms to a hole. After three or four weeks they had essentially 100 percent survival. They also had observed 24 species of birds from thirteen families on the site, including red-tailed hawks and shore birds such as spotted sandpipers. Eleven species of fish, including five species of juvenile salmonid, also were utilizing the area, and invertebrates were colonizing as well.

Panel Discussion Excerpts: "Creation and Rehabilitation in the Pacific Northwest: Science and Technology Meet Policy and Management"

[Editor's note] As the next-to-last portion of the conference program, a panel discussion was held among several participants with different perspectives on and experiences with creation and restoration of wetlands. Each panel member was first asked to respond to an initial question: "When is wetland creation or restoration appropriate?" After that, selected additional questions submitted by members of the audience were addressed. The discussion was moderated by Tom Mumford of the Washington Department of Natural Resources. The panel members were:

Dorothy Milligan, Raedeke Associates, Seattle, WA.

Dyanne Sheldon, King County Department of Planning and Community Development, Seattle, WA.

Ron Thom, University of Washington, Seattle, WA.

Rex Van Wormer, Independent Ecological Services, Olympia, WA.

Bob Zeigler, Washington Department of Game, Olympia, WA.

Marc Boulé, Shapiro and Associates, Seattle, WA.

The text below is abridged from a transcript of the panel proceedings to highlight the essential portions of the discussion and to streamline the language somewhat. Every effort has been made to retain the flavor of the original language and the individual points of view. Condensations of the transcript are indicated by ellipses [...]. Editor's clarifications or paraphrasing are denoted by brackets [ ].

Tom Mumford: ...Let the ground rule be this: people have no hats on, they're not representing their agency nor an official position... We would like to address the question, "When is wetland creation or restoration appropriate?"

Dorothy Milligan: ...I think you can look at wetlands as a manageable resource, and it is always appropriate to create them. But then you have to look at the conditions and make sure that the physical environment and biological characteristics are there to create. You have to also consider whether the engineering to create them is feasible, and whether it is cost-effective. I think wetland creation and restoration take time. There's no such thing as instant habitat...

I think it's absolutely essential that the project biologist be involved in every step of the plan, from the initial assessment of the property to actually being on the site when they're doing the planting or the construction work... I've tried to do that on a project I've been involved in, actually working with the construction workers, telling them why... [they were doing things a certain way]. Once they understood... [there wasn't]... any problem at all.

But I think if the biologist is left out of certain stages, especially in the implementation of these designs, then the chances of success are much reduced. Less beneficial plant species might be substituted, structuring of the vegetation might not take place, so all the concepts and design features you included wouldn't be incorporated. Monitoring is necessary to make sure all the objectives of the design have been incorporated. And, lastly, public education is a... critical element for long term success... If there's some kind of interpretative information incorporated into the wetlands, then the chances of preserving the success over time will be much enhanced.

Dyanne Sheldon: I believe it's appropriate to attempt to compensate for permitted wetland destruction with creation of wetland areas, provided that a bunch of steps are met ahead of time:

- a pre-assessment of the existing condition that is to be eliminated so you know what values and functions you're going to try and replicate;
- goals and objectives of what it is you're trying to create;
- a staffing plan with an interagency task force, including the consultants who may be working on it, and Fish, Game, and all the other agency folks;
- a long-term five to ten year monitoring program;
- a contingency plan if it doesn't work.

However, I think the big fallacy is that creation of wetlands can be used as justification for destruction of existing systems, which is often what we see happen.

Restoration of a site could be appropriate if there have been illegal actions affecting the site, or perhaps if there's been a site where somebody wants to create some impact and restore an adjacent site. Again the same factors would be built into that: a monitoring study and a contingency plan, because [if the plan doesn't] work, then there's no way to go back and make things better...

Ron Thom: There's no alternative to preserving a wetland. Creation should be considered if there are limited alternatives. I reviewed as much of the literature as I could from this coast and the east coast... and I got very nervous about the success of so-called successful projects. Margaret Race [evaluated] 30-35 projects in San Francisco Bay which were judged for the most part successful by various agencies... and thought 75 percent [of them were] dismal failures...

Our understanding of how to do this is in its infancy right now. I reiterate that careful planning with appropriate goals [is important]... You should plan it in conjunction with not just the fishery biologists or wetlands ecologists, but hydrologists and geologists and whomever you need... Let's take the appropriate data, and learn how it does function, and I think that the time factor is really important. You have to look at how long the system is going to be out of function, which may be 10 years, 20 years, we really don't know how long it's going to take for it to reach the level of function of the naturally evolved marsh. It looks like five years is a pretty good guess, at least for the plants to establish. We don't know about the epibenthos infauna...

Rex Van Wormer: I'll play devil's advocate for just a little bit here. You have to look at how your wetlands that are involved within an overall development are going to relate to the final product. If a patchwork of small pieces of wetlands... is surrounded with buildings, driveways, and parking lots, you basically destroy the value of the wetlands. A mitigation plan to destroy those wetlands and compile all of that acreage into a viable, protectable wetland on one area of the site has merit. You can't just look at a wetland by itself in a large development. You have to look at that wetland in relationship to everything that's going to go on around it and try to judge the long-term effects... There is a time, I believe, when it is to the benefit both of the wetland and the project to say, "We're going to trash this and start over."

Bob Zeigler: Well, I strongly disagree with Rex, I'll get into that after I answer the question. Wetland creation or restoration is appropriate when you have the will and the commitment to do it. And that includes doing the construction, monitoring it, and going back in and recreating it when it doesn't work. That's going to require political will. That's going to require a commitment of resources. Resources are financial resources, your soil type, your water type, and a study of the systems that are needed in the area. You also have to have enough time...

It is essential that as development occurs, it is designed around natural systems, and not the wetlands designed around the development. A much better approach [than Rex described] would be to have buffers around the wetlands and corridors connecting them...

Wetlands creation and restoration are most appropriate on public lands such as wildlife refuges, state lands, and federal lands, where you have a political will and also some resources available that they can work with.

Marc Boulé: ...The first question is whether or not you can (as Bob was saying) design the project around the existing systems — rather than getting all the way into the project and having it all designed, and saying, "Oh yeah, we have to do something about this marsh, don't we." That might be just a little late in the process, in my mind.

Some habitats are more successfully restored than others. I question whether we know enough yet about some habitats — for instance, sphagnum bogs — to recreate them. I'm not even sure I know how they're formed in the first place. It depends on the values that are being lost... We have all seen sites that are in fact wetlands, but one can really question whether not they have any values. So before we start recreating a system, let's try to find out what's there and what it is we want to recreate.

Finally what it really depends on is very careful and adequate planning... and ultimately on the review, the technical advice that we get from the other people who are involved in the process — the agency people, the academic people who are involved in the process... Monitoring is clearly very important, and enforcement of that monitoring. Contingency plans are very important. Something I've found in several of the projects I've worked on is the basic KISS principal: it's really important to keep it simple. The more we push land around, the more work we have to do, the more chances we have for something to go wrong. Bob just raised the question of whether creation and rehabilitation of wetlands are most appropriate on public lands. It seems to me that public lands are the one place that we have the greatest potential for planning development activities so that it is not necessary. And thus whether is it appropriate on public lands, no, I think the planning process is sufficient to allow us to go around it so that it's not necessary on public lands.

Mumford: Now I'll start through some of these questions. Some of these are directed to individuals, and some of them are open to the panel in general. The first question is : "When each of you monitor the 'success' of a project, what specific criteria do you or others use or would use to rate the 'success?'" ... species, vegetation, etc.

Thom: I don't think we know yet exactly. I think that one first step would be would be, along with the monitoring program, to erect a control site, where you could pick target parameters. To judge success right now, I think, is if you can show no significant difference [between test and control sites] in selected parameters that you've targeted over a certain period of time that is undetermined at this point.

Boulé: It is necessary to identify... some characteristic parameters that we can, in fact, measure. They may be productivity, some measure of diversity, or some measure of population. But regardless of what it is, we have to know up front what the target is. We have to know what it is we're trying to achieve before we can figure out whether or not we've gotten there. The goal with plants is to see if they grow, and in most cases I think we've accomplished that. But whether you've accomplished the larger goal of replacing the functions, or creating some set of functions and values that you have targeted, that is going to take a more detailed monitoring program and depends very much on what those values are.

Milligan: A lot of times if you don't monitor a program through the construction phase, maybe all the design features that you have put down on paper are not exactly what happened out there... You want control.

Van Wormer: That's exactly the point I was going to reiterate. A great deal of maintaining biological integrity is maintaining control, personal control... You want to keep your monitoring very simple and very forthright. If you can't develop a system that can be easily monitored, then you're creating a monster that you can't control.

Zeigler: The question brings up the weakness that exists today: we don't have criteria for success and we don't really even do much monitoring. We don't have the resources to do it. My response about whether something is working or not working is a gut level observational response to what I happen to see. But as far as having criteria, I don't. That is something we need to work towards.

Mumford: Next question: "If we cannot as a body of experts explain how natural systems function, is it reasonable to judge any creation project on success?"

[Audience]: I think most people here would recognize that wetland systems are extremely complex. If you're trying to recreate a complex system by putting in place a simple system, what indeed have you got?

Van Wormer: I think in looking at complex systems you'll find that the physical parameters that wetland functions operate within are very simple. Soil and water. Adequate water, proper soil, proper drainage. You don't create a system where you have to pump the water and do all kinds of manipulative things, where you have an intense amount of management that's required to keep the thing functioning. You try to design it by keeping it simple so that it will take care of itself, so that the water is there because the water is there, and you use the water in the way that is natural so it creates and maintains the system.

[Audience]: OK, I guess I was speaking about the biological system.

Boulé: You can't keep biological systems simple and there's no desire to, but physical systems need to be kept simple...

Van Wormer: You absolutely cannot now and never will be able to duplicate a whole biological system [with all the ecological] structures [and] species in biological systems. Start with the basic premise of what you're working with, a pond system, and recreate that and give it a start, then get out of the way.

[Audience]: It seems to me that those who are destroying wetlands should be paying to fund long-term monitoring of these sites. And I don't see why we can't do a simple ecological study with permanent quadrats and have a certain percent survival or else replant. For example, 80 percent survival in those kinds of species to be replanted on the site is what we're requiring, just as a ballpark.

Van Wormer: You pound it into the heads of people that design wetlands: mitigation, monitoring, studies, it's all a part of the project. It's got to be just like the sidewalks and the windows and the parking lots. It all has to be built in as a part of the project.

But there's a limit and a lot of that is dictated by political reality. The people who regulate, the people who want development, the other regulators within your governments are also involved ... There's a point you can't go beyond with small projects... and you have to accept that fact. Some of these are so small and they're on such marginal wetlands, you have to demonstrate a real value. A lot of times you're really hard put to come up with some real legitimate justifiable reason [to preserve them].

Boulé: To some degree monitoring becomes the responsibility of the regulating agency — to force, to require, to ask for that final report. The consultants doing the design and doing the monitoring can't force that issue. In many cases the proponent won't do it unless they're forced to do it.

Sheldon: Monitoring may be within the purview [of regulatory agencies], depending upon how their regs are written, but as one of those regulators, sometimes it is hard to have time to enforce it... When your staff is spread out and you don't have the ability to follow up, it comes down to a matter of public opinion — is there a constituency out there forcing the agency to acquire more staff to flesh out the program?

Mumford: The cost of all this is not borne by the developer, it's always passed on to the consumer. Your rent goes up in those condominiums or whatever. If you demand this sort of environmental protection, these costs are passed on. You pay for it one way or another, it's as simple as that...

Van Wormer: There's another cost. It's a hidden cost, and its a cost I've worried about since I was at the Fish and Wildlife Service. This is backlash. The environmental community and environmental regulations are always riding right on the edge. You've got this element out here that I work for, Marc works for, we all work for, and they would like nothing better than to see all that go away, and not have to deal with it. The only reason a lot of them deal with us is because the law says they have to. And if we ride the edge too hard, particularly in some of your small communities and some of these not really highly sensitive areas, my concern is that we're going to get backlash. All of a sudden the emphasis we've got now on local land use plans being improved and enforced would reverse. And if it ever starts to reverse, the pendulum always swings to the other side.

Thom: There's another backlash ... for example, in San Francisco Bay where there were all these projects and most of them were failures. A developer could say, "Why should I try to build a wetland when all of them were failures? Why should I spend the money?"

Milligan: I just wanted to add something to what Tom said about costs. We are paying for the cost of mitigation, and we are also paying for the cost of the loss, so we're really paying twice.

Mumford: One of my pet peeves is that the word mitigate does not necessarily mean to re-create. It means to avoid, which always gets kind of lost in the shuffle.

Next question: "Succession as defined by Clements may not be a valid concept when applied to wetlands. However, we can address the successional changes in processes as a site grows from an early created/rehabilitated state to a functionally mature state. What is the utility of integrating this process — the succession concept — into the measurements and evaluation procedures used in the determination of the success of a project?"

Van Wormer: We are doing this, a little bit. We're working on a five-year monitoring plan. We're not going to find true succession within that five year period. What we do on North Creek is look at an annual change in plant diversity.

Boulé: We have to recognize that some kind of successional process is going to occur... You can't create an old-growth forest by putting a great big lot of great big trees in the ground and expecting everything else to show up immediately. The rest of the pieces have to be in place first. Even if succession as a concept as presented by Clements really is perhaps not quite valid, I think that it is a viable way of watching what's occurring as communities go from bare ground toward whatever is our target. They may or may not get there... If we find out in three years that we're not moving in the right direction, then it's time to think about whether the right goals were selected, or whether we might want to perturb the system. So I don't think that we should deny the concept, and it's perfectly feasible to incorporate it into the planning and design process.

Zeigler: In many wetland alterations, the concept of succession isn't really built into the evaluation. It is sometimes used as an argument for an alteration such as mining peat from a peat bog: "We're not altering the wetland, we're just making it younger." Yes, younger by about 12,000 years.

Sometimes one wetland is filled to enhance another wetland area, for some particular species or use or value. But we have a net loss in wetlands in the area. [The lost wetland might not appear valuable today, but through successional processes or manipulation it might have gained value over time]. That's something we lose when we evaluate wetlands and write off those with low value.

Mumford: Next question: "What consideration is being given to the use of nursery stock versus stock from off-site, relative to impacts on the genetic integrity of the natural populations ...?"

Milligan: I don't think it's a good idea to take plants from one wetland and put them in another. Maybe if you have enough space, enough time and money to start a nursery, that may be feasible. But if you bring in native species from a nursery that have a year's warranty saying that the survivability of that plant will be guaranteed for at least a year, then I think that is a better possibility. I would rather use nursery stock than try to dig them out of another natural area and bring them into a wetland to plant.

Van Wormer: I agree. The biggest concern is not so much genetic integrity, though that is a concern, it's with the physical response of the plant to chemical and physical conditions in the soil [such as] pH and salinity. Nursery stock is not that bad, because if you get a guarantee and you know a little bit about the nursery stock and where it came from, then it's a reasonable alternative.

[Audience]: Getting nursery stock just kind of skirts the whole genetic diversity issue. I don't think either one of you answered that question very well... Nursery stock may or may not be a good genetic source for a particular site even though soil characteristics might be the same.

[I'd also like to hear more about the creative possibilities out there for creating and enhancing wetlands, not just trying to compensate for their destruction]... I can think of thousands of acres that have been created opportunistically where you're not specifically mitigating for a specific loss.

Van Wormer: Can you give an example?

[Audience]: Sure, there's thousands of acres of habitat the Fish and Wildlife Service created just to raise waterfowl. Lots of private individuals do it. The SCS [Soil Conservation Service] constantly is dealing with private individuals who are, in effect, creating wetlands.

[Audience]: I'm from Olympia and they've asked for proposals for parks and I saw this after they had accepted these things, and why doesn't somebody propose making a wetland somewhere a park? It's like a positive aspect.

[Audience]: Stormwater retention centers in housing developments where you're not specifically destroying a wetland, but you have an opportunity to create one because you are going to create a stormwater retention and a grass swale. There is a creative opportunity that is not involved specifically in the destruction of a wetland.

Milligan: In urban situations, where are you going to get stock to plant a wetland and create the instant habitat? We're trying to incorporate aesthetic values because people are going to live around these things. And we all know that if something doesn't look good, if it looks like a big blackberry bramble, they're going to trash it. I think working in an urban situation is really different than working out in the "back forty" with acres and acres of land. You're really under a different set of constraints. And I just feel that I don't want to go into another wetland five miles down the road and dig out a lot of species, just trash that wetland, to have the same species.

[Audience]: Did I hear you address the possibility that if you're about to destroy a wetland, can you take the plants from it?

Milligan: Yes, but it's expensive because you've got to hire somebody to maintain that nursery. And it has to be fairly large. A lot of the projects that we've been involved with are wetlands that are about two acres [0.8 ha]. It's just not feasible or cost-effective to do that when you can make sure that the stocks you are getting from the nursery are viable and healthy and at least you're giving that habitat you created a good start...

Boulé: ... That's the optimal choice, but you don't always have that opportunity... If you can dig it out of the one next door that's about to be eliminated to create your own new wetland, that's real cost-effective. There's not a proponent yet that wouldn't like to take the cheapest way out, but it's not always a possible way out.

Sheldon: I think those of you who are listening carefully and looking for work could possibly see a vast potential right here. If one was clever and went around the countryside salvaging those wetlands about to be dozed under, and had a big piece of ground and got your hydrology going and plugged all these things in, you could create yourself a nursery and turn around and sell it back to everybody... Oh, I'm sorry, am I blowing somebody's cover here? ... I agree, nursery stock is not a good option. But I'd rather see nursery stock used than have some midnight floral supply company digging it out across the road.

[Audience]: Can anyone on the panel or anyone in the audience tell the genetic difference between a cattail here and a cattail from Seattle?

[Audience — Mary Kentula]: I'll answer that question and I might as well confess to writing the question, because I wanted to mention briefly why. [I am told] that from experience in restoring riparian [vegetation] in the intermountain region of Idaho, you cannot use nursery stock of willow. Willow has a very discontinuous distribution in that area and you have to find very distinctly local willow for cuttings because it won't survive. There must be very ecotypic differences genetically in those plants. In something like alder that has a very continuous distribution you don't have the problem.

[The problem is that by] increasing homozygosity in your population, you risk wiping everything out that you've built because you have no resilience, if you have a change in climate or a disease or something. Also, if you collect things from all these [foreign] ecotypes and regions, what are you doing to the genetic integrity of the population?

Mumford: Next question: "What is the panelists' honest appraisal of the presumed status of the Pacific Northwest natural wetlands and estuaries 50 or 100 years from now, given the present rate of removal and regional population growth?"

Van Wormer: I think we have not only a depletion but a degradation of the wetland systems going on. We're constantly losing wetlands through the development process. We've got a lot of wetlands that are undergoing the stress of impacts of surrounding developments. I know it is a dirty word for a lot of people, but think if we're going to maintain the productivity of natural systems as we see them now, it's going to require some level of management, which is going to require a tremendous amount of ingenuity, innovation, and money.

Sheldon: My concern is overall simplification of the diversity of habitat types that we have. Because we are limited in what we are able to create or restore, what we see within developments in the urban setting is the creation and compensation for losses with open water emergent wetlands with nesting islands in the middle, at the expense of the loss of sedge meadows, scrub shrub communities of either simple or complex nature, and even perhaps forested wetlands. If this trend continues, even though the numbers may show that we get a net increase in biomass or production, even though we may get more ducks to shoot at or look at, my concern is that we're reaching a simplification of our own diversity.

Milligan: I'm also concerned about our vanishing resources, but the development is going to occur, and that's a fact of life. I'm convinced you can create certain types of wetlands — I don't make any statement that I know all there is to know about it, but I think that that's an option we have. [You can't just protect them all by saying] don't touch, because... without any enhancement... they get trashed. You put up a fence and that's an invitation for little kids to go in and do things.

Boulé: The losses of wetlands, particularly the estuarine wetlands, were dramatic around the turn of the century and up to perhaps the '20s and '30s. But if you look at the rates of loss that have been occurring in the last ten to twenty years, it's fallen off to practically zilch. Fortunately, since we've already lost 90 percent, it's probably a very good thing that it stopped at this point. But from the perspective of the estuarine wetlands I think the major losses have been brought pretty much to a halt as a result of many of the activities of the agencies that are represented here.

The outlying inland wetlands that are on the fringes of urban development are perhaps scarcer and more sensitive, and those I fear we have not yet brought under control. I'm thinking most particularly of are the low-elevation bogs. Those are systems that we do not yet know enough about, and I suspect that some of the development activities that we'll be permitting in and around them are going to continue to have an impact and will reduce the total area.

Thom: I agree. Looking just at our project on Commencement Bay, it's like it's a scratch on the surface. It's very small and it's a very expensive project. They're not going to come along that often.

Zeigler: The question of wetland creation and restoration is an important one, and it's one that I found out has been addressed for thousands of years. The ancient Hebrew prophet Isaiah said, "Waters will gush from the deserts, streams in the wastelands, the parched ground will become a marsh, the thirsty land springs of water." However, unless we do things differently, it is unlikely that 50 or 100 years from now we will have more than 50 percent of the wetlands we have now. Some types we will have, but again some of the forested wetlands, some of the bogs, are liable to be gone.

Mumford: I just came back from two months in Thailand, and if any of you want a real perspective on what can happen when you don't take care of things, go to a place like Thailand. It's a sad situation. I come back here and I'm very grateful that a group of people like this are doing what they're doing. My point is I think there needs to be education. The demand for preserving wetlands can't just come from the people in this room, it's got to be much broader based than that. And one of the biggest chores that we have is teaching people about the functions and the values, or all this is for nought.

Chapter 8 — Closing Address

Summary of the Conference and Information Needs for Mitigation in Wetlands

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The plenary speakers were charged with addressing the state of knowledge about the functions of the wetlands in the Pacific Northwest. The purpose of this paper is to synthesize and summarize the major issues of the conference. Some common points presented by the speakers are listed below.

Most of the plenary papers were able to identify important factors or relationships affecting each function. These factors were often interrelated and not easy to measure. The following are examples:

- The physical dimensions of the watershed and the characteristics of the inflow flood are important in affecting the flood storage capacity.
- The sediment trapping accumulation rate declines with the age of the receiving system, but site specific data are not readily available.
- Macrophytic and algal production are important sources of food chain support in estuaries, but their importance in riparian systems is subject to controversy.
- The richness and diversity of a system are not a function of the size of the system but do appear related to amounts of habitat stress and productivity.

Additional information was needed to understand the mechanisms that controlled each function.

While most speakers felt that there were measurements or relationships that could be used to determine the effectiveness of a particular function, long-term studies and databases are needed before these relationships can be determined.

Several of the speakers felt that extreme events and long-term environmental variability were often important in affecting how a particular function operated.

In the workshop sessions, there were also several points that were common between the sessions.

- Some of the workshop panels identified additional factors they felt needed to be considered before the wetland functions could be determined.
- The workshop participants reiterated the need for long term data and studies to determine the relationships that were important for the various functions.
- There is a need for multidisciplinary assessment teams to determine how and how well a particular wetland is functioning.
- There is a need for training to help those doing assessments to understand what measurements are important and what the limitations of these measurements are.
- The process of getting a diverse group of experts to discuss wetland functions is beneficial because it allows individuals to become acquainted with experts in other fields, and to begin to educate each other about the state of knowledge of the various functions.

What are the Needs for Determining the Importance of a Wetland?

The purpose of this workshop was to bring together experts to assess what is and is not known about the various functions of Northwest wetlands. There is such interest in wetland functions by managers and regulators because of their need to understand what will happen in the local and sometimes not so local area if a particular wetland is lost or altered. They need to be able to rank the ability of a wetland to perform the various functions that wetlands are known to perform (Barnard 1986), and to judge what effects the loss of a wetland will have.

I have listed four needs to determine the importance of a wetland. Parts of these have been discussed in more detail by the other speakers.

We need to understand the area of what wetland habitats we have left, what we have lost, and what is being lost. It is also useful to know the location of the wetland relative to other habitat types and to know its configuration, i.e., whether it is square, linear, or irregular. Differences in the ratio of perimeter to enclosed area are likely to be influential on some functions and on the vulnerability of the wetland to impacts originating in adjacent habitat or land use types.

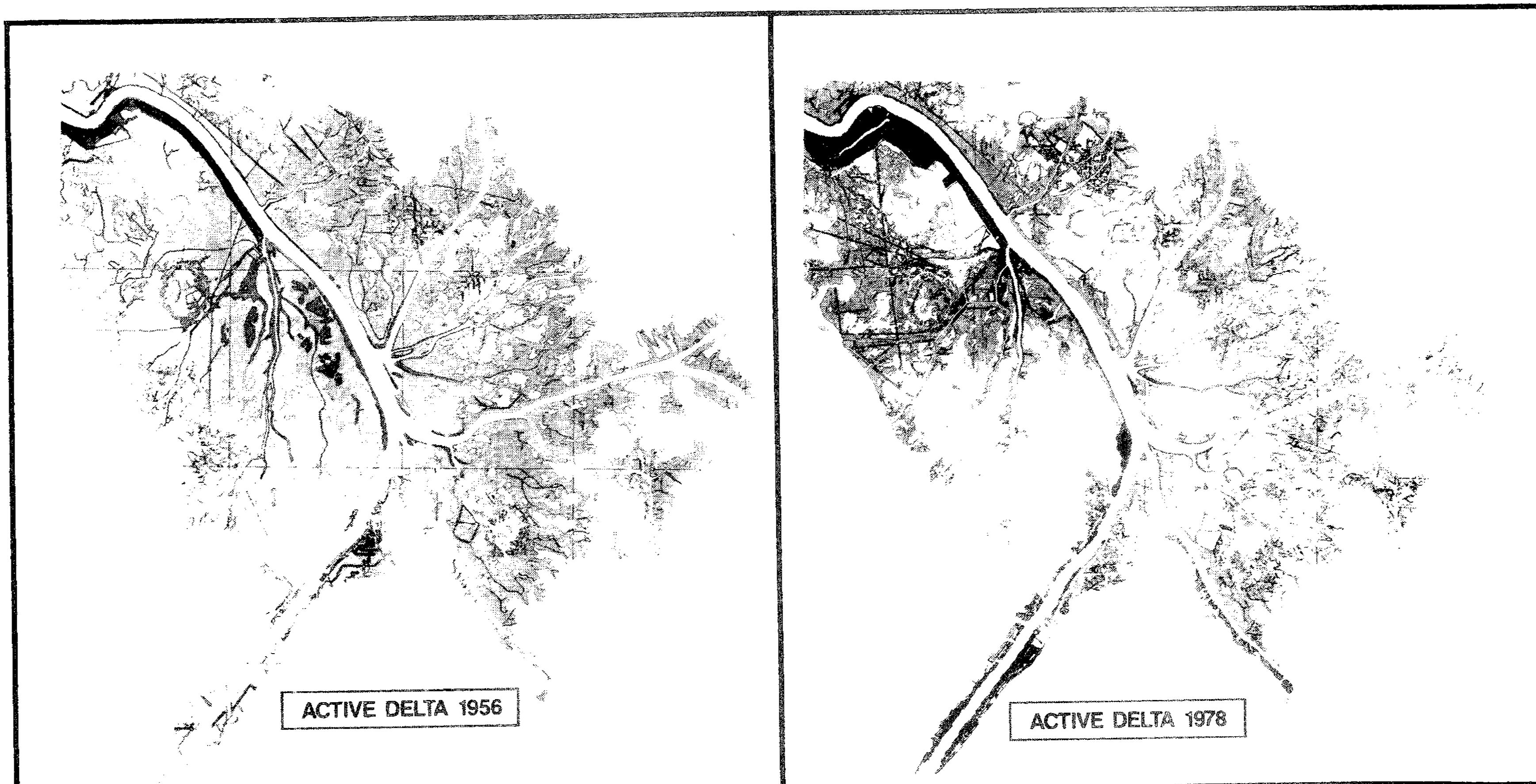
One of the important things done at U.S. Fish and Wildlife Service's (U.S.F.W.S.) National Coastal Ecosystems Team is the development of computerized geographic information systems of wetland and upland habitats using maps produced by the U.S.F.W.S. National Wetland Inventory (NWI). Habitats present in different years in a particular area are digitized in the system to look at trends in habitat changes (Figure 8-1). These data could also be used in simulations of a variety of scenarios about habitat and species changes with the additions of appropriate overlays. Some of the previous speakers indicated that habitat maps are being developed for some parts of the Pacific Northwest. This type of system would also be useful to track future losses and the cumulative effects of individually small losses.

The NWI is in the process of establishing a wetland data base in map format for the entire country using the classification system defined in Cowardin et al. (1979). Most maps are produced at a scale of 1:24000. In the Northwest, maps have been or are in the process of being produced for approximately 25 percent of the area in Idaho, approximately 50 percent of Oregon, and approximately 75 percent of Washington.

We need to understand the contributions of each habitat to the various wetland functions. To do this we need to understand the processes yielding the goods and services that we refer to as wetland functional values. This is what this symposium has been about and the other papers should be consulted to learn what we know and do not know.

We need to understand what functions will be lost or affected if the wetland habitat is lost or altered. This need is not that different from need two, but I express it this way because decisionmakers would like to be able to quantify what functions would be lost or altered if a wetland is lost or altered. Managers who have to make these determinations, and developers who want to use the land for other purposes, would like fast, easy, consistent, and reliable methods to make the determinations of what functions would be lost.

The U.S. Army Corps of Engineers has work underway to evaluate existing methods for assessing wetland functional values, and to determine what research is needed to improve existing methods or develop new ones. They have identified the method



HABITAT TYPE	1956 ACREAGE	1978 ACREAGE	ACREAGE CHANGE	% CHANGE
MARSH & FORESTED WETLAND	190,732	92,614	-98,118	-51%
& UPLAND & DREDGE DEPOSIT	6,419	18,284	+11,866	+185%
OPEN WATER				

Figure 8-1. **An example of the habitat maps produced to show changes in wetland habitats over time. This example shows the wetland changes in the Mississippi Active Delta for the years 1956 and 1978. (U.S.F.W.S National Coastal Ecosystems Team, unpublished data).**

developed by the Federal Highway Administration (Adamus 1983; Adamus and Stockwell 1983) as providing a useful framework, and have initiated a long-term effort to refine this method and make it more reliable in different habitats and regions. As a scientist it is difficult to accept that decisionmakers rarely have the time or money to collect thorough and long-term data to make these determinations. Long-term data and thorough studies are needed to provide the information necessary to develop reliable assessment methods. However, quick and reliable assessment methods must be developed as soon as possible for use by the people who are required by law to comment on permits within a short time frame.

Another concern expressed in this conference was the need to have the assessments done by an expert in the field. The hydrologists do not want biologists assessing hydrology, the biologists do not want the engineers assessing ecology and biology. While the use of experts is recommended whenever feasible, often it is not possible. Again it is important that the people doing the assessments have the most reliable and easy-to-use methods of assessing wetland function. They also need to understand the limitations of the methods, and know when an expert needs to be consulted.

There is a need for agreement between regulatory agencies on regional goals for each function and habitat, and for a commitment to preserving or providing the functions and habitats.

Regional goals are policy decisions intended to provide guidance on managing those functions and habitats that are important or desirable to preserve within a region. Examples include preservation or replacement of habitat that has become rare, preservation or provision of habitats to support a particular species or community of animals, or the preservation or provision of areas to minimize erosion or provide flood control. By looking at the region as a whole, the requirements for the support of key species and other functions can be related to the relative abundance and scarcity of various habitats, and recommendations on the types and locations of habitats to be preserved or restored can be identified. This allows for coordination between individual projects within a region, and prevents piecemeal alterations in the region that may do more harm than could be anticipated by evaluating each alteration in isolation. However, getting the various agencies such as the U.S. Army Corps of Engineers, the U.S. Fish and Wildlife Service, the U.S. Environmental Protection Agency, and different state and local agencies to agree on which functions and habitats are important is probably not going to be easy given their different mandates. Decisions about what kinds of habitats to preserve and where they should be located would aid in the local planning and mitigation planning processes, to the benefit of the ecological and development needs of the region.

The Council of Environmental Quality's definition of mitigation in the National Environmental Policy Act says that wherever feasible, impacts on wetlands are to be avoided or minimized. Only when all these options have been exhausted are measures to reduce, rectify, or compensate for the remaining unavoidable impacts to be employed. However, many state policies only recognize restoration or compensation of habitat as mitigation. Also it is often difficult to identify projects where avoidance, reduction, or minimization of impacts has occurred, since this type of planning often occurs before the documentation required with the permitting process. It is important to remember that avoidance, reduction, and minimization of impacts is the preferred mitigation approach. Restoration and creation of wetland habitats are still in their infancy as a science and, as I will discuss later, success has been limited.

If Restoration of Creation of a Habitat is Required

One goal of the mitigation process is to provide functional and productive habitat for fish and wildlife, while accomodating necessary economic development that is clearly in the public interest. If a project is approved and its plan requires some sort of habitat restoration or creation as mitigation for unavoidable impacts, then there are several questions that need to be answered.

What Kind of Habitat Should be Restored or Created?

In-kind replacement has been and is the recommended method for compensation because mitigation is required for habitats that are recognized as important or in short supply. Out-of-kind replacement may be recommended to provide for habitat that has become regionally rare or that is limiting for an important species. If the site is large enough to provide useful habitat, a mix of in-kind and out-of-kind replacement may be acceptable when one is trying to increase habitat diversity. Regional goals, identifying where and which types of habitats are needed, would assist in answering this question.

Where Should the Restoration or Creation Occur?

On-site replacement, or replacement adjacent to the site, is the most common recommendation to answer the question of where the mitigation should occur. It is assumed that the higher probability of colonization from the original site increases the chances of successful recovery of the habitat. This is still the preferred type of replacement, provided the restored area is not isolated and is large enough to provide useful habitat. Off-site replacement, or replacement occurring away from the development site but within the same ecological system, is acceptable when it provides for the preservation and restoration of large sites or sites identified as important to fulfill regional goals.

How Should a Habitat be Restored or Created?

To answer this question, one must first know or specify what functions and species the habitat is expected to support. In the past, mitigation recommendations usually only specified that the habitat that was lost needed to be replaced or that a particular plant species was to be planted. Functions or species expected to occur in the restored habitat or the time it takes for these to be established were rarely specified. Yet it was expected that the restored area would successfully result in the replacement of the functions or species that had been lost. Habitat design criteria, or the biological and physical requirements to provide suitable habitat for a particular function or species, need to be known (Josselyn and Buchholz 1984). If the processes that control the various functions or species distributions are understood, then the specific habitat design criteria can be identified. If these are not known, then an experimental approach to provide tests of which conditions or processes are necessary should be used (Zedler 1984). If the functions and species are specified, then it is clear what goals are expected of the restored site. When the restoration goals are stated, the task of monitoring whether the restoration is successful becomes easier to define. So does the task of determining whether the goals address the habitat and functional needs of the region. This approach also provides the information needed to improve the design of future restorations.

How Much Should be Restored or Created?

To provide a fair mitigation program, agencies must have a way to evaluate the losses and gains of a development project and the proposed mitigation. Factors that must be considered in determining how much habitat must be rehabilitated or created are: the values of the habitat lost and habitat gained, how long it takes to replace the habitat, and the probability of successful replacement or a safety factor.

The U.S. Fish and Wildlife Service has developed its Habitat Evaluation Procedures (HEP) (U.S.F.W.S. 1980) to provide a measure of the capability of an area to support each of several evaluation species. The analysis consists of selection of a set of species to be representative of the key features of the areas to be evaluated. The selection is agreed upon by the evaluation team. For Federal projects, the evaluation team consists of the principal interested parties — the project sponsor, often the Corps of Engineers or Bureau of Reclamation, the key state resource agency, and the U.S.F.W.S. The team can be constituted differently for other applications. The Habitat Suitability Index (HSI), which is scaled from 0.0 for unsuitable to 1.0 for optimal, is determined using documented relationships between habitat quality and environmental variables. How much should be restored is derived from the product of the HSI and the area of the project. This product is determined for the project area and the restoration area as each exists, and as each would exist in the future with and without the development and restoration project. The amounts gained and lost are determined from the difference in the products computed for existing and future conditions with and without the project.

The applications of these procedures in estuarine environments have been few, in part because of the lack of appropriate models. The number of models is increasing for estuarine areas. The ability of these models to truly measure the losses and gains has not been tested. Only by monitoring how well the predicted conditions meet the actual restored conditions can the models be adjusted to ensure protection of the habitat and the biological resources. The amount of time needed to achieve functional ecosystems is taken into account in projecting future conditions; however, cumulative impacts on these resources also need to be considered when evaluating the amount of habitat necessary to replace the habitat lost. One way to accomplish this is to assume that the HSI for the future conditions involving the restoration will always be less than the HSI for the existing area that will be lost.

These procedures assume successful replacement and have no factor to account for restorations that are less than successful. Since monitoring rarely results in a project having to be redone, biologists should consider a including a safety factor, such as those included in engineering design, to provide for some margin of error in case the restoration effort fails.

Monitoring

There are two levels of monitoring that should be considered. The first I call **compliance success**. This is an assessment of how often the recommendations of the commenting agencies are accepted and implemented, and a qualitative field assessment of how successful those projects are that were implemented. The assessments of acceptance and implementation require that complete and accessible records be available for a significant number of projects in a region. The qualitative field assessment would be easiest to accomplish if there were a written restoration plan describing where the restoration was to occur, what type of and how much habitat was to be restored, when the restoration occurred, and how it was done. Measurements in the field should check the location and area of the restoration. If various hydraulic alterations were performed, were these done and are they providing for the flushing and circulation they were planned to accomplish? If planting was required, what is the percent cover of the species planted, and are the plants producing seeds? If planting was not required, was natural recruitment expected, what species have invaded, and what is the percent cover of each? Does the amount of cover or recruitment meet that expected for the age of the restoration? Sediment characteristics such as texture and buildup of an organic layer should also be determined using grain size analyses or percent organics.

These measurements are the minimum necessary. I have tried to make them relatively easy and fast to collect, and did not include animals because the time to collect the data is great. These types of studies are now beginning (Eliot 1985; Maguire 1985; Reimold and Cobler 1985; Dial and Deis 1986), but often the documentation to conduct them is not readily available and success is difficult to define. The U.S.F.W.S. National Ecology Center in Fort Collins, CO is currently conducting a mitigation follow-up project. One of the products will be a computer-based bibliography on mitigation evaluation activities.

In a Norfolk, Virginia study (Maguire 1985) 32 sites were evaluated for area, vegetative cover, and implementation of the restoration plan. Sites included both salt- and fresh-water marshes. Fifty-nine percent of the projects were complete, 22 percent had not been done, 13 percent were in progress and not evaluated, and six percent could not be determined. Only 41 percent of the total number of projects were found to be successful, or to have the potential to be successful. In San Francisco 32 restoration sites that should have been completed were reviewed for completion (Eliot 1985); 56 percent were found to have been completed and 44 percent had not been started. Success was not evaluated in this study, although the report stated that only two projects have been called successful. A study of five sites in New England (Reimold and Cobler 1985) found that success was at best marginal, and a study of nine sites in Tampa Bay, Florida (Dial and Deis 1986) found that 33 percent were considered to have resulted in vegetation similar in percent cover and type to that lost.

The second type of success to be monitored is what I call **functional success**. These studies would be designed to determine whether restoration successfully replaced those functions and species for which it was designed. These types of studies require long-term, well-designed studies that should begin before the restoration begins, and should include some sort of control area where conditions are similar but an artificial restoration has not occurred.

Examples of these types of studies are fewer. A New Jersey study (Shisler and Charette 1984) of eight salt marshes compared natural and artificial marshes that were more than two years old for vegetative characteristics, sediment characteristics, and macroinvertebrates. They found that many of the vegetative characteristic measurements such as total, live, and dead standing crop, and number of reproductive heads, were lower in the artificial marshes. Sediment type was different and nutrients, organic matter, and salinity were lower in artificial marshes, while pH was not different. Differences in macroinvertebrate populations were found in most sites and may be the result of differences in sediment or other aspects of the habitat.

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*This paper was written by Millicent Quammen in her private capacity. No official support or endorsement by the U.S. Fish and Wildlife Service is intended or should be inferred.

Chapter 9 — Conclusions

This conference provided many valuable insights into the current state of our knowledge of wetlands science in the Pacific Northwest, and in some cases, it did so in different ways than expected. As anticipated, a great deal was accomplished by assembling experts on Pacific Northwest wetlands for three days to discuss wetlands issues and to exchange views on research. The conference also confirmed that the areas of confident knowledge about Northwest wetlands are tiny islands in a sea of uncertainty. Efforts to chart the unknown territory must continue, and in the meantime wetlands managers must set a cautious course and stick closely to what they know.

Products of the Conference

Three tangible and useful products were generated out of this conference: these conference proceedings; a Resource Guide to Wetlands Scientists; and a Northwest Wetlands Bibliography. In addition, the foundation of the wetland function evaluation matrix was created, on which future improvements can be built. These products will significantly improve the ability of wetlands scientists, as well as local planners, to retrieve available information on the functions of wetlands in this region.

- These **Proceedings** contain a great deal of existing information that has never been synthesized nor widely disseminated, such as the data compiled in the plenary papers on the functions of Northwest wetlands and the shared experiences of regional experts in wetland creation and rehabilitation. They also contain new information, such as the identification of data gaps and consensus on directions for future research.
- The **Resource Guide to Wetland Scientists** is a directory of Northwest wetlands scientists, organized by their fields of specialization. Individuals are referenced in the directory under the categories of wetland types and functions used in the wetland function evaluation matrix (Tables 1-1 and 1-2). Names and research abstracts for all listed scientists who have expertise in a particular wetland type (such as estuaries) and function (such as breeding and rearing) can be retrieved from the database by specifying those keywords. The Resource Guide currently is in the form of a computerized data base along with the matrix. In the future the Resource Guide will be available in printed hard copy.
- The **Wetlands Bibliography**, also part of the computerized data base associated with the matrix, contains about 700 citations. These citations are also classified by wetland type and function, and may be retrieved using the same keywords. The Bibliography is continually being updated as new citations are received.
- The **Wetland Function Evaluation Matrix**, from which the Resource Guide and Bibliography are derived, is a flexible and powerful organizational tool for collecting and classifying large amounts of data according to wetland type and function. It was used in a first attempt to develop a method for evaluating functional performance of wetlands in the Pacific Northwest, and it will retain an important role in future improvements to that method. The matrix was proven useful for identifying and documenting gaps in the data and literature on Northwest wetlands. Work is continuing to enhance the value of the matrix as an informational resource.

Results of the Conference

A major task of this conference was for participants to gather in working groups and, using the plenary presentations and the data gathered in the Wetland Function Evaluation Matrix, to establish and document what is well understood and what is poorly understood about the functional performance of Northwest wetlands. The results of this effort clearly bore out expectations: that what is not known about wetland functions in the Northwest exceeds what is known.

This conclusion applies both to the availability of raw data and to the analysis and integration of those data into useful scientific and management principles. The assessments leading to this conclusion emerged first from working group discussions specific to the matrix, but are evident also in the working group responses to the discussion questions, in the plenary presentations, and in the presentations and discussions of the issues surrounding wetland creation and rehabilitation.

Wetland Function Evaluation Matrix

Most of the discussion of the wetland function evaluation matrix in the working group sessions focused on the structure and purposes of the matrix. Participants talked more about perceived shortcomings of the matrix design, and about possible misuses of the matrix, than about the meaning or adequacy of the data in the matrix. Comments fell into three categories: inconsistencies in the operation and interpretation of the matrix; suggestions for improvement in the matrix structure; and differences over the philosophy embodied in the matrix.

The **operative and interpretive problems** arose because participants with differing backgrounds took different meanings from the matrix instructions, categories, and definitions. It was difficult for all participants to make generalizations about multiple variables and site-specific conditions. As a result, participants rated functional performance and data adequacy in different ways. They also had difficulty interpreting the resulting numerical scores in the matrix output. High variances in these scores reflected the small sample size of participants, differences of opinion and interpretation, and artifacts of the lumping together of different wetland types and physiographic regions for discussion purposes. Fine-tuning of some definitions was recommended to minimize ambiguity. For all of these reasons, the current matrix data are not suitable for public distribution or for use as a management tool, and are not included in these proceedings.

The **structural problems** in the matrix were mostly associated with the simplifying assumptions made to keep the size of the matrix manageable. Certain functional categories may require more detailed treatment in future versions of the matrix. There is still difficulty in reconciling the conflicting needs for detail and simplicity in devising a wetlands classification and management tool.

The **philosophical differences** at the conference arose over whether the matrix approach to gathering and evaluating data on Northwest wetlands might do more harm than good. The substance of this argument was that the information in the matrix was subjective opinion rather than objective fact, and that it could not be responsibly used for making policy or management decisions on wetlands. No accepted method has yet emerged for evaluating the relative abilities of different wetland types to perform various functions, and attempts to do so are controversial. Any such method must account for the adequacy of data on which it is based. Rejecting the matrix because it embodies opinion rather than fact, however, does not address the issue the conference was intended to serve. Decisionmakers are currently faced with making decisions largely on the basis of opinion. They cannot avoid taking a stand by pleading that the data are inadequate. The real choice is not one between fact and opinion, but between educated versus uneducated opinion.

Other Working Group Findings

The working groups converged on several observations about Northwest wetlands and the current state of our understanding about them. These findings run as common themes throughout the conference and these proceedings.

Data Availability. Little information on wetland functions has found its way into the published literature on Pacific Northwest wetlands. The data that are available are mostly descriptive and qualitative, not quantitative. Research on wetland systems has focused primarily on structure rather than function, and there are few studies defining the relationship between the two, especially for biochemical functions. Two important areas of research that have been systematically neglected are below-ground processes and the world of microscopic plants and animals. These processes and organisms are critical links in virtually every wetland function.

Variability. All wetland functions exhibit a high degree of spatial and temporal variability in response to similar variability in the physical environment. The best-known aspects of variability are the frequency, duration, and amplitude of hydrologic events, especially on seasonal time scales. More attention needs to be paid to several factors related to variability:

- rates of change in some wetland types, such as slow-changing forests and bogs;
- the dependence of some wetland functions and responses on the age of the wetland, including their sediment trapping ability and resiliency after disturbance;
- the importance of extreme events, rather than average conditions, in determining some wetland properties and functions.

Functional Interdependence. There is a high degree of interdependence among all wetland functions, so that it is difficult to assess performance of one function without consideration of several others. This interdependence extends well beyond the fundamental interaction of all wetland functions with hydrology.

Human-Related Functions. Wetlands play several roles that are related more to human perceptions than to functions in the natural environment. Wetlands have aesthetic, recreational, and educational properties that in some cases may be of greater "value" to society than any of their natural functions. Full evaluation of functional performance by wetlands from a management perspective must include these considerations as well.

Creation and Rehabilitation. Wetland creation in the Pacific Northwest is in its infancy — more trial and error than science and technology. The majority of wetland creation projects have been constructed west of the Cascade Mountains; few techniques have been developed for wetland creation or restoration of systems in the arid regions of the Northwest. Most of the wetland creation projects required by regulatory agencies and/or courts as compensatory mitigation are less than five years old, and few have included monitoring programs as part of the permit requirements. What little monitoring has occurred has been largely observational and descriptive rather than quantitative.

Consequently, little information is available with which to evaluate success, failure, longevity, or functional viability of artificially created wetlands.

At this point in time, the best that any creation techniques can do is to approximate structure, in the hope that function will follow along in its wake. Our ability both to monitor and re-create functions in artificial wetlands must await a broader, general understanding of these functions in natural systems. In turn, the greater our understanding of the functioning of natural systems, the greater our potential ability to design effective artificial systems. Since even our knowledge of structure is limited to the macro-environment above ground, creation and rehabilitation are likely to remain trial-and-error pursuits, pending a concerted effort to fill both ecological and technological information gaps.

Future Research. There is a general need for a more quantitative approach and a more long-term, interdisciplinary perspective in wetlands science. The science needs to become more oriented towards planned and controlled research rather than simple observation and evaluation. One specific proposal at the conference was for the establishment of "Intensive Wetland Study Sites" in representative wetland systems. Such dedicated areas would allow multidisciplinary teams to conduct long-term, coordinated studies targeted at the habitat and ecosystem levels. These studies could provide uniform, high quality data valuable to ongoing management. The creation of a centralized repository for data gathered from monitoring wetland creation and restoration projects would greatly accelerate the learning curve in this field of research, and would also aid the formulation of enlightened wetlands management policy. In the realm of creation and rehabilitation, wetland scientists should be involved at every stage of project design, construction, and monitoring, with long-term monitoring built into project designs.

Implications for Policy

All of the above findings and recommendations have obvious implications for the promulgation and implementation of wetland mitigation policy in the Pacific Northwest. The exercise of organizing data into a matrix structure highlighted areas in which scientific knowledge is sufficient for application to policy and management. More importantly, it demonstrated that such cases are the exception, and that usually the knowledge we would like to have for enlightened care of wetlands is not available. The great preponderance of what is not known over what is known in Northwest wetlands science has some practical applications: more caution must be used in managing areas where data are sparse. Clearly we are "light-years" from a thorough understanding of most wetland functions, one sufficiently detailed to be routinely applicable to wetland management. Yet just as clearly the search for appropriate policies and management schemes cannot wait for science to catch up.

Little information has appeared in the literature about wetland creation and rehabilitation in the Northwest, and what little has appeared also has pertained more to structure than to function. As a result, it is currently impossible to assess the functional ramifications of altering wetland structure. There is an abiding risk that the attractive prospect of wetland creation and restoration will become policy before it is proven practicable. Even if these measures are shown to be feasible, they may not be desirable if more benign mitigative measures are available. The scientific recommendation in the current situation would be to proceed with the utmost caution before adopting wetland creation as a routine tool of land development, and to err on the side of wetland preservation.

Chapter 10 — Appendices

Appendix A
Conference Program

Day 1 — Wednesday, April 30, 1986

USO Building	10:00 AM - 2:00 PM	Registration
	11:00 AM - 1:30 PM	Field Trips (pick up sack lunch at Registration)
	12:00 PM - 1:30 PM	Lunch (Sack lunches provided)
	Plenary Session	
USO Building	2:00 PM	**Welcome:** Bill Alkire and Mary Burg Washington Department of Ecology
	2:10 PM	**Opening Address:** "Wetlands Restoration: Trials and Errors or Ecotechnology?" Joy Zedler, San Diego State University, National Wetlands Technical Council

Plenary Session - Review of Wetland Functions

	2:40 PM	**Hydrology:** Alan Wald & Mel Schaefer Washington Department of Ecology
	3:00 PM	**Sedimentology:** James Phipps Grays Harbor College
	3:20 PM	**Water Quality:** Richard Horner University of Washington
	3:40 PM	**Carbon/Detritus Cycling:** Robert Wissmar University of Washington
USO Building	4:00 PM - 6:00 PM	Refreshments, Late Registration
Dining Hall	6:00 PM - 7:00 PM	Dinner
	7:00 PM - 8:00 PM	Dessert Slide Presentation: Michael Houck Portland Audubon Society

Day 2 — Thursday, May 1, 1986

Dining Hall	7:00 AM - 8:00 AM	Breakfast

Plenary Session - Review Of Wetland Functions (continued)

USO Building	8:30 AM	**Introduction:** Bill Alkire and Mary Burg
	8:40 AM	**Primary Production:** Ian Hutchinson Simon Fraser University
	9:00 AM	**Consumer Support:** Colin Levings Fisheries and Oceans Canada
	9:20 AM	**Wetland Creation/Restoration:** Mary Kentula Northrop Services, Inc.
	9:40 AM - 10:00 AM	Coffee Break
	10:00 AM	**Introduction to Working Group Meetings:** Charles Simenstad, University of Washington
Schoolhouse	10:15 AM	Working Group Meetings — Session 1

Dining Hall	12:00 PM - 1:00 PM	Lunch
Schoolhouse	1:00 PM	Working Group Meetings — Session 2
	3:00 PM - 3:20 PM	Coffee Break
	3:20 - 5:00 PM	Working Group Meetings — Session 3
Dining Hall	6:00 PM - 7:00 PM	Dinner
	7:00 PM - 8:00 PM	Guest Speaker: Buddy Clairain U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi

DAY III - Friday, May 2, 1986

Dining Hall	7:00 AM - 8:00 AM	Breakfast
Working Group Reports		
USO Building	8:00 AM	**Introduction:** Bill Alkire
	8:10 AM	Hydrology/Sedimentology
	8:40 AM	Water Quality/ Carbon Cycling
	9:10 AM	Primary Producers
	9:40 AM	Consumer Support
	10:10 AM - 10:30 AM	Coffee Break
Wetlands Creation and Restoration		
USO Building	10:30 AM	**Introduction:** Fred Weinmann Puget Sound Water Quality Authority
	10:35 AM	**Creation/Restoration** — Working Group Report
	11:00 AM	**Slide Show:** "Best and Worst Experiences in Wetland Creation and Restoration"
Dining Hall	12:00 PM - 1:00 PM	Lunch
USO Building	1:00 PM	**Panel Discussion:** "Creation and Restoration in the Pacific Northwest: Science and Technology Meet Policy and Management."
	2:25 PM	**Conference Synthesis:** Millicent Quammen National Coastal Ecosystems Team U.S. Fish and Wildlife Service, Slidell, LA
	2:55 PM	**Closing Remarks:** Bill Alkire
	3:00 PM	Conference Adjourns

Working Group Assignments

Hydrology/ Sedimentology	Water Quality/Carbon Cycling
Wald/Schaefer	Horner
Phipps	Wissmar
Terich	Nichols
Houck	Dinnel
Lines	Duxbury
Ryan	Geiger
Ugolini	Grace
Wheeler	Wrye
Gearheart	Moore
Bohn	Determan
Breckenridge	Fuerstenberg
Peterson	Heinle
Megahan	Spyridakis
Eckel	
Lightcap	

Primary Producers	Consumer Support	Rehabilitation/Creation
Hutchinson	Levings	Kentula
Smythe	Rogers	Mitchell
Boulé	Albright	Bierly
Broch	Armstrong	Chamberlain
Campbell	Auler	Conlin
Ewing	Backman	Fraser
Frenkel	Bisson	Good
Webber	Boyd	Herb
Hett	Dawe	Milligan
Lamberti	Gibson	Moody, A.
Thom	Harrington-Tweit	Moody, R.
Ruckelshaus	Lang	Osis
Sheldon	Miller	Robbins
Stevens	Mishaga	Saikewicz
Thilenius	Penttila	Schafer
Trethewey	Reese	Schauman
	Schwarz	Shanewise
	Brunner	Stout, D.
	Rodrick	Stout, H.
	Wechsler	Tabor
	Swanson	Vanbianchi
	Houck	Van Wormer
	Dawe	Way
		Wayne
		Williams
		Brownlee

Appendix B
Wetlands Classification

[Editor's Note] The following two appendices are duplications of materials mailed to conference participants along with blank copies of the Wetlands Functional Evaluation Matrix forms. This appendix shows all the categories into which Northwest wetlands have been classified, with some explanatory notes. Appendix C is a glossary of terminology used in the matrix.

The classifications and terms used in the matrix have been adapted from existing, accepted sources for the purpose of evaluating Northwest wetlands as **functional systems**. We have made every effort to avoid the creation of new terms and jargon, or even new definitions for existing terms and jargon.

For those of you who are already familiar with, and presently using, the **Classification of Wetlands and Deepwater Habitats of the United States** (Cowardin et al. 1979), you will be comforted to know that the classification system used in the matrix is compatible with (although not identical to) the Cowardin system. We chose the Cowardin system as our starting point for two reasons: it has become a national standard; and comparability of data with existing wetland inventories and other studies was deemed essential.

The important alterations to the Cowardin system are as follows:

- The Palustrine System has been divided into two "systems" in recognition of important **functional** differences. Those palustrine wetlands **associated with flowing water** but **not in the channel** of a river or stream are here treated under the heading "Riparian Wetlands." All other palustrine wetlands are treated under the heading "Freshwater Impounded Wetlands."
- Lacustrine wetlands are here treated under the "Permanently/Semipermanently Flooded" hydrologic regime, "Freshwater Impounded Wetlands."
- Terms common to the matrix and the Cowardin system (e.g. flooding regimes) are defined as they are by Cowardin et al. (1979) with the exception of substrate particle sizes.
- "Aquatic Bed" is herein referred to as "Submergent Vegetation."
- "Shallow Subtidal," a category created for the matrix, would be considered a deepwater habitat in the Cowardin system.

Marine Wetlands
- Intertidal
  - High Intertidal
    - Unvegetated (Non-Macrophyte)
      - Bedrock/Boulder
      - Cobble/Gravel
      - Sand
      - Silt/Mud
      - Clay
      - Organic
    - Submergent Vegetation (Macrophyte)
      - Bedrock/Boulder
      - Cobble/Gravel
      - Sand
      - Silt/Mud
      - Clay
      - Organic
  - Low Intertidal
    - Unvegetated (Non-Macrophyte)
      - Bedrock/Boulder
      - Cobble/Gravel
      - Sand
      - Silt/Mud
      - Clay
      - Organic
    - Submergent Vegetation (Macrophyte)
      - Bedrock/Boulder
      - Cobble/Gravel
      - Sand
      - Silt/Mud
      - Clay
      - Organic
- Subtidal
  - Shallow Subtidal
    - Unvegetated (Non-Macrophyte)
      - Bedrock/Boulder
      - Cobble/Gravel
      - Sand
      - Silt/Mud
      - Clay
      - Organic
    - Submergent Vegetation (Macrophyte)
      - Bedrock/Boulder
      - Cobble/Gravel
      - Sand
      - Silt/Mud
      - Clay
      - Organic

Estuarine Wetlands
- Intertidal
  - High Intertidal
    - Unvegetated (Non-Macrophyte)
      - Bedrock/Boulder
      - Cobble/Gravel
      - Sand
      - Silt/Mud
      - Clay
      - Organic
    - Submergent Vegetation (Macrophyte)
      - Bedrock/Boulder
      - Cobble/Gravel
      - Sand
      - Silt/Mud
      - Clay
      - Organic
    - Emergent Vegetation
      - Bedrock/Boulder
      - Cobble/Gravel
      - Sand
      - Silt/Mud
      - Clay
      - Organic
    - Shrub Vegetation
      - Bedrock/Boulder
      - Cobble/Gravel
      - Sand
      - Silt/Mud
      - Clay
      - Organic
    - Forested Vegetation
      - Bedrock/Boulder
      - Cobble/Gravel
      - Sand
      - Silt/Mud
      - Clay
      - Organic
  - Low Intertidal
    - Unvegetated (Non-Macrophyte)
      - Bedrock/Boulder
      - Cobble/Gravel
      - Sand
      - Silt/Mud
      - Clay
      - Organic
    - Submergent Vegetation (Macrophyte)
      - Bedrock/Boulder
      - Cobble/Gravel
      - Sand
      - Silt/Mud
      - Clay
      - Organic
    - Emergent Vegetation
      - Bedrock/Boulder
      - Cobble/Gravel
      - Sand
      - Silt/Mud
      - Clay
      - Organic
- Subtidal
  - Shallow Subtidal
    - Unvegetated (Non-Macrophyte)
      - Bedrock/Boulder
      - Cobble/Gravel
      - Sand

Silt/Mud
Clay
Organic
Submergent Vegetation (Macrophyte)
Bedrock/Boulder
Cobble/Gravel
Sand
Silt/Mud
Clay
Organic
Freshwater Impounded Wetlands
Sphagnum Bogs
Alkali Wetlands
Inland Saline Wetlands
Marl Fens
Serpentine Wetlands
Vernal Wetlands
Alpine Wetlands*
Subalpine Wetlands*
Midmontane Wetlands*
Seasonally Flooded or Saturated
Unvegetated (Non-Macrophyte)
Bedrock/Boulder
Cobble/Gravel
Sand
Silt/Mud
Clay
Organic
Submergent Vegetation (Macrophyte)
Bedrock/Boulder
Cobble/Gravel
Sand
Silt/Mud
Clay
Organic
Emergent Vegetation
Bedrock/Boulder
Cobble/Gravel
Sand
Silt/Mud
Clay
Organic
Shrub Vegetation
Bedrock/Boulder
Cobble/Gravel
Sand
Silt/Mud
Clay
Organic
Forested Vegetation
Bedrock/Boulder
Cobble/Gravel
Sand
Silt/Mud
Clay
Organic
Low Elevation Wetlands
Seasonally Flooded or Saturated
Emergent Vegetation
Bedrock/Boulder
Cobble/Gravel
Sand
Silt/Mud
Clay
Organic
Shrub Vegetation
Bedrock/Boulder
Cobble/Gravel
Sand
Silt/Mud
Clay
Organic
Forested Vegetation
Bedrock/Boulder
Cobble/Gravel
Sand
Silt/Mud
Clay
Organic
Permanently/Semipermanently Flooded
Unvegetated (Non-Macrophyte)
Bedrock/Boulder
Cobble/Gravel
Sand
Silt/Mud
Clay
Organic
Submergent Vegetation (Macrophyte)
Bedrock/Boulder
Cobble/Gravel
Sand
Silt/Mud
Clay
Organic
Emergent Vegetation
Bedrock/Boulder
Cobble/Gravel
Sand
Silt/Mud
Clay
Organic
Shrub Vegetation
Bedrock/Boulder
Cobble/Gravel
Sand
Silt/Mud
Clay
Organic
Midmontane Wetlands
Permanently/Semipermanently Flooded
Unvegetated (Non-Macrophyte)
Bedrock/Boulder
Cobble/Gravel
Sand

Silt/Mud
Clay
Organic
Submergent Vegetation (Macrophyte)
Bedrock/Boulder
Cobble/Gravel
Sand
Silt/Mud
Clay
Organic
Emergent Vegetation
Bedrock/Boulder
Cobble/Gravel
Sand
Silt/Mud
Clay
Organic
Shrub Vegetation
Bedrock/Boulder
Cobble/Gravel
Sand
Silt/Mud
Clay
Organic
Low Elevation Wetlands*
Seasonally Flooded or Saturated
Unvegetated (Non-Macrophyte)
Bedrock/Boulder
Cobble/Gravel
Sand
Silt/Mud
Clay
Organic
Submergent Vegetation (Macrophyte)
Bedrock/Boulder
Cobble/Gravel
Sand
Silt/Mud
Clay
Organic

Riparian Wetlands
Alpine Wetlands
Subalpine Wetlands
Midmontane Wetlands
Low Elevation Wetlands
Seasonally Flooded or Saturated
Unvegetated (Non-Macrophyte)
Bedrock/Boulder
Cobble/Gravel
Sand
Silt/Mud
Clay
Organic
Submergent Vegetation (Macrophyte)
Bedrock/Boulder
Cobble/Gravel
Sand
Silt/Mud
Clay
Organic
Emergent Vegetation
Bedrock/Boulder
Cobble/Gravel
Sand
Silt/Mud
Clay
Organic
Shrub Vegetation
Bedrock/Boulder
Cobble/Gravel
Sand
Silt/Mud
Clay
Organic
Forested Vegetation
Bedrock/Boulder
Cobble/Gravel
Sand
Silt/Mud
Clay
Organic
Permanently/Semipermanently Flooded
Unvegetated (Non-Macrophyte)
Bedrock/Boulder
Cobble/Gravel
Sand
Silt/Mud
Clay
Organic
Submergent Vegetation (Macrophyte)
Bedrock/Boulder
Cobble/Gravel
Sand
Silt/Mud
Clay
Organic
Emergent Vegetation
Bedrock/Boulder
Cobble/Gravel
Sand
Silt/Mud
Clay
Organic
Shrub Vegetation
Bedrock/Boulder
Cobble/Gravel
Sand
Silt/Mud
Clay
Organic
Backwater Areas

* Not including Sphagnum Bogs, Marl Fens, or Alkali, Inland Saline, Serpentine, or Vernal Wetlands

Appendix C
Guide to Terminology

Alkali Wetland: A palustrine impounded wetland whose unusually high concentrations of sodium ions result in a distinctive biota. (See also: Freshwater Impounded Wetland).

Alpine: The elevation range above the upper limit of (erect) tree growth. (See also: Subalpine).

Biochemical Processing: The alteration, decomposition, or removal of organic matter or pollutants through a combination of chemical and biological processes (remineralization).

Boulder: A large rock fragment, >256 mm in diameter.

Breeding/Rearing: Serving as mating or reproduction areas and/or nursery grounds.

Carbon/Detritus Cycling: The flux of carbon through biological cycles, principally pertaining to: (1) conversion of inorganic carbon to organic carbon (photosynthesis); (2) transfer of matter through trophic pathways; and (3) conversion of organic to inorganic carbon (respiration and decomposition).

Circumneutral: Having a pH in the range 5.5 - 7.4.

Clay: Rock fragments less than 0.002 mm in diameter; as a textural class, consisting of a mixture of particles ≤20% sand, ≤50% silt, and ≥30% clay.

Cobble: A rock fragment between 64 mm and 256 mm in diameter.

Complexity: Structural heterogeneity of the physical and biological components of an ecosystem.

Consumer: Any heterotrophic organism.

Created: A system which has been produced by humans from another system by accident or by design. NOTE!!!: "Can You Create?" means, "Is it possible to **purposefully** make a **predetermined** type of wetland which mimics the natural system?" (by design, **not** by accident).

Detritus/Carbon Cycling: The flux of carbon through biological cycles, principally pertaining to: (1) conversion of inorganic carbon to organic carbon (photosynthesis); (2) transfer of matter through trophic pathways; and (3) conversion of organic to inorganic carbon (respiration and decomposition).

Disturbed: Directly or indirectly altered, by humans, from a natural condition, yet retaining some natural characteristics.

Diversity: The number of species in a community, and their relative abundances, per unit area or volume.

Emergent Vegetation: Dominated by erect, rooted, herbaceous angiosperms which may be temporarily to permanently flooded at the base but do not tolerate prolonged inundation of the entire plant.

Estuarine: Tidal habitats that are usually semienclosed by land but have open, partial, or sporadic access to the open ocean, and in which ocean water is at least occasionally diluted by fresh water runoff from land. Ocean-derived salinities are usually greater than or equal to 0.5 ppt (during average annual low flow) and less than or equal to 30 ppt; salinities may periodically exceed 30 ppt due to evaporation.

Feeding/Foraging: Providing habitat for collection or consumption of food, gravel, or other necessities for nutrition.

Flood Desynchronization: The process by which simultaneous storage of peak flows within numerous basins within a watershed, and their subsequent gradual release in a non-simultaneous, staggered manner, results in containment of flow within the channel downstream and, usually, more attenuated flow peaks downstream.

Flood Storage: The process by which peak flows (from precipitation, runoff, groundwater discharge, etc.) enter a wetland and are delayed in their downslope journey.

Foraging/Feeding: Providing habitat for collection or consumption of food, gravel, or other necessities for nutrition.

Forested Vegetation: Dominated by woody vegetation ≥6 m in height.

Freshwater Impounded Wetland: A palustrine or lacustrine wetland formed in a topographic depression, or by the **natural or artificial** damming of a river, stream, or other channel. (As distinguished from an out-of-channel wetland associated with flowing water [See also: Riparian Wetland]). Tidal or non-tidal with ocean-derived salinity less than 0.5 ppt. NOTE: This category includes wetlands with varying soil and water chemistries, including acid, alkaline, circumneutral, and inland saline wetlands.

Gravel: An accumulation of rounded, waterworn pebbles between 2 mm and 64 mm in diameter.

Groundwater: Subsurface water in porous strata within the zone of saturation.

Groundwater Discharge: The movement (usually laterally or upward) of water from a groundwater body to its emergence into a surface water system (such as a spring, seep, or stream channel).

Groundwater Recharge: The movement or percolation (usually downward) of surface water through an unsaturated zone of soil or rock into a groundwater body (the subsurface zone of saturation).

High Intertidal: From the upper limit of the associated splash zone above the elevation extreme high water (EHW) to the elevation of mean high water (MHW) or, if lower, to the seaward extent of wetland emergents, shrubs, or trees. (See also: Intertidal; Low Intertidal).

Hydric soil: Soil that is wet long enough to periodically produce anaerobic conditions, thereby influencing the biota.

Hydrophyte: Any plant growing in water or on a substrate that is at least periodically deficient in oxygen, during some part of the growing season, as a result of excessive water content.

Impounded: Formed in a topographic depression or by the **natural or artificial** damming of a river, stream, or other channel. (As distinguished from an out-of-channel wetland associated with flowing water). (See also: Freshwater Impounded Wetland; Riparian Wetland).

Inland Saline Wetlands: Non-coastal palustrine wetlands whose high concentrations of mineral salts result in a distinctive biota (e.g. the of presence halophytes).

Intertidal: The substrate is exposed and flooded by tides; includes the upper limit of the associated splash zone above extreme high water (EHW) to the elevation of extreme low water (ELW). (See also: High Intertidal; Low Intertidal).

Lacustrine: Permanently flooded lakes and reservoirs, intermittent lakes, and tidal lakes with ocean-derived salinities below 0.5 ppt, whose total area exceeds 8 ha or whose maximum depth exceeds 2 m at low water. Lacustrine systems are situated in topographic depressions or naturally or artificially dammed river channels, and are lacking in trees, shrubs, persistent emergents, and emergent mosses or lichens with greater than 30% areal cover. (See also: Palustrine; Riverine).

Low Elevation: The elevation range between sea level and the Midmontane zone. NOTE: The upper limit of this region varies with microclimatic conditions and may extend above the base of adjacent foothills.

Low Intertidal: From the elevation of mean high water (MHW) to the elevation of extreme low water (ELW) or, if lower,to the seaward extent of wetland emergents, shrubs, or trees. (See also: Intertidal; High Intertidal).

Macrophyte: Macroscopic plants, including macroalgae.

Marine: The open ocean and its associated high-energy coastline where ocean-derived salinities exceed 30 ppt with little or no dilution.

Marl fen: A palustrine impounded wetland with a mineral-rich substrate which is high in calcium and whose vegetation is characterized by calciphytes.

Midmontane: A montane zone identified by characteristic vegetation which does not extend below the base of adjacent foothills nor into the Subalpine. The boundary between the Midmontane and Subalpine zones varies considerably from one geographical region to another and with microclimatic conditions (thereby defying all our attempts to nail down a precise definition!!!); it is therefore necessary to make this boundary determination on the basis of regional sources or expertise. (See also: Low Elevation; Subalpine).

Migration: Providing wintering grounds, stopover sites, or acclimatization to, or transition between, environments (as from fresh water to salt water).

Mud: A mixture of silt and clay.

Natural: Dominated by native biota and occurring within a physical system which has developed through natural processes (without human intervention), in which natural processes continue to take place.

Organic Soil: A soil that consists primarily of plant and animal residue in various stages of decomposition; a Histosol.

Palustrine: Tidal and non-tidal wetlands dominated by trees, shrubs, persistent emergents, and emergent mosses or lichens where salinity due to ocean-derived salts is below 0.5 ppt; also included are wetlands lacking such vegetation, but with all of the following characteristics: (1) area less than 8 ha; (2) active wave-formed or bedrock shoreline features lacking; maximum water depth less than 2 m at low water; (3) ocean-derived salinity less than 0.5 ppt. (See also: Lacustrine; Riverine).

Permanently Flooded: Water covers the land surface throughout the year in all years. (See also: Semipermanently Flooded).

Physical Filtration: Selective removal, including adsorption, of organic or inorganic matter.

Productivity: Net annual primary productivity. The amount of plant biomass that is generated per unit area per year.

Rearing/Breeding: Serving as mating or reproduction areas and/or nursery grounds.

Refuse: Providing shelter from predation or environmental hardship.

Restore (Can you Restore?): To return a wetland to a state which mimics its original, natural state or condition. (See also: Restored).

Restored: Artificially returned from a disturbed or totally altered condition, to a state which mimics the original, natural condition.

Riparian Wetland: An out-of-channel, palustrine wetland associated with flowing water (i.e. associated with a Riverine system).

Riverine: All wetlands and deepwater habitats contained within an open conduit (channel) either naturally or artificially created, which periodically or continuously contains moving water, or which forms a connecting link between two bodies of standing water, EXCEPT: (1) wetlands dominated by trees, shrubs, persistent emergents, and emergent mosses or lichens; and (2) habitats whose ocean-derived salinity exceeds 0.5 ppt.

Sand: Rock fragments between 0.02 mm and 2.0 mm in diameter; as a textural class, a mixture of ≥50% sand, ≤40% silt, and ≤20% clay-sized particles, or ≥75% sand-sized particles.

Saturated: The substrate is saturated to the surface for extended periods during the growing season, but surface water is seldom present.

Seasonally Flooded: Surface water is present for extended periods especially early in the growing season, but is absent by the end of the season in most years. When surface water is absent, the water table is often near the land surface. (See also: Semipermanently Flooded).

Sediment Trapping: The process by which particulate matter is deposited and retained (by any mechanism or process) within a wetland.

Semipermanently Flooded: Surface water persists throughout the growing season in most years. When surface water is absent, the water table is usually at or very near the land surface. (See also: Seasonally Flooded).

Serpentine Wetlands: Wetlands in which the water and/or soils are chemically affected by serpentine or olivene rocks.

Shallow Subtidal: From the elevation of extreme low water (ELW) to a maximum depth of -20 m (MLLW=0 m). (See also: Subtidal).

Shoreline Anchoring: The stabilization of soil at the water's edge, or in shallow water, by fibrous plant root complexes; may include long-term accretion of sediment or peat, along with shoreline progradation, in such areas.

Shrub Vegetation: Dominated by woody vegetation less than 6 m in height.

Silt: Rock fragments between 0.02 mm and 0.002 mm in diameter; as a textural class, a mixture of 20-50% sand, 30-80% silt, and 10-30% clay-sized particles.

Sphagnum Bog: A palustrine impounded wetland with a mineral-poor substrate composed primarily of *Sphagnum* spp. and which is acidic (pH < 5.5).

Subalpine: The elevational region, identifiable by characteristic vegetation, between the Midmontane and Alpine zones. The boundaries between these zones vary considerably from one geographical region to another and with microclimatic conditions (thereby defying all our attempts to nail down a precise definition!!!). It is therefore necessary to make these boundary determinations on the basis of regional sources or expertise. (See also: Alpine; Midmontane).

Shrub Vegetation: Dominated by plants that grow principally on or below the surface of the water for most of the growing season in most years; best developed in relatively permanent water or conditions of repeated inundation or flooding.

Subtidal: The substrate is continuously submerged beneath tidal waters. (See also: Shallow Subtidal).

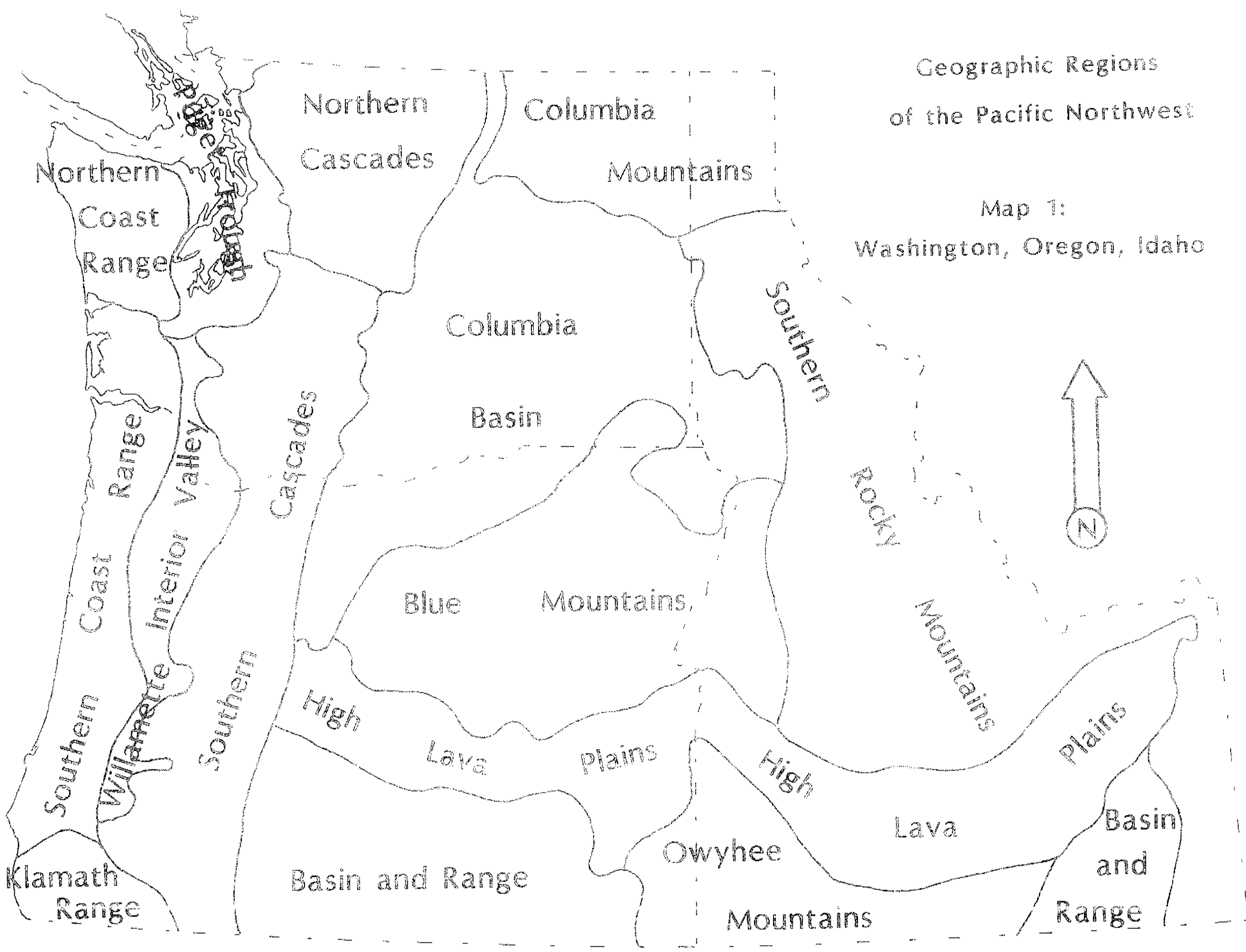
Unvegetated: Lacking macroscopic plants including macroalgae.

Vernal Wetlands: Seasonally flooded, palustrine impounded wetlands whose vegetation's life cycles are synchronized with rising and falling water levels.

Wetland: An area having one or more of the following three attributes: (1) at least periodically the substrate is dominated by facultative or obligate hydrophytes; (2) the substrate is predominantly hydric soil; (3) the substrate is nonsoil and is either saturated with or covered by shallow water at some time during the growing season.

Appendix D
Pacific Northwest Physiographic Regions

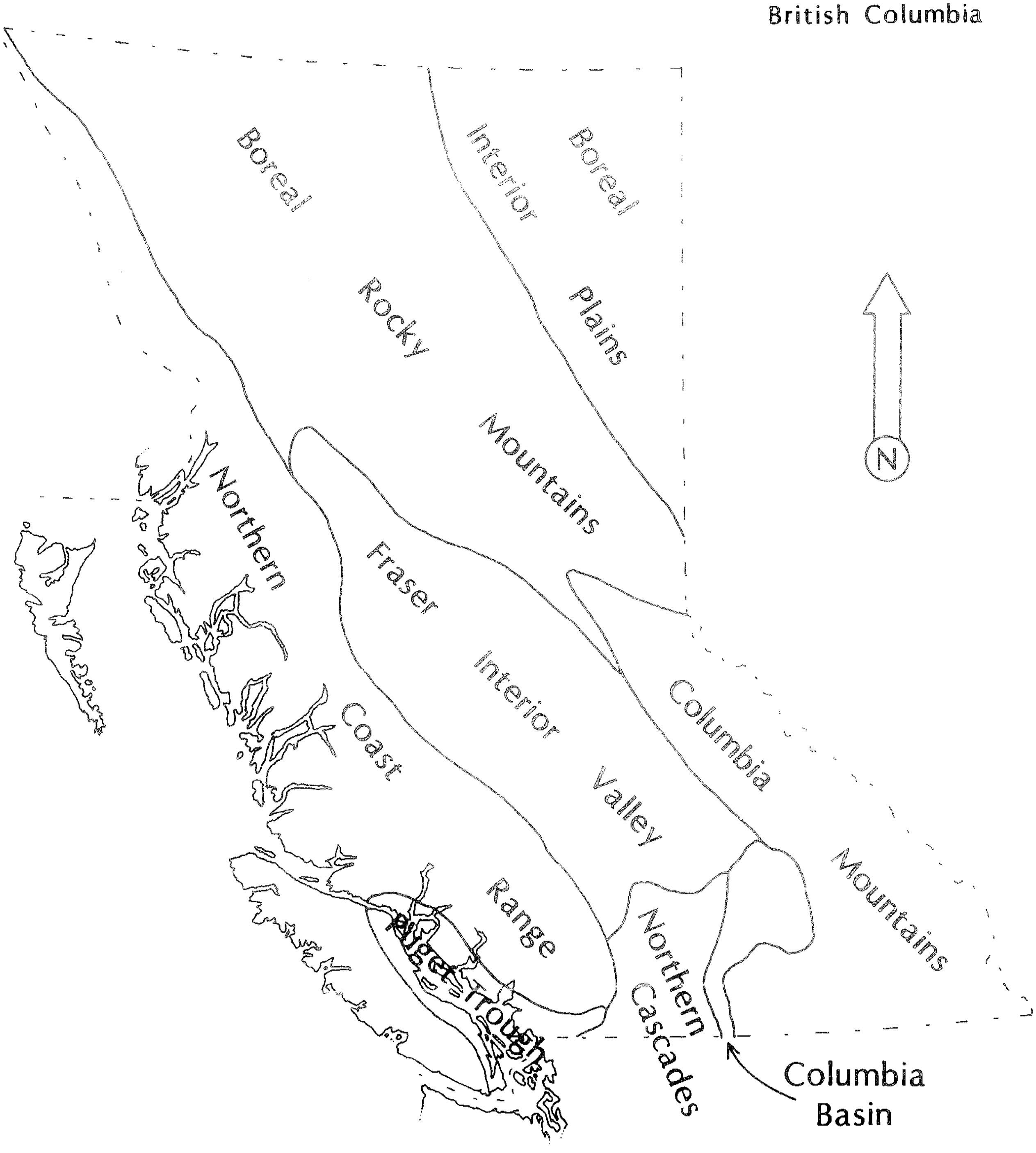
The maps in this appendix were included with the matrices and guides to wetlands classification and terminology that were mailed to conference participants. They show the boundaries of the seventeen Pacific Northwest physiographic regions into which participants were asked to classify their data.



Geographic Regions of the Pacific Northwest

Map 2:

British Columbia



Appendix E
Sample Matrix

The facing page shows a sample blank page from the Wetlands Function Evaluation Matrix as it was mailed to conference participants. The column headings are the fifteen function designated wetland functions grouped into seven functional categories and the questions about creation and restoration. The row headings are some of the wetland types (Appendix B) and the status (Natural, Disturbed, Created, Restored). Each matrix compartment is divided diagonally for separate ratings of functional performance and data adequacy.

Estuarine

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Geographic Region (see map) ____________

Participant's Name ____________

	N=Natural D=Disturbed C=Created R=Restored	HYDROLOGY				SEDIMENTOLOGY		WATER QUALITY		PRIMARY PRODUCERS			CONSUMER SUPPORT				SUMMARY	
		1. Ground Water Recharge	2. Ground Water Discharge	3. Flood Storage and Desynchronization	4. Shoreline Anchoring	5. Sediment Trapping	6. Physical Filtration	7. Biochemical Processing	8. Carbon/Detritus	9. Productivity	10. Diversity	11. Complexity	12. Breeding/Rearing	13. Feeding/Foraging	14. Refuge	15. Migration	16. Can You Create?	17. Can You Restore?
I. Intertidal (cont.)																		
B. Low Intertidal (cont.)	N																	
1. Unvegetated (cont.)	D																	
e. Clay	C																	
083	R																	
	N																	
	D																	
f. Organic	C																	
084	R																	
2. Submergent Vegetation	N																	
	D																	
(Use only if substrate is unknown)	C																	
085	R																	
	N																	
a. Bedrock/Boulder	D																	
	C																	
086	R																	

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